MORPHOLOGY, MINERALOGY, GENESIS AND CLASSIFICATION OF HIMALAYAN FOOTHILL SOILS OF WEST BENGAL

A THESIS
SUBMITTED TO THE
BIDHAN CHANDRA KRISHI VISWAVIDYALAYA
FOR THE AWARD OF THE DEGREE OF
DOCTOR OF PHILOSOPHY
IN
SOIL SCIENCE

BY

Radheshyam Saha

DEPARTMENT OF AGRICULTURAL CHEMISTRY AND SOIL SCIENCE
FACULTY OF AGRICULTURE
BIDHAN CHANDRA KRISHI VISWAVIDYALAYA
KALYANI, NADIA, WEST BENGAL

JULY, 1985

BIDHAN CHANDRA KRISHI VISWA VIDYALAYA
FACULTY OF AGRICULTURE
DEPARTMENT OF AGRICULTURAL CHEMISTRY AND SOIL SCIENCE
KALYANI, NADIA, WEST BENGAL.

Dr. S.S.Sahu,
M.Sc.(Ag), Ph.D.

Reader in Soil Science.

No ....

Date... 25th July, 1985.

C_E_R_T_I_F_I_C_A_T_E

This is to certify that the work recorded in the thesis entitled " MORPHOLOGY, MINERALOGY, GENESIS AND CLASSIFICATION OF HIMALAYAN FOOTHILL SOILS OF WEST BENGAL " submitted by Sri Radheshyam Saha for the award of the Degree of Doctor of Philosophy in Agricultural Chemistry and Soil Science of the Bidhan Chandra Krishi Viswavidyalaya, is the faithful and bonafide research work carried out under my personal supervision and guidance. The results of the investigation reported in the thesis have not so far been submitted for any other Degree or Diploma. The assistance and help received during the course of investigation have been duly acknowledged.

Sakti Sankar Sahu
(Signature of the Advisor)
25th July 85

ACKNOWLEDGEMENTS

The familiar "debt of gratitude" that research students usually acknowledge to their teachers for "inspiring and guiding" is not to be taken only in the literal sense; both the conceptual skeleton and the final shape of this thesis culminated out of the day-by-day tutelage and guidance I have received from Dr.S.S.Sahu, Reader, Department of Agricultural Chemistry and Soil Science, Bidhan Chandra Krishi Viswavidyalaya (BCKV), Kalyani, Nadia, W.B. He as 'Advisor' gave his time and enthusiasm to the final preparations of this thesis far beyond the call of duty and my expectations. I am much beholden to him.

With a profound and immarcescible sense of gratitude I redound to express my heartfelt thanks to Late Prof. S.C.Das, whose sudden demise, the other day, left me dumbfounded. He was the fount of inspiration of all my perspiration.

Prof. N.A.Chowdhury, Prof.N.C.Debnath, and Prof.B.Ghosh, Department of Agricultural Chemistry and Soil Science, B.C.K.V., deserve my sincere thanks for the facilities they extended to me as the Heads of Department during the tenure of my doctoral research. Other staff members especially, Prof.A.K.Mukhopadhyay, Dr.B.Das, Reader, and Dr. D.Mukherjee, Lecturer, were keen to see through the completion of this thesis. They were instrumental in my achieving certain ends even beyond the curriculum and hence my obligation to them is natural.

I am highly indebted to the Director-General(Eastern Region), Survey of India, Calcutta, for providing me with the Toposheets of the Restricted Area (Siliguri). I am even more grateful to Dr.N.Dutt, the then Vice-Chancellor, B.C.K.V., (Sr.Professor and presently Emeritus Scientist, I.C.A.R.,New Delhi), and Mr. T.C.Dutta, I.A.S., the then Secretary, Ministry of Agriculture, Govt. of West Bengal, for their help in procuring the Toposheets from the Director-General, Survey of India.

The National Bureau of Soil Survey and Land Use Planning (N.B.S.S. and L.U.P), Regional Centre, Calcutta, actively co-operated in the Reconnaissance Survey work carried out by me during November, 1980 to February, 1981. Mr. A.L.Das, Senior Soil Surveyor,(N.B.S.S. & L.U.P.) deserves special thanks for the help extended by him in the form of correlation and organisation of the field data.

Mr.J.Swaminath, Director-General, and Dr. D.R.Dasgupta, Director, Mineral Physics Division, Geological Survey of India, Calcutta, were kind enough to permit me to perform the X-ray diffraction analysis of all the clay samples. I am grateful to them. It would be niggardly of me if the services rendered by Dr.(Mrs.)S.Guha, Mineralogist; Dr. P.R.Mukherjee, Astt. Mineralogist; and Mr.K.K.Dasgupta, Geophysicist, in the actual X-ray work is not duly acknowledged with a deep sense of gratitude.

A special mention must be made of Prof. B.N.Chatterjee, Vice-Chancellor, B.C.K.V., who enlightened me with the priceless suggestions on land-use.

A chalice of thanks to my dear friends Dipten, Debashis, Naren, Sanmay, Anjan, Partha, Jaga, Pradip, Prabir, and Achintya, who were ever-ready with a helping hand and kept me gay during the tenure of this investigation.

Special thanks are also due to Mr. Dilip Rakshit, Cartographist, who performed the arduous task of preparing the Maps and other diagrams.

The typist, Mr. Shyamal Banik, laboured even into the wee hours. I appreciate his capacity for hard work with great speed, good humour, and finesse, and place his service on record.

Radheshyam Saha
(RADHESHYAM SAHA)

Dated: Kalyani, Nadia,
The 25th July, 1985.

TABLE OF CONTENTS

*** ***

LIST OF TABLES

TABLE NO.			PAGE:

LIST OF FIGURES

LIST OF PHOTOGRAPHS

INTRODUCTION

I N T R O D U C T I O N

The system of classification used in a particular field or discipline tends to reflect the "state of the art" and the current thinking in the field. Kubiena (1948) states that if a classification system is shown then the progress made in the perceptions of research problems in the related field can be interpreted. In a natural classification system, all the attributes of a population are considered and those which have greatest number of covariant or associated characteristics are selected as the ones to define and separate various classes (Mill, 1925; Cline, 1949). In soil classification system, we try to approach a natural classification system as an ideal, though we tend to give weight to properties of higher agricultural relevance.

Early systems of soil classification were quite simple and highly practical. But with the increasing sophistication of agriculture greater knowledge about soils as a collection of independent natural bodies, and greater complexity and diversity of soil uses, the classification of soils has become more scientific and organised. Soils are thus classified and named on the basis of identification of such characteristics *inter alia* as the kinds and number of horizons, or layers that have developed in them. The texture, i.e., the relative amounts of stones, gravel, sand, silt, and clay, the kinds of minerals present and their amounts, and the presence of salts and alkali help distinguish the horizons. Determination of such characters is a wide-ranging activity which includes studying the morphological characters in the field as well as followup physical,chemical, physico-chemical, and mineralogical studies in the laboratory. And on the basis of such detailed analyses the classification of the soil of a particular region can only be meaningful for proper agricultural development. Keeping in view the pivotal significance of soil classification, soil survey work in India has been undertaken throughout the country as early as 1928 when the Royal Commission on Agriculture examined the question of all India Soil Survey (Raychaudhuri, et al.1963). Since then the emphasis of identifying soils have shifted from the old genetic concept to the modern Comprehensive System of Classification or otherwise, popularly known as the "Seventh Approximation".

The National Bureau of Soil Survey and Land Use Planning (I.C.A.R.) together with its Regional Centres, and the All India Soil Survey and Land Use Planning under the Ministry of Agriculture, are engaged in the survey of the land area of the country on a priority basis and consequently some amount of work has been done in this direction. Their activity is limited by several constraints like manpower and as a matter of fact no detailed work has been performed to classify the soils of India in the light of the modern concept. In such circumstances it is natural that the foothill soils of West Bengal (North Bengal) which has a tremendous potential for agricultural production received scant attention. Literature available about the foothill soils of Bengal is meagre and obsessed with limitations and restricted in scope leaving the option open to explore the area in detail and bring out systematic classification of the soils of the region keeping the modern comprehensive system in perspective.

For such a systematic classification of the soils of the area (Siliguri, Bagdogra, Naksalbari, Kharibari, and Phansidewa Blocks of Siliguri Sub-Division in Darjiling district) a Reconnaissance survey was undertaken which aimed at studying soils in relation to geomorphology, physiography, and other biotic systems together with their morphological, physical, chemical, physico-chemical, and mineralogical properties; correlation and classification. This facilitated the interpretation of the soil data for land use planning and integrated development of the area. Soil maps were prepared which helped in identifying the potential and problem areas for various utility purposes, viz., capability, irrigability, and fertility management status.

An understanding of the morphological, physical, chemical, physico-chemical, and mineralogical properties of soil, its genesis and the pedogenic processes operative on the parent material, alongwith its potentialities and/or capabilities of/for crop production is of utmost importance in correlating and classifying soils. All the above properties of soil are nothing but the expression of different active fractions, the inorganic and organic particles present undergoing alteration, transformation in different combination and under different specific soil environment. And therefore, their composition and nature will very much influence the plant growth and soil development as well, under the dynamic effect of the climate.

In the soil environment both the coarse fractions, the silt and sand accompanying the finer fraction, the clay, constitute the mineral part. The clays are the seat of all physico-chemical reaction and play a significant role in the plant nutrition and in the development of soil. The clay fraction of the soil is the well organised crystalline mineral and composed of a mixture of one or more newly synthesized secondary layer hydrous aluminosilicates, with magnesium or iron and with alkalines and alkaline earths present wholly or in part, together with some resistant primary minerals comminuted or reduced to clay size fractions. The influence of clay minerals on some of the important soil physical properties like soil structure, soil erosion, and soil-water relationships such as water retention characteristics, volume expansion, hygroscopicity, moisture equivalent and plasticity, has been undoubtedly established over the years. The sorption of nutrients from solution or other sources and their release for absorption by plants are the most important processes in which the clay minerals play a significant part. Ion exchange and ion fixation of potassium, ammonium, phosphate and some of the micronutrient ions are characteristic properties of clay minerals. So, in the study of soil properties and its genesis, the identification and characterisation of mineral sp. in the clay fractions assumed great importance.

Characterization and identification of these clay size fractions or clay minerals are possible by the most widely and satisfactorily used technique of X-ray diffraction analysis, which is based on the characteristic C-axis spacing of the clay minerals which are mostly layer lattice crystals. For an unequivocal identification, a single method is usually inadequate. Apart from X-ray analysis, the other methods, to name a few are, integral and differential thermal analysis, chemical analysis, selective dissolution analysis, etc.Since in soils the clay minerals hardly occur singly and in 'pure' state, only the dominant minerals are easily identified. For a quantitative determination of the clay mineral composition no single method, except X-ray diffraction analysis in its present form of refinement, is good enough. Besides the crystalline component, the clay fractions also constitute a significant amount of non-crystalline amorphous material in it.

The principal forms of these amorphous inorganic materials which occur in association with the clays mostly are the free and combined oxides and hydroxides of iron, aluminium, and silicon and silicates of aluminium and iron, all in various combination with water. Generally, a few names such as 'allophane' for a mixed gel of alumina and silica are commonly accepted and justifiable as it is amorphous to X-ray diffraction (Ross and Kerr, 1931). Van Olphen (1971) proposed a tentative definition: "Allophanes are numbers of a series of naturally occurring minerals which are hydrous aluminium silicates of widely varying chemical composition, characterised by a short range order, by the presence of Si-O-Al bonds and by a DTA curve displaying a low temperature endothermic and a high temperature exothermic curve with no intermediary endotherm".

The specific characterization of such amorphous material is problematic due to the difficulty in obtaining pure soil amorphous material from contaminants such as crystalline clay minerals, soil o.m., and iron oxides. Despite this fact, they play a significant role in soils by the formation of crystal colloidal-amorphous constituents complex due to intimate association with each other and are not susceptible to separation from them without chemical destruction (Jones and Mehra, 1973).

Presently, these amorphous materials have been found to occur in varied soil types of tropical and sub-tropical regions, besides the volcanic ash soils (Andosols). They are responsible for many soil properties like high water-holding capacity, low bulk density, high Cation Exchange Capacity (C.E.C.), specific adsorption characteristics relative to phosphates, nitrates, borates, potassium, zinc, fluoride, and arsenic. This emphasizes their important role in determining soil fertility and productivity status. Further, because of high reactivity and large surface area of these materials the chemi-sorption of inorganic fertilizers often make large fraction of added fertilizer unavailable to the plants and the adsorption of pollutants from streams and from atmosphere often causes considerable soil pollution. So among other factors the inherent soil characteristics including the amount and nature of amorphous inorganic fractions in soil determine the physico-chemical behaviour of soil and management practices. The nature and amount of these amorphous constituents is determined by the NaOH Selective Dissolution Analysis (SDA) of Hashimoto and Jackson (1960). In this method, differential dissolution of clays with 0.5(N) NaOH solution boiled for 2.5 minutes gives substantial amounts of allophane, free alumina and silica. To avoid precipitation of silica they stated that the ratio of clay to caustic solution should always be less than 100 mg to 100 ml (i.e.,1:100) and noted that prolonged boiling brings about marked destruction of the crystalline components.

Hence, considering the importance of crystalline and non-crystalline components of the clay fractions it is worthwhile as well as complementary to attempt at an investigation on the genesis of these minerals. Despite recent advances in several other aspects of clay and amorphous material, the search with regard to the origin of clay and amorphous minerals and the relationship with the parent materials, is not only scanty, but is based mostly on assumptions. It is in the context of the above observations in the foregoing pages that the following objectives, each of which is a corollary to and complementary in nature, have been emphasized in the present investigation, so that a comprehensive idea and meaningful knowledge about the soils of the area emerges out.

1. Reconnaissance Survey and tentative classification of the soils of the area in the light of the 'Seventh Approximation".
2. Study of the physical, chemical, and physico-chemical properties of the classified soils.
3. Study of clay mineralogy of the classified soils.
   - 3.1) Study of chemical composition and CEC of soil clays.
   - 3.2) Study of Amorphous constituents in the clay fractions.
   - 3.3) X-ray diffraction analysis for clay mineral identification,characterisation,and quantification.
4. Study of genesis of clay minerals of the classified soils.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

While proceeding to make an objective review of soil classification, morphology, mineralogy, amorphous materials, and genesis, it is obligatory to narrate the historical perspective of soil classification in which we might find an aid in the understanding of the complexity and intricacy of the soil taxonomic problems. But availability of extensive literature in this aspect and with increasing simultaneous acquaintance of researchers exempts this investigation from repeating the same histotical perspective. Thus, a brief and selective review of literature is presented on the following aspects only.

1. Morphology of soils.
2. Amorphous Material in Soil Clay fractions.
3. Soil Clay Mineralogical Studies.
4. Genesis of Soils.

1. MORPHOLOGY AND SOIL CLASSIFICATION

Morphology, a term introduced by Goethe (1749-1832) in 1817, is not a science; but an aid to science, one of the methodsused in scientific investigations. The primary aim of morphology is description. Soil morphology, there fore, means nothing more than a description of the soil body, its appearance, features,and general characteristics as expressed in the profile of a virgin soil. Hence, it is obvious that the single-most important contribution or/and application of morphology is for the purpose of classification. Scientists and workers all over the world studied the morphology of soils and related their results with a particular aspect each of which in the final analysis contributes overtly or covertly to a better understanding of the soils concerned.

Dhamija *et al*. (1956) investigated *inter alia* the morphological characters of Cinchona soils of West Bengal. They examined soils at Munsong, Latpanchor, and Mungpoo where the climate is tropical with high humidity and moderately high temperature with high amount of annual rainfall. They found the soils acidic in nature, rich in clay and organic matter, silty loam to sandy loam, with the surface layers consisting well decomposed humus. They concluded that the soils resemble the Brown Earths of the world group.

Rudra (1956) studied the features of some Forest soils of Barddhaman and Birbhum districts of West Bengal. They found the surface soils porous in nature with free drainage and finer fractions moving down the profile with no massive murrum pan or calcium carbonate layer. These soils were similar to those of Red Lateritic Soil profiles.

Shukla *et al*.(1965) studied the morphological properties of some foothill soils of the Himalayas in Dehradun district of Uttar Pradesh. These soils were brown in colour, loamy in texture and acidic in nature. Closer profile examinations showed signs of heavy weathering which was supported by mineralogical analysis in the laboratory. They categorized the soil under the brown forest soils and order "Inceptisol", sub-order "Ochrept" according to the classification of USDA or 7th Approximation.

Slager and Schuylenborgh (1970) examined the morphology of three clay soils of a tropical coastal plain (Surinam). They opined that these soils were derived from similar marine sediment materials, i.e., two occur on Holocene and the other on Pleistocene sediments. Textural differences were found to be small but differences in soil structure were considerable, particularly in the abundance of biopores. Increasing evidence of clay illuviation was observed but the soils had not developed into true cat clays. The two youngers soils were classified as Inceptisols. A new sub-group of tropaquepts (hydric tropaquepts) was proposed to accomodate them. The older soil was classified as a plinthaqult.

Soils of the Tarai regions of Uttar Pradesh, which have developed from materials deposited during Late Pleistocence and Recent times on gently sloping outwash plain which occurs as a belt below and a few kilometers south of the foothils or outer range of the Himalayan mountains, have been extensively studied by Deshpande *et al.*(1971). They found that the six soils in question occurred in two toposequences of three soils each, one sequence being formed in silty sediments and the other in more sandy materials. Main differences, they stated, in the soils of comparable drainage in the two toposequences were in properties related to differences in texture. The soils had mollic epipedons, cambic horizons and high base status. They compared these soils with the weakly-developed, dark-coloured soils of mid-America and grouped them under the Mollisols order.

Veen et al. (1971) selected four profiles in Surinam (South America) of the Pleistocene alluvial soils and found that the soil development in these profiles were polycyclic, ferric nodules from the first cycle (upper coropina deposits) being still present in the contemporary soils. Clay illuviation occurred in all soils during the second cycle, and the third cycle (present day) was characterized by the manner and degree of weathering of the illuviated clay. Gley formation, podzolization, and ferrallitic weathering were characteristic of the plinthaqult-poorly drained silty clay soil; the tropaquod - sandy soil with impeded drainage; and the tropept - sandy soil with free drainage, respectively.

Fedorova and Yarilova (1972) worked on the prolonged seasonally frozen soils of Western Siberia. They observed that the morphological characteristics of the soils are closely related to the moisture and temperature regimes in different parts of the soil profile studied. These soils are loamy texture of the middle taiga of western Siberia and are affected by prolonged seasonal freezing, and are subject to significantly restricted downward movement of moisture.

Sehgal (1973) made a reconnaissance soil survey of the North West Himalayan mountains and highlands in the Tabul valley (Himachal Pradesh) and undertook five soil profiles from different regions and supporting different vegetation, representing both virgin and cultivated lands. He studied the morphology, described and classified in two major soil series, viz., Krozing and Shainsha. According to him, these frigid-like mountain soils having an epipedon or limit with mollic quality for Dystric Eutrochrepts does not depict the reality. Therefore, they have been logically classified by defining new subgroups of Cryic, Mollic, and Cryollic within Eutrochrepts, as Dystric Cryollic Eutrochrepts (Krozing series). This proposed classification is supported by their geographic situation between Eutrochrepts and/or Hapludolls (in lower valleys) and Cryochrepts and/or Haploborolls (on higher hills).

Working with the morphology of some of the alluvials soils in the Meerut district of Uttar Pradesh, Karale, Bisdom and Jongerius (1974) understood that the clay coatings and clay enrichment in the sub-surface horizons were not invariably associated with an argillic horizon. They argued that several processes might be the casual factor the distinction of which is difficult on field features. In doubtful or borderline cases confirmation could be sought through micro-morphological studies. In an investigation on the diagnostic sub-surface horizons from soils of the Ganges alluvial plain, micro-morphological studies reveal well expressed moderately to strongly oriented argillans in case of an Aeric Ochraqualf and a Typic Natrustalf corroborating thereby the field designations of argillic and natric horizons respectively. The designation of the sub-surface horizon as cambic in Aeric Fluventic Haplaquept was also supported by the micro-morphological results of the investigation. They concluded that the use of merely the clay content as a diagnostic criterion for the recognition of an argillic horizon was insufficient in the two soils studied.

Campbell (1977) made a statistical analysis of the changes in the distributions of morphological properties at the contact between two soil series. Samples collected were analyzed for gravel, sand,and silt content, for pH and for Munsell colour. These measurements were used to calculate a discriminant function which was used to define the boundary between the two soils. The variations of sand, silt and pH measurement were compared with the three models describing changes within the study area. On comparison he observed that the measurements of pH and silt changed slowly within the study area whereas the sand measurements exhibited a sharp change at the contact between the two soils.

Important morphological characteristics like soil texture has been helpful for assessing chemical weathering in soils in a study conducted by Torrent and Nettleton (1979). Chemical weathering affects the particle-size distribution, but little use has been made of this fact other than the inferences of increased chemical weathering generally made from increase in clay content. Torrent and Nettleton (1979) postulated a simple model for assessing chemical weathering from particle-size distribution. Using the model they calculated the theoretical particle-size variations of some loessial soils. Results showed that the fine fractions ($< 50\ \mu m$) were much more affected by chemical weathering than coarse fractions ($> 50\ \mu m$). They concluded that the silt fractions may be used for assessing chemical weathering.

Meixner and Singer (1981) used a field soil morphology rating system to evaluate a chronosequence of soils in the North-Eastern San Joaquin Valley, California. Relative horizon distinctness (RHD) ratings generally were less than 10. RHD ratings greater than 10 were obtained for observed and suspected parent material or soil formation discontinuities. Although monogenetic soil formation will result in high RHD ratings in some cases, the soil tested here usually had high RHD at discontinuties. Relative profile development (RPD) ratings increased with age. They found that the maximum values were in the 4 horizons of younger soils and in the B horizons of older soils.

Beinroth (1982) studied the morphology of eleven highly weathered soils of Puerto Rico of which six were Oxisols, four Ultisols, and one Inceptisol. In all the soils studied by him, profound weathering was largely accomplished prior to rather than as a part of pedogenic alterations. He observed that the clay illuviation cutans could not always be positively identified in the field and the results of thin-section studied did not conform with field observations in all instances. He suggested the need for a re-examination of the diagnostic value of argillans in soils with low activity clays, and as a corollary, a re-evaluation of the definition and taxonomic role of the argillic horizon. He also classified the soils according to the U.S. soil taxonomy, the legend for the FAO-UNESCO Soil Map of the world, and the French Soil Classification system.

Chakraborty et al.(1984) examined the morphological features of alluvial soils of Brahmaputra and Surma valleys. They found the upland levelled soils to be devoid of mottlings and concretions but the soils affected by high water-table resulting in the formation of iron concretions and mottlings. However, profiles of Brahmaputra valley indicated development of a weak argillic horizon . All the soils have been found by them to be acidic and rich in organic carbon.

Bhargava and Abrol (1984) while studying the morphology of some acid sulphate soils of Kerala found a great deal of heterogenity with regard to soil matrix and mottles, salt concentration, pH and organic carbon. They opined that the differences in acidity was due to the heterogenity in the distribution of pyritous clays in the alluvium.

2. AMORPHOUS MATERIAL IN SOIL CLAY FRACTIONS

The clay fractions of the soil contains the finest and therefore the most reactive particles, be they organic or inorganic. In consequence, many of the properties of the soils are determined by the nature of this fraction even though the amount present may be only a few pereent. This fraction is constituted of both crystalline and non-crystalline part. The non-crystalline component is designated as amorphous material. These non-crystalline constituents of clays are very important because of their own properties and their role in governing the characteristics of associated clay minerals. When present in sufficient amounts they may play a noticeable role in regulating the properties of soils. Their importance in the study of soil properties including mineralogical evaluation is being increasingly recognised.

These amorphous constituents are the random arrangement of the tetrahedral and octahedral structure of silicon and aluminium along with various components including water. The chemical forms and its reliable definition (Van Olphen, 1971) is cited in the 'Introduction'(Chapter-I).

It is felt relevant to furnish a good account of the work done in relation to its distribution, occurrence under varying climatic condition and inherited soil type and also its nature and characteristics in the following few pages.

Yoshinga and Aomine (1962) distinctly differentiated two mineral colloids, allophane and a mineral of low crystallinity (imogolite) with respect to the pH of dispersion.

Shoji <u>et</u> <u>al</u>.(1969) examined three kinds of amorphous silica: plant opal, opaline silica with characteristic shapes as disks and ellipsoids and aggregated amorphous silica. Plant opal in small amount is restricted to the coarse silt and fine sand fractions of the 'A' horizons. Opaline silica is most abundant in the 0.4 to 2 μ fractions. A relatively small amount of aggregated amorphous silica is found in the clay fractions.

A study of the Indian laterite of Durg, M.P. was conducted by Gaikwad and Gobindarajan (1971). The soil overlying sandstone was reported to be composed of abundance of ferruginous concretions in all soil profiles - an important morphological feature. The clays are homogeneous and the amorphous constituents dominated over layer silicate clays primarily composed of silicon and iron oxide amounting to about 80 % with high molar SiO_2/Al_2O_3 ratios (upto 20.5).

The volcanic ash soils were studied by Eswaran (1972) with scanning electron microscope (SEM) to observe the morphology and occurrence of allophane and imogolite . Allophane and imogolite were randomly distributed indicating a process of dissolution and recrystallization.

The acid character of H(Al) saturated allophane was reported by Hemni and Wada (1974) in a relatively dry environment (R.H. 10 to 55%). The acid strength was reported to be very much reduced either by increasing its water content or by saturating it with alkali earth metal cations. The allophane showed a marked enhancement of acidity when they have been dried over P_2O_5 and heated to result in dehydroxylation.

An important observation was reported by Fey _et al_.(1975) that the allophane materially was absent from oxisol clays containing large amount of crystalline sesquioxide (chiefly alumino goethite) and relatively small amounts of amorphous Alrich sesquioxide was determined quantitatively in volcanic ash soil clays by allocating OH-water to oxalate soluble SiO_2 plus Al_2O_3 on the basis of an ignition wt. loss/chemical composition function for synthetic amorphous aluminosilicates.

Krishnamurti and Rao (1976, 1981) reported that the vertisols of Hyderabad, developed on basalt had the highest amount of amorphous material (5 to 6.2 %) and the ferruginous red soils of Nandi Hills, Karnataka had the highest amount (30 %). In the latter case , the SiO_2/Al_2O_3 molar ratio ranged from 2 to 3.

Farmer _et al_. (1977) noted that when allophane digested with 5 % Na_2Co_3 at 95°C for 2-100 hours altered the original structure and composition of the starting material, whereas no effect was seen with cold 5 % Na_2Co_3 treatment except partial solution.

In India from the study of some alluvial soils of Delhi area Rao, Singh, and Krishnamurti (1977) reported that the clay fraction ($< 2\mu$) of these soils contained a small amount (varying from 3.40 to 5.33 %) of amorphous material and found the hydroxyl water content averaged 15.7%, C.E.C. varied from 65.2 to 255.3 me/ 100 g and showed a close negative correlation with the outer hydroxy aluminium polymer component. The structural model proposed by Krishnamurti et al. (1976) was applicable to these materials.

Perrott (1977) determined the surface charge characteristics of a range of synthetic amorphous aluminosilicates, hydrous alumina, hydrous silica and two allophanic soil clays by the retention of Na^+ and Cl^- as counter ions from 0.1(M) NaCl solution. In the pH range investigated (3-9), only negative charges could be detected in the hydrous alumina; whereas both positive and negative charges were detected in the amorphous aluminosilicates and the soil allophanes. In all the cases, the surface charge were pH dependent and in the aluminosilicate series, negative charge decreased and positive charge increased with the ratio of $Al/_{(Al + Si)}$. Consequently, the point of Zero charge increased with $Al/_{(Al + Si)}$ ratio. Negative charge can be attributed to isomorphous substitution of Al for Si in the silicate structure and to the dissociation of silanol groups in structure and adsorbed silicate. Positive charge is attributed to protonation of hydroxyaluminium sp. occupying cation exchange sites.

Cabezas Viano et al. (1979) studied the selective dissolution of Si, Al, and Fe by the acid base technique for segalen in a climatic sequence of volcanic soils on Tenerife Islands (Andosols and Brown soils). By X-ray analysis before and after treatment, they revealed that amorphous forms could not be differentiated from very soluble crystalline forms (Gibbsite and Imogolite).

Pyman et al. (1979) examined the heterogeniity of amorphous silico-aluminas and allophane using the electron microscope. He prepared the amorphous silico-aluminas of varying composition by simultaneous precipitation from aluminium nitrate and sodium silicate solution and observed its heterogeneity. But the samples of Si/Al, atomic ratio 1.5, showed no heterogeneity for varying conditions of preparations. Silico-aluminas prepared by the cohydrolysis of ethyl orthosilicate and aluminium isoproposide were more heterogenous and their heterogeneity showed a greater variation with composition. The most likely explanation of the heterogeneity is thought to be the presence of a matrix of variable composition surrounding the particles. Two out of five natural allophanes showed no evidence of heterogeneity.

De Kimpe et al. (1980) investigated the C.E.C. relationship of 2 Quebec spodosols. When an application soil released 5% Al_2O_3+ SiO_2 and 1% Fe_2O_3 by NaOH and Na-citrate treatment treated with citrate only a moderate increase of C.E.C. was observed and related to Al interlayer removal, while after NaOH + citrate treatment the C.E.C. decreased slightly because of amorphous material removal. Another sample from the Laurentian sites releasing 9.3 to 10 % 'Al_2O_3 + SiO_2' in NaOH and subsequently 1.6 to 6.0 % Fe_2O_3 in Na-citrate. The presence of large amount of amorphous material prevented the identification of clay minerals by X-ray diffraction analysis and its removal caused a strong decrease of the C.E.C. of this soil.

From a study of the Newzealand soils, Russel and Claridge (1981) has estimated the amount of allophane and other materials present in it. They observed that the 'tephra' which accumulated during 3500-10,000 years B.C. (30-80 cm depth) in the Egmont profile had the highest allophane content (about 70 % of the clay fractions). The allophane was identified as the proimogolite form of allophane.

Recently, Gupta and Tripathi (1983) reported the amorphous mineral component of different location of north west Himalayas (Kangra District - H.P.) varied from 3.90 to 23.60 % and alumina from 1.3 to 7.0 % , irrespective of the soil depth. Their distribution did not show a definite relationship with profile depth. SiO_2/Al_2O_3 molar ratios ranged from 2.18 to 9.20. The variation of SiO_2 content followed the same trend within the biosequences indicating less effect of vegetation on this constituent. However, on the basis of weighted average values, the soils under grass and forest cover showed higher content. The amount of Al_2O_3 was unaffected by the type of vegetation.

From a study of clay mineralogy of soils of Western Rajasthan Choudhuri and Dhir (1983) reported the significant amount of amorphous alumino silicates in these soils with varying C.E.C. They observed that the soil clays of Dune contained highest amount (8-15%) of amorphous aluminosilicates followed by interdune (3.5 to 15%), sandy alluvial plains (3-7%), and medium to fine textured alluvial plains (4 to 12%). The amorphous aluminosilicate content of the fine clays was nearly twice that of the coarse ones.

3. SOIL CLAY MINERALOGICAL STUDIES

Greater significance is now being attached to the mineralogical character of the solum and of the underlying material than was done in the early days. This results in narrowing the range of some series and the consequent cognition of more soil series. At the same time, however, every effort consistent with the concept of the genetic profile is being made to limit the number of series and maintain the category at an appropriate level of abstraction.

Soil formation is a function, primarily of climate and secondarily, of the nature of underlying parent rocks. It has been stated by Grim (1953) that the climatic conditions give the soil its 'Zonal' character, to the extent of synthesis of clay minerals. The predominant clay mineral fractions of a soil largely reflects the process of weathering of the soil. A study of the process of weathering would also indicate to what extent such weathering occurs with the influence of external climatic factors and thus facilitate the classification of soils into 'zonal' groups.

The clay mineralogical composition of Indian soils in general and of West Bengal soils in particular, regarding its quantification and qualification, has not been studied in detail. Sparse information on the distribution of minerals in various soil groups in the state, however, is available from the studies beginning in early 1950's but most of the earlier work was mainly limited to the identification of dominant clay mineral. Information on quantitative mineralogy, particularly of the profile samples was lacking. The general pattern of distribution of clay minerals in the major soil groups, as evolved in various laboratories, is summarised below.

In an earlier study of clay fractions of laterite soil of West Bengal, using X-ray diffraction technique Bagchi (1951) reported that the predominant mineral was kaolinite with considerable amount of quartz.

Chatterjee (1951) utilizing the chemical, electrochemical, viscous, X-ray diffraction and petrographic properties, reported the occurrence of 10% montmorillonite, 50% illite, and 40% kaolinite in less than 1 μ fraction of the clay soils of Hooghly, W.B.

Dhamija *et al*. (1956); and Rudra (1956) from a study of chemical composition, molar ratios and C.E.C. of the clay fractions of red and laterite soil profiles under forest cover in the districts of Bardhaman and Birbhum found illite as the dominant clay mineral in the upper toposequence.

Das (1956) made an X-ray examination of some soil clays isolated from black cotton soils of Indore, brown Matasi soils of Labhandi, and alluvial soils of Delhi and Karnal region. Montmorillonite with small amount of kaolin and traces of illite were found to be the predominant minerals of black cotton soils of Indore. The Brown matasi and Delhi soil clays consisted mainly of illite and kaolin whereas the Karnal soil clays were found to consist mainly illite with small amounts of kaolin.

Klages and White (1957) found a mineral of basal spacing of approximately 14 Å which is a constituent of many Indian soils. They studied the properties of this mineral and suggested that during the weathering of the soil profile, the pH decreased and 14 Å mineral replaced illite as the dominant clay mineral. X-ray diffraction studies revealed that many of the characteristics of this mineral were similar to those reported for dioctahedral vermiculite. It was concluded that during weathering of illite, aluminium could replace potassium between the clay plates. The form of this inter-layer aluminium was probably influenced by soil pH.

Adhikari (1957) investigated the physico-chemical properties of clay fraction of some soils of W.B. from Maynaguri, Suri, and Bardhaman and indicated the presence of illite with small amount of kaolinite. Adhikari (1958) by means of electro-chemical, X-ray, and DTA investigation, reported the dominance of illite in both Contai and Kakdwip soils of W.B. Later Basak (1969) showed the dominance of kaolinite with some illite in Suri soils of W.B. which was not in agreement with the findings of Adhikari (1957).

Brown hilly soils of Kalimpong (W.B.) contained abundance of illite with significant quantity of kaolinite, quartz, and 2:1 - 2:2 intergrades as shown by Ghosh (1964); Sarkar and Chatterjee (1964), and Basak (1969) by X-ray diffraction and other techniques.

Sarkar and Chatterjee (1964) investigated that laterite soils of Bankura and Suri contained mainly kaolinite with some amount of illite and possibly montmorillonite and the alluvial soils of Baharampur and Uluberia (W.B.) contained illite as the dominant mineral with some kaolinite and possibly montmorillonite.

Anjaneyulu et al.(1965) found that illite (60%) is the dominant clay mineral with some kaolinite (20%) and chlorite (20%) in Dinhata and Okrabari soils of KochBihar district (alluvial soils) of W.B.

Das and Das (1966) made a mineralogical investigation on clays from some Black, Brown, and Red soils of Mysore by X-ray diffraction and supplemented by chemical analysis. Black and Brown soil clays were similar in their mineralogical composition containing expanding lattice minerals as dominant fraction with small amount of kaolinite and also degraded illite and vermiculite in some cases, whereas illite was found to constitute the dominant fraction in Red soil clays with less quantities of kaolinite and expanding lattice minerals. A 2:1 lattice 14 Å chloritic mineral constituted the characteristic feature in all the soil clays.

Gawande et al.(1968) studied the genesis of catenary soils on sedimentary formation in Chattisgarh Basin of Madhya Pradesh. They found a gradual decrease in the preponderance of illite with concurrent increase in montmorillonite in the clays of the soils in toposequence. Illite with traces of kaolinite and occasionally quartz were principal mineral constituents of clays of the soils in the upper slope and mid-slope while montmorillonite with traces of illite and kaolinite was predominant in the soils of the lower slope. Illite in the upland soil was found mostly degraded.

Prasad et al. (1968) found the dominance of kaolinite with fair amounts of illite and small amounts of chlorite-like minerals in the sedentary soils of Bihar. Montmorillonite was found in the clays of Chaibasa, Putida, and Giridh soils. Illite and kaolinite constituted the main bulk of clay fractions of alluvial soils, possibly with some amount of chlorite.

Chatterjee and Gupta (1970) studied the clay mineralogy by X-ray diffraction, DTA, and chemical analysis of some western Uttar Pradesh soils. They found that the clay from surface and sub-surface layers of alluvial soils was composed of illite with some chlorite and, in some soils, traces of kaolinite.

Clay minerals in Al-Fe humus podzolic soils and their role in the formation of the soil profile were studied by Sokolova et al. (1971). They found that the main source of clay minerals in Al-Fe humus podzolic soils to be the layered silicates of parent rock. The main mechanism of clay formation was the phase transformation of these silicates which was most intense in the podzolic horizon. As a result a swelling mineral of the montmorillonite type predominated in podzolic horizons and chlorite and its derivatives predominated in the illuvial metamorphic layer.

Sehgal and Coninck (1971) identified 7 Å and 14 Å minerals from over 50 clay samples representing 30 soil profiles from Punjab. Their study indicated that all soils hitherto have been reported to contain chlorite as a second dominant mineral (illite being the first) did not show the presence of such a mineral, but on the other hand, contained intergrade minerals (chloritised vermiculite and chloritised montmorillonite) which resisted collapse and/or expansion to clays without sodium citrate treatment (pH 7.3). The degree of interlayering seemed to have direct correlation with the amount of alumina extract.

The studies of the mineralogy of some soil clays from some localities of West Bengal and one from Coimbatore conducted by Sahu and Das (1972) revealed that the hilly soils of Midnapore at different altitudes composed mainly of illite and chlorite with some kaolinite except the bottom hill soil. It has been found to compose of kaolinite and halloysite with traces of illite and chlorite. The alluvial soils of Gayespore (Nadia district, W.B.) composed dominantly of illite and chlorite, with fair percentage of montmorillonite. Black cotton soils of Coimbatore has been found to be rich in montmorillonite but the Red soils of Puruliya was rich in illite and chlorite with some kaolinite type of clays.

Murali et al. (1974) discussed the quantitative mineralogical composition of the clay fractions of two red soil (Alfisol) profiles developed on gneissic rocks in Mysore, in relation to the genesis of these soils. They found both the silt and sand fractions to be kaolinite with considerable amorphous material. They suggested a possible weathering sequence of transformation of the minerals.

Recently X-ray diffraction of clay minerals of some soils of W.B. has been reported by Ghosh and Datta (1974). They indicated that the <u>tarai</u> soils of Naxalbari and Alipurduar contained dominance of illite along with 25-40% chlorite mineral in association with mixed layer minerals, kaolinite and quartz. The red sandy soils of Gogra and Sriniketan and the laterite soils of Medinipur were characterized by the dominance of kaolinite in the clay together with some illite and smectite. Their investigation also revealed the dominance of fairly high content of smectite in some of the alluvial soils studied by them.

Ghosh and Datta (1974) also reported the predominance of illite (60%) in association with 20% mixed layer minerals, 15% chlorite mineral and 5% kaolinite in the clay fraction of red loamy soils of Malda district of W.B. In the same year they found that kaolinite (50-55%) is the dominant mineral in association with illite (25-55%), smectite (10-15%), chlorite minerals (0-5%) and mixed layer minerals (0-5%) in the soil clays from Bankura and Birbhum districts of West Bengal.

Sahu and Das (1974) with the help of titration curve and C.E.C. investigated the first three horizons (0-19 cm, 19-39 cm, and 39-65 cm) containing a mixture of kaolinite and illite in laterite soil clays of Bankura, W.B. The 4th horizon indicated the presence of traces of montmorillonite in the mixture. But in the 2nd and 4th horizon the kaolin concentration was more. The viscous studies also supported the above evidence. Sahu and Das (1974) found that the Medinipur red soil clay of the 1st horizon was composed of more illite with kaolinite but the 2nd horizon is composed of more kaolinite with some illite. The 1st and 3rd horizons of Medinipur hilly soil clays were composed of illite with some kaolinite minerals and the 2nd and 4th horizons were composed mostly of kaolinite with some illite. Nadia soil clays were mixture of montmorillonite and illite with traces of kaolinite and the proportion of montmorillonite increased with depth and the reverse was true in the case of illite content.

In the study of chemical, electro-chemical, viscous properties and surface areas of clay fraction of Moynaguri soil clay, Ray and Sahu (1975) reported that 2:1 fixed lattice clays were mostly illite with possible presence of chlorite. The proportions of illite and chlorite was more in surface layer than in sub-surface layer with fair amount of kaolinite and traces of smectite.

Abe and Araake (1975) analyzed the clay mineral composition of fine-textured paddy soils in Japan and applied the data for the classification of soil. Four soils consisted respectively mainly of montmorillonite, chlorite, kaolinite + vermiculites, and a mixture of several kinds of crystalline minerals. They suggested that the classification of soil series according to the composition of their clay minerals is of practical importance for soil drainage.

To find out the relationship of geomorphology to the origin and distribution of a high charge vermiculite clay, Lietzke et al. (1975) made a fertility trial on a well drained terrace of the St.Joseph river at Sodus Horticultural Experiment Farm located in Berrien country, Michigan. A study of the glacial geology and more recent geomorphology revealed that the oldest land surface had acid leached soils with the surface layer containing considerable chloritized vermiculite clays but little or no vermiculite. In contrast the younger well and moderately well--drained river terraces had soils that were higher in pH, and the surface layers contained vermiculite clay but very little chloritized vermiculite. Analysis of the soils on the river terraces showed a relationship of vermiculite clay content to soil pH. The vermiculite in the river terrace soils is apparently derived from chloritized vermiculitic soil clays that were eroded from the older upland soils.

Naga and Abdel-Aal (1975) while studying the crystalline materials in fluvio-marine soils of Egypt by X-ray diffraction found that silica and alumina had been translocated to greater depths of the soil profile than iron oxide.

Loveland and Bullock (1975) found the crystalline components of the clay fractions in Brown Podzolic soils of Silurian siltstone, Devonian slate, Granite and Pokrite. It has been observed by them that the clay-size changes significantly towards the surface, due to weathering. Mica and chlorite alter to vermiculite and intergrade 2:1 - 2:2 minerals and in the surface horizons of two of the soil, to a smectite mineral.

From studies on some saline deltaic alluvial soils of Coastal W.B., Ghosh et al. (1976 b) reported illite as the dominant clay mineral (45%) with smectite (25%), vermiculite (10%), chlorite (8%) and kaolinite (5%). Occas ional presence of mixed layer minerals was also noted.

Chatterjee and Dalal (1976) noted that illite (mica) was dominant alongwith fair amount of kaolinite and traces of chlorite in some alluvial soils of W.B. In the same year they also reported the dominance of illite (50-60%) together with kaolinite and possibly halloysite (35-45%) and little quartz in the Red Ferrallitic soils of Puruliya, W.B.

Chatterjee and Rathore (1976) studied the clay mineral composition of some soils developed from basalts in Madhya Pradesh. The quantitative estimation of clay mineralogical make-up of four typical black soil profiles showed that the soil clays were essentially dominant in smectites with the presence of some amount of kaolinite and small quantities of illite and quartz. Electron micrographs corroborated the mineralogical composition as estimated by other methods and revealed that the kaolinite present in the soils is in a very poor crystalline state.

Sahu et al.(1977) determined the clay mineralogy of a Tarai soil profile from Mohitnagar, Jalpaiguri district of West Bengal. They found the characteristic feature of the profile to be the presence of a mica-vermiculite regularly inter-stratified mineral with a mean (001) spacing of 24.48 Å. Besides these inter-stratified mineral, mica, chlorite, vermiculite, kaolinite, quartz, and feldspar were also found, with mica dominating.

Rangaswamy et al.(1978) studied the mineralogy of a profile on the acidic peninsular gneiss, of the Mysore Plateau. The soils of the older, fairly smooth landscape were composed of colluvium over truncated laterite profiles, with a gravel layer and a prominent kaolin layer over the weathered rock. These soils showed an accumulation of pedogenic haematite grains in the sand fraction and had considerable kaolinite and AFAS minerals in the clays. The soils of the younger rugged landscape had similar clay mineralogy but did not have a gravel layer, or haematite grains. While attempting to classify these soils they found that these ancient soils did not fit the criteria for oxisols in the U.S.classification, but fitted well in the French system as "Sols Ferrallitigues, subclass" Fiablement de'satures en (B)".

The clay fractions of the soils of two toposequences derived from gneissic rock (Peninsular gneiss) in Southern India were studied by Murali et al. (1978) . They found it chiefly consisting of kaolinite and amorphous ferri-alumino-silicates (AFAS).Considerable amounts of smectite were present in the clays of these soils. They proposed two hypothetical pathways for the formation of the clay minerals.

Refahi (1978) determined the types of clay minerals in four different alluvial soils of Iran. His results showed the presence of illite, vermiculite, chlorite, and quartz. Some intergraded minerals of illite-vermiculite and chlorite-vermiculite were also found.

Roy and Das (1979) from a study of chemical composition SiO_2/R_2O_3 ratio of original clay, SiO_2/Al_2O_3 ratio of H-clay and non-exchangeable K_2O% in laterite soils of Birbhum, W.B., found that the clay was kaolinite-illite type. X-ray and DTA also confirmed illite as the dominating mineral in these soils.

Dolui and Roy (1979) from a study of X-ray, DTG and DTA investigation of six alluvial soil clays of W.B. showed that montmorillonite and illite were the characteristic feature of these soils alongwith traces of kaolinite. The parent materials were transported alluvium type and the soils were immature. The clay mineral distribution and frequency showed insignificant variation.

Sahu _et al._(1981) studied the clay mineralogy of a _Tarai_ soil profile collected from the State Govt. Farm at Moynaguri. The most interesting feature of this profile, they stated, was the occurrence of a mica-vermiculite regularly inter-stratified mineral with 24.44 Å spacing. Mica was found to be dominant mineral constituting 56 to 70% of the clays. Other associated minerals were 11 to 18% chlorite, 6 to 9% kaolinite, 2 to 3% quartz and 2% smectite. It was also reported by them that the concentration of mica increased with the depth of the profile and that the inter-stratified mineral, chlorite and kaolinite decreased.

Loi et al.(1982) studied the relationships of clay mineral suites to the parent rocks of eight soil profiles in Sarawak, Malayasia. Their results indicated that the mineralogies of the parent rocks controlled the type of clay minerals formed in Sarawak. In the soils derived from pyroclastic and coarse-grained acid igneous rocks without muscovite, the clay mineral suites consisted almost exclusively of kaolinite and gibbsite with small amount of goethite. In contrast, they found, that in the soils developed from fine-grained and igneous and sedimentary rocks with muscovite, the clays contained relatively large amounts of inter-stratified mica-vermiculite in addition to gibbsite and/or kaolinite. The presence of gibbsite in these soils depended on the presence of plagioclase feldspar in the parent rock.

Sahu and Ghosh (1982) conducted a mineralogical investigation into the clay, silt and sand fractions of a pedon from Darjiling Himalayan region. Various analytical methods were adopted for determining the mineralogy of clay whereas the mineralogy of sand and silt fractions were studied by X-ray diffraction technique only. They found mica to be the dominant mineral in both clay and fine silt fractions. The characteristic feature of this pedon was the presence of a mica-vermiculite regularly interstratified mineral with (002) spacing at 12 Å . Small amounts of vermiculite, chlorite and kaolinite were the other associated minerals in the clay fraction. Chlorite and mica in the clay appears to have been inherited from the parent material, they opined, whereas the inter-stratified mica-vermiculite and vermiculite were the product of weathering of biotite mica.

Jones <u>et al</u>.(1982) investigated the mineralogy of eleven highly weathered soils of Puerto Rico by X-ray fluorescence spectrocopy, X-ray diffraction and Electron microscopy. On the basis of the total oxide analysis and X-ray diffractometry to establish the presence of detectable minerals, a semi-quantitative mineral allocation was made with aid of a 'balance-sheet' method.

The clay mineralogy of Dune and Associated Sandy plain soils of Western Rajasthan studied by Chaudhuri and Dhir (1982) showed that the fine clay contained smectite, mica, mica-smectite, and kaolinite. In addition to these, they found that the Dune soil clay contained minor amount of inter-layered smectite and chlorite minerals whereas the inter-Dunal soil clay had vermiculite and the alluvial plain soil clay chlorite minerals. Coarse clay in all the soils were found to be dominated by illite (mica) followed by smectite and kaolinite.

Kapoor *et al.*(1982) found quartz and feldspar to be the dominating mineral in the sand fractions of four profiles from Hissar, Sumiaheri, Tohana, and Bhasiva soil series. They also observed that in semi-quantitative estimates of minerals in the silt-fractions the dominance of illite followed by mixed-layer minerals, chlorite, and vermiculite. A similar distribution pattern was also observed by them in the clay fractions which contained, in addition, smectite and chloritized-smectite. The illite present in the soil was found to consist of both the dioctahedral and trioctahedral varieties, and the latter appears to have undergone transformation to smectite-like minerals through intermediate stages of (10-14 Å) inter-stratification.

Parfitt *et al.*(1983) studied three soils from volcanic ash involving allophane and halloysite, in New Zealand. The Kereone soil (mean annual rainfall 1200 mm) contained halloysite as the predominant clay mineral, whereas, the Mairoa soil (mean annual rainfall 2600 mm) was mainly allophanic. The Ohanpo soil (mean annual rainfall 1400 mm) contained considerable amounts of both allophane and halloysite.

The clay mineralogy of semi-arid region soils of Rajasthan were studied by Saxena and Singh (1983). Four soil groups viz., alluvial soils of recent origin, non-calcic brown, grey brown, and brown soils, were examined for their clay mineral characterization. Illite was found to be predominant in recent alluvium and grey brown soils whereas the clay from non-calcic brown and brown soils were found to consist of dominantly montmorillonite type of minerals.

Sahu et al.(1983) investigated the mineralogy of two red and laterite soil profiles in Orissa. Both the red soils were found to develop on charnockite and khondalite rocks of the Eastern Ghat region. Acidic reaction and high permeability have led to the dominance of kaolinite in the soil from semiliguada while a higher proportion of potash feldspar and mica were responsible for the dominance of illite in the Phulbani soils. The laterite soils were found to be derived from Athgar sandstones, an extension of lower Gondwana rock system, under hot and humid climate. Higher proportion of K-bearing minerals in the sand fraction reflected the prevalence of moderate weathering conditions which was conducive for illite in the laterite soils from Khurda. Parent rocks rich in quartz and orthoclase fledspar subjected to more leaching had resulted in kaolinitic and illitic type of clay in Bhubaneswar soils.

Kaswala and Deshpande (1983) determined the quantitative mineralogical make-up of clay and silt fraction of coastal and inland soils series of black soils of South Gujarat. Smectite was found to be the dominant mineral in the clay fraction whereas quartz and feldspar were so in the silt fraction. They found vermiculite, mica, kaolinite, and allophane in small and variable amounts. Coastal clays and silts were more micaceous than the inland ones. Chlorite was also found in both the fractions mixed with smectite and/or vermiculite. Chloritization was observed more in coastal ones as compared to inland silt.

The clay mineralogy of seven soil profiles from Himachal Pradesh developed under four different agro-climatic zones and classified as Alfisol, Inceptisol, and Mollisol orders were studied by Gupta et al.(1984). Profiles belonging to Alfisol and Mollisol orders had similar mineralogical composition with mica, a complex of 14 Å minerals, kaolinite, quartz, and feldspar. Some of these soils also showed the presence of interstratified minerals. The same minerals were present in profiles of Inceptisol with the dominance of smectite. The transformation of mica and chlorite into interstratified and swelling minerals were found to increase toward the upper horizons of the profiles.

Chakraborty et al.(1984) found illite to be the dominant mineral with chlorite and/or kaolinite as a minor phase in the five profiles of alluvial soils of Brahmaputra and Surma valleys of Assam.

4. GENESIS OF SOILS

Soil genesis is that phase of soil seience that deals with the factors and processes of soil formation. It includes description and interpretation of soil profiles, soil bodies, and patterns of soil on the surface of the earth.

The factors of soil formation which Dokuchaev (1846-1903) listed at the turn of the century are still being considered with respect to soil formation to-day. These factors which are also the same as those considered in connection with rock weathering, have been grouped into soil forming or active (energy-supplying) factors and relatively passive (energy-receiving) factors. The division is made only for convenience. Although climate and organisms are definitely important in the process of soil formation, the other factors - parent material, time, and topography - do exert strong, and in some cases decisive, control on process to make their influence felt in the resulting soils. All these factors are important in their own right; they all mutually interact to form the soil body.

Since these five factors have been identified, many workers have studied them and expatiated on them, especially in terms of the soil-soil formers equation. The original Dokuchaev equation was

$$s = f(pm, c, b, a, t) \quad \ldots\ldots\ldots\ldots \quad (1)$$

where, s = soil; f = function, pm = parent material,
c = climate, a = age of land, b = biosphere, and
t = topography.

This was later modified by Jenny (1941) as

$$s = f(cl'', o, r, p, t) \quad \ldots\ldots\ldots\ldots \quad (2)$$

where, the comma denotes internal function, cl" is soil climate, o is soil organism, r is the shape of the soil surface, and p and t stand for parent material and time respectively. Jenny (1941) also proposed a different version of the latter equation as follows :

$$s = f(cl, o, r, p, t) \quad \ldots\ldots\ldots\ldots \quad (3)$$

in which cl is external climate, o stands for all organisms (possibly man inclusive), r for forms rather than slope, and the rest are as in his first equation. He also recognized the possibility of discovering other factors and so left the equation open. Crooker (1952) for instance has proposed that it is more useful to express soil as an integral of five factors against time. He proposed the equation

$$s = f(c, o, r, w, p)\ t, \quad \ldots\ldots\ldots\ldots \quad (4)$$

where, f is integral function, c is climate, w is water table, and the rest are again as in Jenny's equation.

$$s = f(pm, c, b, a, t) \qquad \ldots\ldots\ldots\ldots \qquad (1)$$

where, s = soil; f = function, pm = parent material,
c = climate, a = age of land, b = biosphere, and
t = topography.

This was later modified by Jenny (1941) as

$$s = f(cl", o, r, p, t) \qquad \ldots\ldots\ldots\ldots \qquad (2)$$

where, the comma denotes internal function, cl" is soil climate, o is soil organism, r is the shape of the soil surface, and p and t stand for parent material and time respectively. Jenny (1941) also proposed a different version of the latter equation as follows :

$$s = f(cl, o, r, p, t) \qquad \ldots\ldots\ldots\ldots \qquad (3)$$

in which cl is external climate, o stands for all organisms (possibly man inclusive), r for forms rather than slope, and the rest are as in his first equation. He also recognized the possibility of discovering other factors and so left the equation open. Crooker (1952) for instance has proposed that it is more useful to express soil as an integral of five factors against time. He proposed the equation

$$s = f(c, o, r, w, p)\ t, \qquad \ldots\ldots\ldots\ldots \qquad (4)$$

where, f is integral function, c is climate, w is water table, and the rest are again as in Jenny's equation.

The processes of soil formation which act both singly and collectively to modify saprolite, or essentially inorganic (dead) rock debris, to produce the living soil are (i) the accumulation of solid and also colloidal matter, e.g., the process of rock weathering; and (ii) the differentiation of horizons by addition, removal and transfer of materials and energizing solutions. Additions to the profile include mainly organic matter from the biosphere; removals concern the soluble substances, e.g., the salts and carbonates; while humus and sesquioxides are generally transferred from one part of the profile to another. Transformations also occur, e.g., of primary organic matter to humic acids, and of primary minerals to secondary ones.

Another way of looking at soil-forming processes is to consider them at different level. Some processes are simple, in the sense that they involve a single process; others are complex and involve an amalgam of a number if not all of the single, simple processes. Examples of the former are humification, mineralization, eluviation, leaching, illuviation, ammonification, nitrification, and denitrification to list only a few; examples of the latter are the climatically controlled processes such as podzolization, laterization (and/or ferralitization), calcification, salanization, gleization, and solodization.

It is obvious from the above observations that the study of soil genesis is essential for a better understanding of the soil classification system. It is also quite understandable that the field of soil genesis is a broad avenue of which soil weathering (chemical, physical and biological) is the single most important factor of soil formation. Researchers and Scientists over the years have studied the factors and processes of soil formation considering or emphasizing one or more than factors/processes of soil formation, i.e., added information to the field of soil genesis only.

Jackson and Sherman (1953) studied the process of chemical weathering of minerals in soils. They found that a mixture of minerals when deposited together in one rock formation was subjected to the agencies of chemical weathering, some minerals were weathered faster than others. The reaction rates, they observed of chemical weathering were controlled by various intensity and capacity factors operating as a function of time, and different combination of intensities, capacities, and times of weathering might produce a given degree or stage of weathering. The capacity factor of weathering included the specific surface of the material and the specific weather-ability of the minerals. The intensity factors of weathering was classified as temperature, water and leaching, acidity, biotic, and oxidation - reduction factors. They concluded that chemical weathering together with some hydrothermal and deuteric alterations was responsible for the frequency distribution of colloidal minerals which occur in soils.

Ghosh (1965) investigated the development of the desert plains in the central luni basin of Western Rajasthan, through aerial photographs. His examinations revealed that prior well integraded drainage system was responsible for the building up of the extensive alluvial plains of the region. Climate in the recent past was humid, but as the aridity set in this prior drainage system was disorganised. The Rann of Sanwavla which look like playas are nothing but disconnected segments of old stream beds.

The genesis of soils developing in stable landscape under natural vegetation within the altitude limits of 3350-2500 m and 2500-1700 m above m.s.l were described by Dhir (1967). The genesis of these soils were found to be essentially distinct from that of podzols and podzolic soils. Distinguishing role in their formation appeared to belong to the eutrophic nature of mull-like moder layer or to the conditions of decomposition of organic residues. In fact, they opined, that these Himalayan soils appeared distinct from various known world soils.

Smith and Buol (1968) conducted a study with three semi-arid soils to find the genesis and relative weathering intensity. Two Haplargid profiles revealed very few illuviation cutans and some stress cutans and the ratio of fine clay ($< 0.2\mu$)/coarse clay ($2-0.2\mu$) increased in the argillic horizon. Relative weathering intensities were estimated from CaO/ZrO_2 molecular ratios obtained by X-ray spectrographic analysis of the silt fraction. The molecular ratios indicated that maximum weathering had decreased with depth in all of the profiles studied. It was concluded by them that clay formation <u>in situ</u> was not solely responsible for the development of an argillic horizon in arid and semi-arid soils. More likely, both clay formation <u>in situ</u> and enrichment by illuviation of fine clay ($<0.2\mu$) were responsible for the argillic horizons in soils of arid and semi-arid regions.

The influence of climate and parent material and also relative merits of the two factors on the process governing soil development were studied by Karale <u>et</u> <u>al</u>.(1969). They found two distinct groups of soils varying in morphology, physico-chemical and chemical properties have developed from basaltic parent rocks under low to medium and high rainfalls. High reactivity of the non-clay separates from the basaltic soils of low to medium rainfall was found to be a characteristic feature, clay, silica and sesquioxide content of the soils were found to be more related to parent material. The climatic factors appeared to be decisive in characterizing the soils through their influence on weathering reaction. However, they concluded, that the potential ability of the parent material, particularly under the mild reaction processes, as under low to medium rainfall, played an important role in soil development.

Gowaikar and Datta (1971) investigated the role of moisture regime on the genesis of laterite soils in south India. Their morphological studies, physico-chemical characteristics and the chemical composition of seven soil profile sample indicated that though the degree of laterization was intensified with increase in rainfall, high rainfall distributed over a longer period retarded the same. Excessive rainfall with high intensity had not materially enhanced laterization under similar duration of rainfall distribution as that of high rainfall group with low intensity. Lower physiographic positions resulted in detrital lateritic soils. Later Gowaikar (1973) classified these soils into Alfisols and Inceptisols. Only those soils under prolonged high rains and continuous dry period of three months were classified under the order Ultisols.

Deshpande et al. (1971) studied the genesis of the mollisols of Tarai region of U.P. The major changes which have occurred in the development of these soils were the addition of organic matter and the formation of mollic epipedons and development of structure and formation of cambic horizons. They found slight evidence of mineral weathering, leaching of carbonates and some leaching of bases, formation of clay with slight movement, and transformation and movement of iron. These Tarai soils of U.P., India, had developed in calcareous, medium to moderately coarse textured materials with a high micaceous component under the influence of mixed tall grass and forest vegetation in a monsoon climate. Artesian water augmented the soil moisture supply and much of the area was naturally swampy. However, they concluded, because of local variation in natural soil drainage, imperfectly to moderately well and well-drained soils, as well as poorly drained soils, were present.

Zonn (1971) attempted to enlist the role of Al and Fe-clay minerals in the diagnosis of recent crust and soil formation processes. Various aspects of weathering crust and soil formation in the tropics were examined. It was demonstrated that the former belief that the lateritic (ferrallitic) process predominates in the tropics had given way to the view that the soils and weathering crusts that form are of ferrallitic allitic, ferritic and sialtic composition.

Brinkman *et al.*(1973) studied the clay decomposition or weathering of the clay minerals in seasonally wet, acid soils.

Individual argillans in thin sections were studied by petrographic microsoope, X-ray diffraction micro camera, and electron microprobe. Their data suggest that, under seasonally reducing and leaching conditions, free iron is reduced and partly leached; smectite and illite are decomposed while at least part of the aluminium, magnesium and potassium liberated was removed by leaching; silica liberated from the smectite and illite was reprecipitated as micro-crystalline quartz; and the argillans were residually enriched in rutite and kandite.

To find the effect of parent rock in the genesis of soil Chesworth (1973) studied the weathering trends emanating from the compositional field of the common igneous rocks. It was seen to graphically converge on compositions relatively rich in SiO_2, Al_2O_3, and Fe_2O_3. This convergence meant that in chemical terms, the effect of the composition of igneous parent rock on the composition of the resulting soil, was an inverse function of time. Given enough time the chemical effect of a parent rock would be nullified.

Gaikwad and Rao (1974) made a study of soils in relation to Geological (structural) formations from Combum Areas in Prakasam district of Andhra Pradesh. This area had sedimentary metamorphic rocks consisting mainly of phyllites, slates and quartzite of Pre-Cambrian age and from upper part of Cuddapahs. The rise of

Nallamallai hills in the West of Combum, caused the formation of localized synclines and anticlines. It was observed that the soils occurring near anticlines were shallow, light in colour, coarse-textured, gravelly and had very low ground water table. On the other hand, soils occurring near Synclines were deep, grey in colour, fine textured, and had high ground water table. Studying other physical and chemical properties they concluded that a pattern of catenary relationship indicated the dominant role of topography in the formation of these soils.

Roy <u>et</u> <u>al</u>.(1974) studied the characteristics of three different soil profiles on a catenary sequence in West District of Tripura, situated in upland, midland, and in the valley. Most of the physical and chemical properties were found to have a distinct gradation with the toposequence. Clay content, pH, and C.E.C. of the soils increased down the slope. Fertility status increased from upland to low land <u>pari</u> <u>passu</u> with decrease in the intensity of drainage condition. They suggested that topography was the dominant factor in the development of the catenary sequence.

Gupta <u>et</u> <u>al</u>.(1974) found out the catenary relationship that existed among the soils of lower Vindhyan Plateau in Uttar Pradesh. Soils assumed well defined catenary relationship with decreasing drainage intensity down the slope exhibited the changes in colour from yellowish brown or reddish brown to very dark grey and texture from loam to clay loam, clay or silty clay. In general, soils of first catena were lighter in texture, slightly acidic in reaction, richer in silica, poorer in sesquioxides, Ca and Mg as compared to the soils of the second catena developed on limestone and shales. Soils of upland and terraces were classified as 'Alfisols' whereas those of lowlands as 'Inceptisols' in both the catenas of lower Vindhyan Plateau.

Govinda Rajan and Krishna Moorthy (1974) studied pairs of Red and Black soils in close proximity under similar climate and topographic conditions from two areas of Andhra Pradesh. Their study revealed that the formation and occurrence of Red and Black soils in close proximity under identical climatic conditions were attributable to minor differences in the mineralogical make-up of the parent rocks.

In a similar study under Rajolibunda Diversion Irrigation Scheme, Andhra Pradesh, Krishna Moorthy and Govinda Rajan in the same year opined that the formation and occurrence of Red and Black soils in close proximity in this area were attributable to the minor differences in mineralogical make up and topographical features.

Siddhu et al.(1974) investigated the genesis of three soils in Central Punjab at varying stages of development. These soils developed on recent to old Sutlej alluvium under semi-arid climatic conditions. The morphology revealed significant differences in their profile development. While no profile development had been observed in pedon-1, the pedon-2 showed definite profile development with a cambic horizon and pedon-3 an argillic horizon. The physico-chemical properties corroborated the morphology elucidating the path of genesis from the Entisols, through the Inceptisols to Alfisols.

Siddhu et al.(1974) attempted to find the genesis of Fe-Mg concretions from the alluvial soils of Central Punjab. Though the various properties of the soils, such as higher chromas and good drainage did not suggest the presence of reducing conditions for the formation of concretions, but the nodules might be the result of alternate reducing and oxidizing conditions. As these soils under study represented the one-time flood plain of Sutlej river, it was expected that they periodically passed through alternate reducing-oxidizing conditions.

Investigation on the genesis of acid sulphate clays (Cat Clays) from Southeast Norway by Khera et al.(1974) revealed that whereas iron was mobile and accumulated in the deeper layers, there seemed to be no significant movement and accumulation of mobile Aluminium. The soils were weakly developed, cyric , had low chromas, very low pH (3-4) and lacked characteristics of sulfidic nature. These soils were classified as Sulfic Cyraquents.

Roy and Pal (1974) studied the genesis of some lateritic and red soils of Bankura district, West Bengal. Soil depth, contents of Fe concretions, clay content, pH, exchangeable Ca, all varied according to the topographic situation which had a dominating influence on these properties of the soils investigated.

Roy and Rudra (1974) investigated the pedological characteristics of some lateritic soils of Midnapore district of West Bengal. All the characteristics studied showed that the soils were mature resulting from intense weathering and the soil profiles had been formed from a uniform parent material.

Digar et al.(1974) studied one representative catena in the lateritic part of Birbhum district, West Bengal, to evaluate morphologic variations in relation to genesis. Three soil series, viz., Matimahal, Kharbona, and Jagdishpur were identified in the three district toposequence from the forest upland to the lowest bottom land which also had distinct geomorphic sequence. Digar and Haldar (1974) made a similar study on some soils of Burdwan district, West Bengal.

Bhattacharjee et al. (1974) worked with shallow, medium, deep, and very deep black soils occurring in catenary sequence in subhumid part of Maharashtra state. The significant pedogenic heterogenity in these soils were observed to be due to the influence of differential expansion and contraction of surface and subsurface layers as a result of changes in soil climate induced by topographic variation despite the uniform overhead climate.

The genesis of the salt affected soils in the Indo-Gangetic Plain of Punjab was investigated by Sharma et al. (1974). The soils of three series under study, developed on slightly lower topographic position with a relatively shallow ground water table and occurred in association with the normal cultivated soils rule out the influence of parent material, time, climate, and vegetation in their genesis. Their geographic distribution also suggested no correlation with the existing canal system. The genesis of natric/ argillic horizon in these soils in a relatively short period than in their associated normal counterparts suggested high RSC underground water which rose to within one metre of the surface during the monsoon and hence direct alkalization of these soils.

In a similar study by Kausik and Shukla (1974), accumulation of run off water in land depressions, impeded drainage - a consequence of high Na content or initial poor soil structure, original high Na salt content in the profile, redistribution of salts with fluctuating water table, shallow water table and use of brackish water for irrigation were identified as some of the causes of the development of salt affected soils in that area.

Dhir and Kolarkar (1974) studied the genesis and evolution of soils of the Arid Zone. Soil formation from eolian sediments showed a significant though weak argillization and a distinct illuvial accumulation of carbonates. The *in situ* pro-alluvial landscape, which in all likelihood escaped eolian activity was characterised by moderately deep, medium to heavy textured solum followed by a well developed zone of carbonate accumulation even where the parent material was derived largely from acidic igneous rocks. This reflected the dominating influence of arid climate in their genesis.

To find the effect of rainfall on the development of soil morphological properties Biswas (1974) made a Reconnaissance Soil Survey of Ghod Catchment in Poona district of Maharashtra. It was observed that soils of zone 1 (rainfall 2780-5820 mm) were very deep brown in colour and devoid of lime in contrast to the soils of zone 2 (rainfall 730-850 mm) and zone 3 (rainfall 250 mm). The forest vegetation was also found to change in succession from evergreen type to thorny scrub as the rainfall decreased.

The frequency and the pattern of cropping have been found to have induced discernible changes in the soil development process.

But the effect of bio-cycling on soil development has been found to be significant by Kalbande et al.(1974). Their study revealed that in regard to the biotic effect in recycling the soil constituents, the soils under double cropped paddy had been enriched appreciably with exchangeable Ca^{2+} and Mg^{2+} and available N and K.

Soils developed on terrace I and recent flood and meander plains of Sutlej in Central Punjab had been studied by Pundeer et al. (1974) for their mineralogical characteristics and soil profile development. Muscovite/illite was the dominant mineral in all the studied soils. Kaolinite, vermiculite and montmorillonite was found in the decreasing order of abundance. Sand/silt ratio as well as field observations indicated the presence of stratification in all the studied soils. Decrease of montmorillonite and increase of vermiculite with depth indicates vermiculite-montmorillonite transformations in the surface layers. Illite and kaolinite were inherited, whereas chlorite in the flood-plain soils was due to change of provenance of the parent material.

Raghu Mohan and Murthy (1974) found a definite relationship among soils, geomorphic units and the rock types occurring in the Union Territory of Goa. The coastal plains were found to comprise of entisols of Colva and Colangute series; the alluvial plains consists of inceptisols of Zakari series. Major part of the area was occupied by ultisols with plinthite, which had been distributed over piedmont plains, steep hills and valleys. The Netrolim series which was characterized with plinthite was largely derived from the Precambrian phyllites and banded ferruginous quartzites occupies the piedmont plains. Zaimolo series which was found in patches in the colluvic plains was derived as an outwash of the laterite ridges. The Darbandra series occurring on the steep hills of Sahyadri range was formed from the quartzites and schistose rocks. Soils of the Ugem series had been found to have a definite genetic relationship with the distribution of granites and granite gneisses which probably formed the monadnoks.

To find the process of soil formation through clay migration in the formation of argillic horizons in soils developed under varying moisture regimes, Sehgal, Gombeer, and D'Hoore (1976) started with five pedons representing major soil groups of N.W. India. Clay migration was investigated involving the use of thin sections, contact - capillarography and the clay translocation was also observed on the chromatographic paper and on the Metricel Gelman membrane. The results generally indicated a very low effective clay mobility in Udic soils having thick, continuous and strongly oriented argillans, and moderate to high clay mobility in Ustic soils where clay cutans were either not observed or were weakly oriented. The potentially mobile, that is dispersible, clay is the highest in Ustic soils and the lowest in Udic soils having optimum conditions for clay translocation suggesting that the highly birefringent argillans in the Udic soils were not a definite proof for the present day illuviation but could be taken to indicate the past illuviation process.

Rouston et al.(1977) studied the process of soil formation through mineral weathering in an arid watershed containing soil developed from mixed basaltic-felsic parent materials. A theoretical reconstitution of primary rock forming minerals in the arid water-shed from spring water and soil clay mineral compositions demonstrated that soluble SiO_2 resulted from the weathering of Plagioclase, Pyroxene and iotite and not from abundant Quartz; and the Fe and Al were largely retained in solid phases within the watershed. Weathering reactions were relatively rapid and probably occurred largely within the soil profile, as indicated by a high soil pH in B horizons and soil parent material.

Prasad et al. (1977) selected nine profiles in an area around Junagarh, Gujarat, to study the soil genesis from complex geological rocks. These nine profile formed an altered Quartz - Gabbra, altered medium - grained Basalt, Syenite and Hornblende Syenite, fine-grained Basalt, Amygdaloidal Basalt, Dolerite, Miliolite, Limestone, and Spherulitic Rhyolite were described and data on mechanical composition, C.E.C., exchangeable cations, elemental composition and clay mineralogy were presented. They concluded that apart from aspects of clay mineralogy and clay content, the influence of parent material on soil formation was generally overshadowed in this area by the predominant influence of physiography and bioclimatic factors.

In a cold and humid temperate zone (Northern France) Jamagne (1978) observed the soil forming processes in a progressive evolutionary sequence on loessial silty formations. He recognized three stages of formation : (i) mechanical alteration associated with slight geochemical transformation in a saturated medium, (ii) differentiation of the profile by 'lessivage' (leaching) associated with slight geochemical transformation, and (iii) strong geochemical transformation associated with secondary 'lessivage' in an unsaturated and reducing medium.

Duchaufour and Souchier (1978) while investigating the role of Fe and clay in the genesis of acid soils under a humid, temperate climate opined that the occurrence of acid brown soils, podzols and podzolic soils, and the intermediate types of ochreous brown, and brown podzolic soils over arenaceous granite in Vosges was closely correlated with the contents of Fe rather than with Ca plus Mg in the parent materials. Acid brown soils were found to be associated with high and podzols and podzolic soils with low contents of Fe, the limiting value being near 5 per cent. Additional investigations in beech forest soils derived from a variety of acid rocks indicated that content of Fe and clay in the parent materials controlled the type of humification of litter. With higher content of Fe and clay, humification gave rise to Mull. With lower contents, mor or moder was formed. The nature of humification was believed to be responsible for tilting pedogenesis toward brunification or toward podzolization . In brunification, clay - Fe-humus complexes that were formed tend to be immobile and promote formation of crumbly structure. The 'active Fe' occurs as films around clay particles and thus linked them to humus. In podzolization, on the other hand, the complexes formed were of humus with Fe or Al but without clay. These were mobile and were translocated downward in profiles to form spodic horizon. The organometal complexes in ochreous brown and brown podzolic soils were mobile to only a limited extent. The combined results of these investigations demonstrated that contents of Fe and clay rather than Ca in parent materials determine the pathway of pedogenesis from acid rocks under humid, temperate climates.

Rusanova (1979) studied the major elementary processes of soil formation that form the profile of peat-podzolic-gleyey illuvial-humic soils developed on lithologically heterogenous binary parent material in the central taiga subzone of the Komi, USSR.

Dasog and Hadimani (1980) made a detailed study of the genesis of three vertisols formed under semi-arid climate on Deccan Trap, Limestone and Gneiss. The soils under study were found to be developed under similar set of factors of soil formation except parent rocks. However, the influence of parent rock was subdued in the solum as evident from the soil properties, they all were clay in texture, had more than 15% exchangeable Na and were highly calcareous. They contained less free Fe and have Ca-P as the dominant P-fraction, indicating mild intensity of weathering.

Under semi-arid conditions in Iran Abtahi (1980) observed the affect of topography and time on soilgenesis in highly calcareous parent materials. Topographic features of the study area (Sarvestan Basin of Southern Iran) were related to variation in soil texture and salinity. Slightly saline, coarse-textured soils occured at high elevations, whereas fine-textured soils of higher salinity occured at low elevations. Based on salinity status, these two general soil types were classified as sols and Aridisols, respectively. Soils comprising a chronosequence differed mainly in the redistribution and accumulation of carbonates. They ranged from those developed in Holocence alluvium (Typic Zerofluvents) and lacked any evidence of carbonate redistribution to those developed on lower or middle Pleistocence surfaces (provisionally classified as Petrocalcic Xerochrepts) and showed distinct petrocalcic horizons. X-ray and electron optical analyses indicated a clear gradation in the relative contents of Palygorskite and Smectite clay minerals within this chronosequence. Palygorskite was found to increase as Smectite decreased in older soils.

Campbell and Claridge (1982) studied the development of soils of the cold deserts of Antarctica and the influence of moisture on it. Soils of these cold deserts were found to have many features in common with those of hot deserts. They generally had dry surface horizons, capped by a desert pavement of lag gravel, a zone of accumulation of water-soluble salts, and a permanently frozen layer beneath, which might be ice-cemented in its lower part. They were also distinguished by their very low temperatures and as a consequence of this they had very low moisture status and humidity.

The influence of broad climatic differences in Antarctica was reflected in the soils by differences in moisture supply, in terms of precipitation, and its availability, which was dependent on the length of time any given soil was, in whole or part, above freezing. This in turn influenced the development of morphological properties including soil depth and horizon development. On the basis of these features it had been possible to group soil in terms of moisture availability; those in which moisture was rarely, if ever, available and in which there was no leaching of soluble materials (Ultraxerous moisture class); soils in which moisture was sufficient to allow some leaching of soluble material (Xerous moisture class); and soils in which relatively large amounts of moisture were available (Sub- Xerous moisture class). Sub-surface iee, present during the early stages of soil formation as the soil parent material was formed by the ablation of ice-cured moraine, represented an important source of profile moisture during the early stages of soil formation. Its main influence on soil morphology, however, was in the mixing and sorting of coarse and fine materials during the formation of patterned and hummocky ground. In local areas, where there was an abundance of moisture, often as a saline solution on hollows or depressions, intrazonal soils might be developed. Apart from a wetter soil moisture regime, these soils were characterized by the presence of higher concentrations of soluble salt, by olive rather than brownish soil colours and by higher clay contents as well as by differences in weathering and clay mineral formation.

Dubey et al. (1984) studied the formation of soils in the northern side of Nal Sarovar lake in Ahmedabad district of Gujarat and revealed that flat topography and aridity were the main factors responsible for formation of these salt affected soils. Impedance of natural drainage, they opined, had resulted in water stagnant condition favouring the formation of Aquic Natrargids.

MATERIALS AND METHODS

MATERIALS AND METHODS

1. MATERIALS

Soils of Siliguri Sub-Division (Bagdogra, Naksalbari, Kharibari, Phansidewa, and Siliguri) of Darjiling District have been surveyed and studied by digging pits and augur boring for correlation and classification of the soils as well as samples collected from each profile for further detailed physical, chemical, physico-chemical, and mineralogical analyses in the laboratory. Before proceeding further it is essential to present a brief description of the area, covering all aspects of climate, physiography, relief, drainage, geography, geology, natural vegetation, land use, agriculture, public facilities, population, and history as related to the soils and their use and management.

1.1 Climate :

The entire area of Siliguri Sub-Division (Fig.1) undergoes an alternate phase of wetting during the months of June to September and drying during the months of October to May. The average (last ten years) monthly rainfall varies from 848 mm during the months of July-August to 1 mm during the months of November-December (Fig.1.1). Consequently, the relative humidity ranges between 58-90% on an average, the highest corresponding with the peak of the monsoon months and the lowest during the months of March-April. 80-90% of the average rainfall is received during

FIG. 1 MAP OF WEST BENGAL SHOWING STUDY AREA (DARJILING DISTRICT)

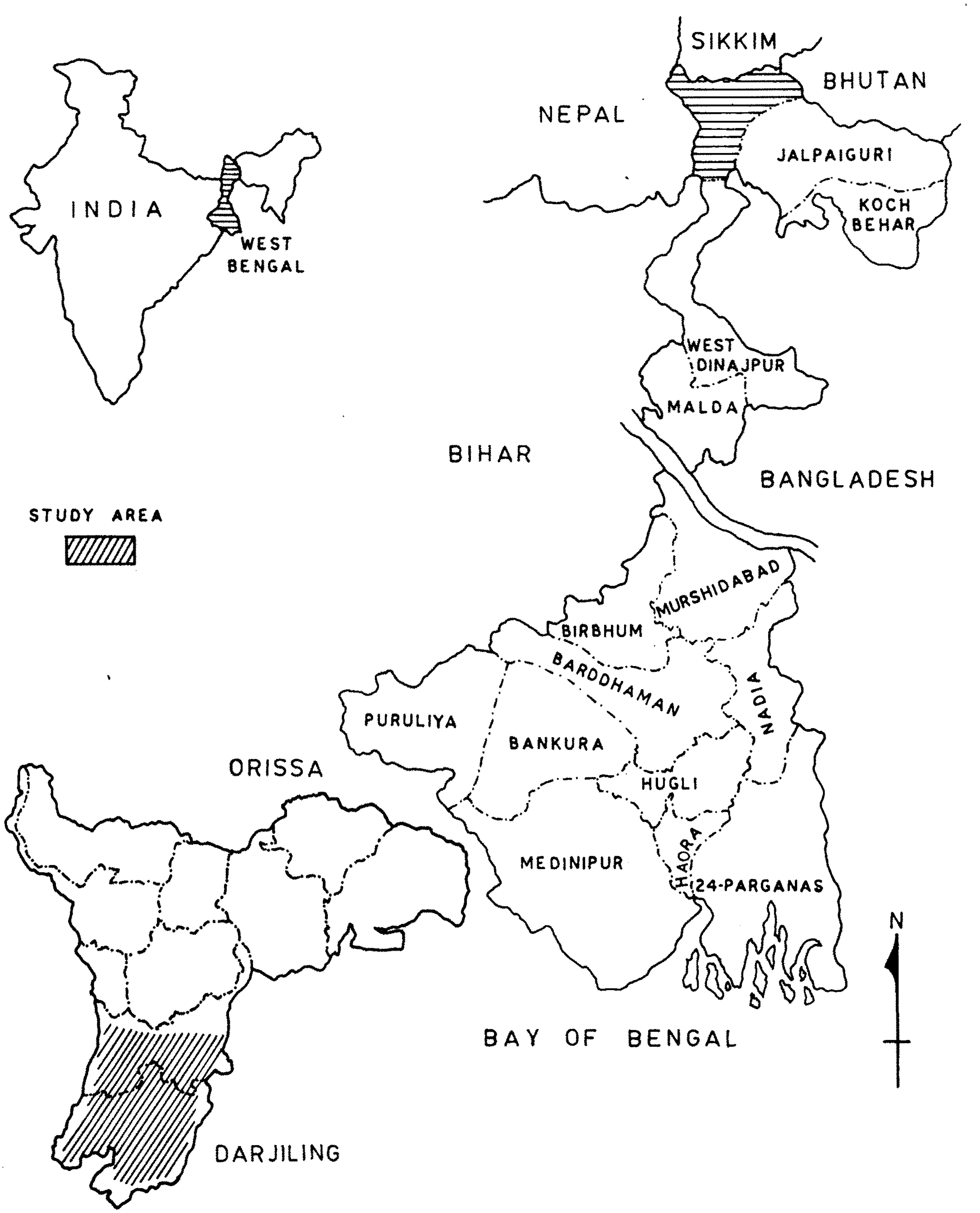
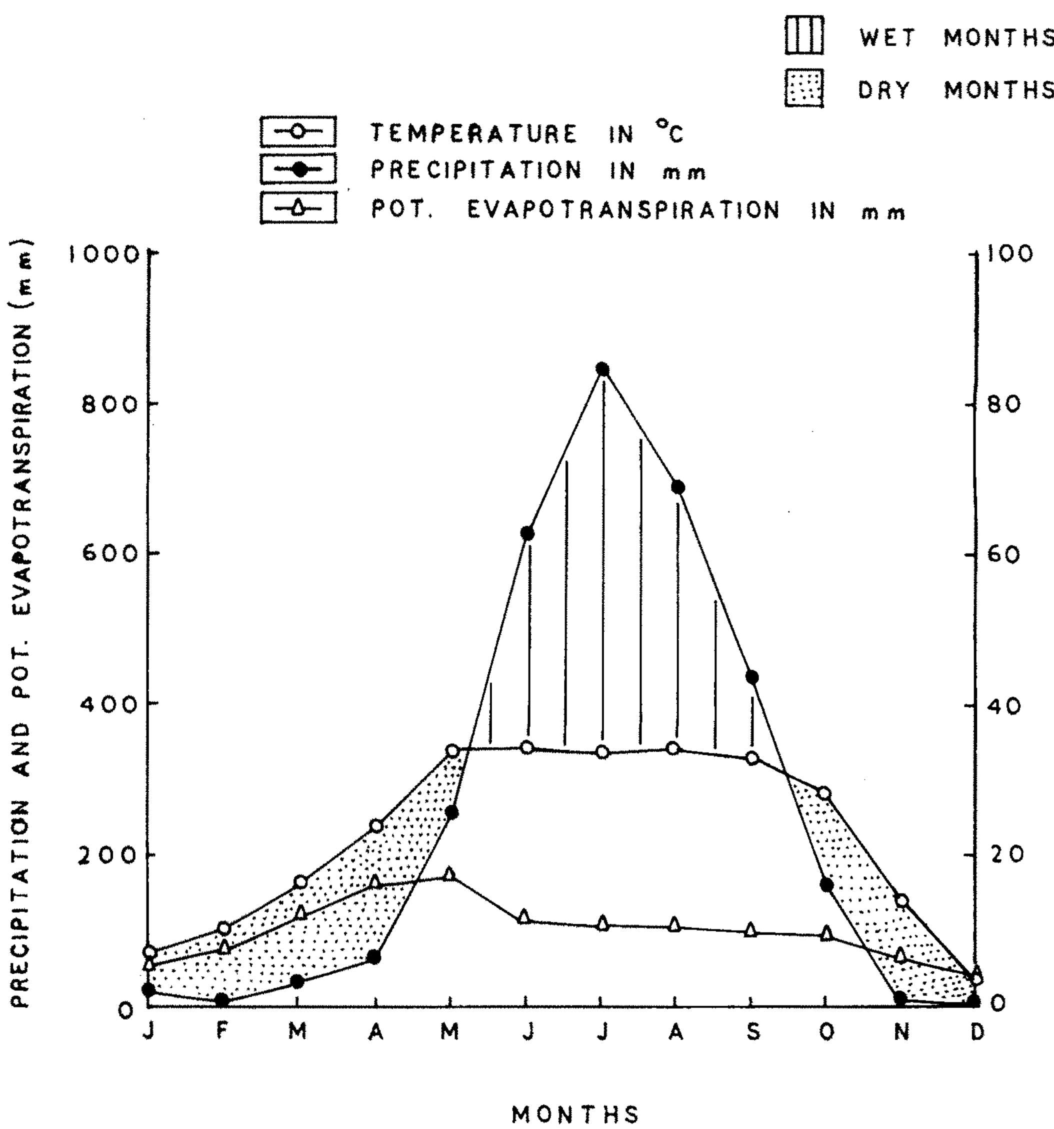


FIG. 1.1 TEMPERATURE, PRECIPITATION AND POTENTIAL EVAPOTRANSPIRATION DIAGRAM (BAGDOGRA, SILIGURI)



the months of June-September which in turn increases the relative humidity to a great extent. But on the other side, the potential evapotranspiration is found to be higher during the months of March-May, the average (last ten years) of which throughout the year ranges between 49-169 mm. From the ombrothermic diagram (Fig.1.1) it is evident that the potential evapotranspiration is lowest during the winter months of November-February.

The mean daily maximum and minimum air temperature for summer months are 34°C and 25°C respectively whereas for the winter months the values are 23°C and 4°C respectively. The temperature difference between the mean maximum and minimum is less remarkable during the wettest months indicating the moderating influence of rainfall and relative humidity. Though the winter months show a remarkable fall in the mercury thread the relative humidity does not decrease appreciably concluding that the weather does not become too dry. The only period of the year which suffers the sting of aridity and dryness are during March-May when the mean daily temperature rises to its maximum and the relative humidity is at its nadir alongwith an abrupt rise in the potential evapotranspiration data viz., 119-169 mm during March - May.

In fine, it can be concluded about the climate of Siliguri that it experiences cold and heat to a considerable degree with a good amount of precipitation, though unevenly distributed, throughout the twelve months of the year.

1.2 Physiography, Relief, and Drainage:

The three physiographic divisions of India afford most pertinent illustrations of the main principles of physiography. The prominent features of the extra-Peninsula, the great mountain border of India, are those due to upheaval of the crust in late-Tertiary times, modified to some extent by the denuding agents which have since been operating on them; those of the Peninsula are mainly the results of the sub-aerial denudation of a long cycle of geological ages, modified in some cases by volcanic and in others by sedimentary accumulations; while the great plains of India, dividing these two regions, owe their formation to sedimentary deposition alone, their persistent flatness being entirely due to the aggrading work of the rivers of the Indus-Ganges system during comparatively recent times (Wadia, 1981).

A gentle slope from the North-West to the South-East is characteristics of this region with elevation between 300 m to 50 m above mean sea level (msl). This area is criss-crossed by many fast flowing rivers like Mahananda, Teesta, and their tributaries. These rivers while coming down the steep slopes of the Himalayas collect debris from land slips which are quite prevalent because of wanton deforestation and mismanagement of agricultural lands on hill slopes, and as they enter the plains, their velocity being much reduced because of flat gradient, these debris are deposited on the beds.

Soils of the area can be classified into two broad tracts :

(a) Old-Himalayan Piedmont Plain : This tract (Fig.3) spreads over along the northern part of the area from Kharibari-Phansidewa in the West to Kumargram in the East covering northern part of Siliguri Sub-Division and Jalpaiguri district.

(b) Teesta Flood Plains : This tract (Fig.3) spreads along the Southern portion of the area covering southern portions of Siliguri and Jalpaiguri district and the entire Koch-Bihar district.

1.3 Geography :

Siliguri is situated in the northern part of West Bengal and is a Sub-Division town under the auspices of Darjiling district. Darjiling district is geographically located at 26° 15′N to 27° 30′N latitude and 88° 18′E to 89°E longitude while Siliguri lies at 26° 42′N latitude and 88° 25′E longitude. The total Geographical Area of Siliguri is 82.74 thousand hectares.

1.4 Geology :

The district of Darjiling (Fig.2) is partly covered by different rock types varying from Pre-cambrian metamorphites to sedimentaries of the Tertiary age. The rest of the area is covered by reeent to sub-recent alluvium and older terraces. The rocks of the mountainous part of the district is characterized by intense folding, thrusting and metamorphism resulting in a number of tecton stratigraphic succession and reverse grades of metamorphism. From South to North the rock types of Siwalik, Gondwana, Buxa and Darjiling formation are observed. The Darjiling formation comprises of garnetiferous and biotite gneiss, varieties of high grade schists and migmatite.

1.5 Natural vegetation:

The natural vegetation comprising common trees, shrubs, herbs and grasses are given below:

The trees are *Ficus religiosa* (Pipal), *Ficus benghalensis* (Barota), *Zizyphus jujuba* (Ber), *Azadirochta indica* (Neem), *Bambusa sp*. (Bamboo).

The fruit trees include *Mangifera indica* (Mango), *Psidium guajava* (Guava), *Musa sp*. (Banana), *Ananus comosus* (Pine apple).

A large number of herbaceous plants found in habitats like cultivated fields, road sides, waste land etc., contributed weeds to the cultivated crops are *Cyperus rotundus* (Deela), *Euphorbia sp*. (Dudhi), *Cynodon dactylon* (Dub grass), *Saccharum spontaneum* (Kans), *Chinopodium album* (Bathua) etc.

1.6 Present Land Use :

The total geographical area of Siliguri Sub-Division is 82.74 thousand hectares. A major part of the total area viz., 53.97 th. hectares is not available for cultivation and consequently the rest viz., 29.77 th. hectares i.e., 35% of the total area is available for cultivation. Other relevant information regarding present land use pattern is summarised below.

(a) Area under Tea Plantations = 20.10 th.hectares.

(b) Area under Forest = 11.24 th. hectares.

(c) Area under Orchard = 4.0 th.hectares.

(d) Other non-cultivable area = 22.63 th.hectares.

(e) Net Area Sown = 25.77 th. hectares.

(f) Gross Cropped Area = 45.6 th.hectares.

(g) Area Sown more than once = 19.83 th.hectares.

(h) Intensity = 176.94 %.

1.7 Agriculture :

Total number of workers in this sub-division amounts to 1,31,675. 21.04 % or 27,706 and 8.66% or 11,404 of them are cultivators and agricultural labourers respectively. Area under major crops are as follows:

(a) Aus paddy = 9.2 th.hectares.

(b) Aman paddy = 25.2 th.hectares.

(c) Jute = 2.4 th.hectares.

(d) Wheat = 3.2 th. hectares.

(e) Oilseeds = 0.8 th.hectares.

(f) Potato = N.A. (Not Available)

(g) Pulses = N.A. " "

(h) Tobacco= N.A. " "

More than 10 per cent of the total cultivable area is under irrigation.

1.8 <u>Population</u> :

According to the 1971 Census the population of this Sub-Division is 17,50,159. The density of population is 280 per sq.km.

2. METHODS

The use of good cartographic base material is essential for a successful soil survey and classification. On it depends the accuracy of plotting the soil boundaries and symbols, the rate of progress, the methods and costs of map construction, and the quality of published map. No area should be selected for survey in advance of good base material unless the most compelling reasons exists for doing so (Soil Survey Staff, 1951). For surveying the area under investigation, Survey of India Toposheet Nos. 78 B/2, B/5, and B/6 (1" = 1 mile) and Physiography Map of Darjiling district were used as base maps published by the Surveyor-General, Survey of India; and National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) respectively. The topographic maps (toposheets) present.both horizontal and vertical positions of the physical features of the land area on a flat plane at definite scales. These toposheets also show such cultural features as roads, railroads, buildings, drainage features, contour lines, and also vegetation. The reliable accuracy of these toposheets gives definite advantage in measuring distances and directions. Incidentally, it may be mentioned here that the only factor guiding the selection of Toposheets as base maps is none but non-availability of any other genuine base material for the purpose.

After the assemblage of cartographic data, preliminary study, correlation, and analysis, traversing and locating the original area and selection of scale for mapping was done before proceeding for the actual survey work. The Reconnaissance Survey Method was decided upon as this is particularly helpful in a new and relatively undeveloped region for identifying areas of promise for agriculture, settlement or more intensive use.

2.1 Reconnaissanee Survey :

On the soil map based on reconnaissance survey the boundaries between the mapping units were plotted from observations made at intervals and not necessarily throughout their whole course as on the detailed soil map.

During the progress of the work, representative sample areas of each soil series were mapped in the detail. This scheme of reconnaissance soil mapping has a wide application in new and relatively undeveloped areas. It permits the rapid surveying of large areas where development cannot await the completion of a detailed soil survey. At the same time it gives advisory agriculturists an opportunity to make those specific recommendations that can only be made on the basis of local narrowly defined soil types and phases.

Good reconnaissance maps can be made only if there is enough detailed mapping of representative sample areas to establish the model definitions of the taxonomic units and their permissible ranges of variability. Specifications for individual maps will vary widely. In foothill regions like this or other areas not likely to be used intensively, traverses were made at less frequent intervals than on land suitable for farming.

Consequently, in this sub-division, reconnaissance survey was carried out during the winter months of 1980-81, viz., December, 1980 to February, 1981 with the help and active collaboration of National Bureau of Soil Survey and Land Use Planning, Regional Centre, Calcutta (I.C.A.R.). Some fifty two spots were located for excavation to carry out detailed morphological examinations. First of all, a description of the relief - the gradient, length, and shape of slopes and their pattern were noted. This was usefully supplemented by brief description of the kind of land form. Relief and drainage were noted separately. Although runoff (or external soil drainage) is closely related to slope, internal drainage depends upon the permeability of the soil and of the material beneath it. Thus a permeable soil was found to be well drained on a gentle slope, whereas a slowly permeable soil was imperfectly or even poorly drained on the same slope. Where differences in elevation were significant those were recorded, either from the toposheet, or by approximate measurement with an altimeter.

Then a clear description of the parent material itself - its texture, structure, colour, consistence, and other significant features including depth and stratification were noted. Suggestions regarding approximate mineralogical composition and the rock source of the material were also incorporated. Important suggestions about probable or possible differences between the substratum (as C horizon) and the original material from which the solum itself has been developed was also noted down.

After the excavations or digging of pits of dimension 1.25 m x 1.25 m at the spotted sites with depths varying from 120-150 cm. depending on the condition of a particular profile, the study of the soil profile was undertaken. Major horizons were located first. Whereever possible letter designations, as A, B, C, and their sub-divisions were given and uncertainities about designations were indicated with a question mark.

With the horizon boundaries located, the depth and thickness of each were recorded, together with the character of the boundariesbetween them. The zero point for measurement was usually the top of the A horizon. After measurement each horizon was described with special attention to the following colour, texture, structure, porosity, consistence, reaction and effervescence, concretions and other special formations, organic matter, roots etc.; where stones were present, notes on their number and size and their distribution in the profile were recorded for evaluating the use capabilities of the soil, and in correctly establishing phases for stoniness within soil types.

Notes on erosion, and especially its effects, were incorporated for estimating the erosion hazard of the soil unit under different uses and management systems.

The principal plants of the area were noted, both dominant and associate and comments were made about the cover generally. The principal crops and their condition and the type of farming, were also recorded.

After the completion of the above field study of each individual profile, soil samples from each individual horizon within a profile amounting 800-1000 g were collected, labelled , and packed for the laboratory where further detailed physical, chemical, physico-chemical, and mineralogical analyses were performed.

2.2 <u>Physical properties</u>:

2.2.1 <u>Sampling</u> :

Sampling was done by the usual method described by Piper (1950).

2.2.2 Separation of different sized soil profiles (Particle Size Analysis) :

2.2.2.1 Pretreatment of Soil Samples for the removal of Carbonates, Organic Matter, and Iron Oxides and Dispersion :

The carbonates commonly encountered in soils in quantities sufficient to cause difficulties are those of calcium and magnesium. The more crystalline, concretionary forms of the carbonates are less troublesome than the poorly crystalline, finely divided forms. Unless these are removed, it is impossible to achieve any meaningful separation of silt and clay. Whereas, the soluble salts were most simply removed by dissolution in water. Carbonates were removed by treating the soil samples with sodium acetate buffer(pH 5.0).

Organic matter has an aggregating effect; hence its removal is necessary for a good dispersion of the soil samples. Hydrogen peroxide, first used by Robinson (1922), was used to oxidize organic matter. Efficient use of H_2O_2 requires an acid medium and this is after Jackson (1956) according to whose suggestion the soil samples were pretreated with sodium acetate buffer for the removal of carbonates.

Free iron oxides, occurring as discrete particles or as coatings, should be removed from the soil samples to expedite mineralogical studies. The sodium bicarbonate-dithionite -

citrate procedure (Mehra and Jackson, 1960) was followed to remove free iron oxides from the soil samples with a minimum of destructive action to the clay minerals. Sodium citrate served as the chelating agent for ferrous and ferric forms of iron. The sodium bicarbonate buffered the solution, while sodium dithionite reduced the iron.

After the soil samples were made free of carbonates, organic matter, and iron oxides, effective dispersion was achieved by boiling and shaking the samples with a solution of 2 per cent sodium carbonate (pH 9.5).

2.2.2.2 Separation of different-sized particles :

Segregating the particles coarser than 0.05 mm was achieved by sieving the sodium - dispersed soil suspension. The determination of the percentage distribution of different sized particles or the particle size analysis of all the soil samples was done by Robinson's Pipette method (1922 b).

2.2.2.3 Determination of Clay Concentration or Percent Clay determination :

A suitable aliquot of the suspension (Na-saturated sample) containing about 100-200 mg of clay was placed in a 20 ml centrifuge tube. The clay was washed 3 times with 1(N) NaOAC buffer solution of pH 5.0, the tube being placed for 5 minutes in a boiling water-bath for each washing, to ensure complete dissolution of the carbonate present if any. Following this ; 5 drops of 1(N) NaOAC buffer solution of pH 5.0 and 5 ml of 30 per cent H_2O_2 were added. The tube containing the sample was heated on a steamplate (70-80)°C for about 3 hours to complete the destruction of any residual organic matter such as growth of organism and mineral organic complexes. A slightly acidic medium enhances the oxidizing action by H_2O_2.

The aliquot was then saturated with K^+ or NH_4^+ to obtain the clay concentration. The sample was then transferred quantitatively to a weighing bottle, dried at 110°C for 24 hours and then weighed again.

2.2.3 <u>Determination of Bulk Density</u> :

Bulk density was determined by the widely used Core Method.

2.2.4 <u>Determination of Particle Density</u>:

Particle density of the soil samples were determined by employing a Pycnometer (specific-gravity flask).

2.2.5 <u>Determination of Porosity</u> :

Porosity of the soil samples were calculated indirectly from density measurements which simply involves converting data from densities to volumes. Since bulk density (D_b) is defined as M_s/V_b in which M_s is the mass of soil (oven dry) in bulk volume (V_b) then

$$V_b = M_s/D_b \qquad \text{.........} \qquad (5)$$

Similarly, from the definition of P_p, the particle density , one obtains the relationship $V_p = M_s/P_p$, in which V_p is the collective volume occupied by solid particles having total mass M_s. But V_b is the whole volume of the space to be partitioned, and consequently V_p/V_b is the fraction of the volume occupied by solid particles. From the above definitions, it follows that this fraction equals D_b/P_p. Total porosity S_b, is defined as the percentage of the bulk volume not occupied by solids, that is,

$$S_t = 100 \left[1-(D_b/P_p)\right] = 100 \left[(P_p - D_b)/P_p\right] \quad .... \quad (6)$$

2.2.6 <u>Determination of Soil-Water Content</u>:

The water content in the soil samples were determined gravimetrically by oven drying at 110°C for 48 hours in all the determinations. Water - content on volume basis was calculated by multiplying the water-content on weight-basis by the bulk density of the soil sample.

$$\theta = D_b \theta_w \quad .... \quad (7)$$

where, θ = volume of water per unit soil volume, cm^3/cm^3;

θ_w = weight of water per unit soil weight, g/g or cm^3/g ;

and D_b = Bulk density of soil, g/cm^3.

2.2.7 Determination of pH :

pH of the soil samples were determined using water and 1(N)KCl solution, mixing soil to water and soil to 1(N)KCl solution in the ratio of 1:2.5. pH was determined with the help of glass electrode pH meter (Jackson, 1958). The suspensions of soil-water and soil - 1(N)KCl were stirred well just before the electrode was immersed andthence reading was noted down.

2.3 Chemical and Physico-Chemical properties:

2.3.1 Cation Exchange Capacity :

The soil samples were treated with 1(N) NH_4OAC at pH 7.0 and kept overnight. The very next-day treated samples were filtered and repeatedly leached with 1(N) NH_4OAC and then with 60 per cent alcohol to make the samples free of NH_4OAC and then distilled with MgO. The distillates were collected in Boric Acid mixed indicator mixture and the NH_4^+ was determined by titrating with 0.1(N)H_2SO_4 (Schollenberger and Simon, 1945).

2.3.2 Available phosphorus :

In the Bray No.1 method the soil was extracted with a solution of 0.03 (N) NH_4F in 0.025(N)HCl (Bray and Kurtz,1945) and then the 'P' was determined colorimetrically using 660 m/u filter.

2.3.3 Total Nitrogen :

Total nitrogen of all the soil samples was determined by Kjeldhal's digestion method as described by Jackson (1958).

2.3.4 Organic Carbon and Organic Matter :

Organic carbon was determined by Walkley and Black's (1934) wet digestion method and the amount of organic matter was estimated from organic carbon determinations (values).

2.3.5 Exchangeable Iron and Aluminium :

Exchangeable Aluminium was determined from the 1(N)KCl leachate using Aluminium for colour development and the reading was taken colorimetrically as described by Black (1945).

The exchangeable Iron was determined by leaching the soil with 1(N) NH_4OAC solution of pH 3.0. And Iron was estimated colorimetrically by Orthophenonthroline method as described by Jackson (1957).

2.3.6 Free Iron Oxides :

Free Iron Oxide was also determined colorimetrically by Orthophenonthroline method from the leachate made from soil: sodium dithionite : water in the ratio of 1:1:20 after 16 hours of shaking (Black, 1945).

2.3.7 Exchangeable Calcium, Magnesium, Sodium, and Potassium :

Exchangeable Calcium and Magnesium was determined from the 1(N) NH_4OAC leachate at pH 7.0 by the Versene titration method as described by Jackson (1958). Whereas the exchangeable Sodium and Potassium values were obtained from the Flame Photometer.

2.4 Soil-Clay Mineralogy :

2.4.1 Na_2CO_3 fusion for Total Chemical analysis of Soil clays :

Fusion of K-clays were done according to the method described by Jackson (1958). The ignited mass with Na_2CO_3 was fused at 900°C in a platinum crucible. The melted mass was cooled and dissolved in HCl. Silica remained insoluble.

2.4.1.1 Determination of Silica :

The insoluble silica was made free of extract with repeated washing and ignited and weighed. The weight was expressed in percentage.

2.4.1.2 Determination of Sesquioxide :

After the removal of silica the volume of the extract was made upto 500 ml. 100 ml was taken for estimating sesquioxide after precipitation with ammonia (A.O.A.C. 1959).

2.4.1.3 Determination of Calcium :

In the same aliquot, after the removal of sesquioxide, calcium was precipitated as calcium oxalate (Piper,1950).

2.4.1.4 Determination of Magnesium :

It was estimated in the same aliquot after the removal of calcium, by precipitating it as magnesium ammonium phosphate (Wright, 1939).

2.4.1.5 Determination of Potassium :

It was estimated in the HCl extract by the volumetric cobaltnitrate method as described by Jackson (1958).

2.4.1.6 Determination of Iron :

Iron was estimated after reduction with stannous chloride and subsequent estimation of the reduced iron volumetrically with standard solution of potassium dichromate using diphenylamine as indicator (Treadwell and Hall, 1948).

2.4.1.7 Determination of Aluminium :

The percentage of aluminium was obtained by subtracting Fe_2O_3 % from the sesquioxide percentage.

2.4.2 Mineralogical analysis of amorphous free clay fraction :

2.4.2.1 Determination of smectite percentage by cation exchange capacity (CEC):

The CEC (K/NH_4) is determined by saturating the exchange sites with K, drying the sample overnight at 110°C to ensure fixation of K by vermiculite material, replacing the K in non-vermiculitic material with NH_4 and measuring the K in the leachate.

The calculation is based on Alexiades and Jackson (1965) equation:

$$\% \text{ Smectite} = \frac{CEC_{(K/NH_4)} - 5}{105} \times 100 \quad \ldots\ldots \quad (8)$$

2.4.2.2 <u>Determination of 'Kaolinite and Halloysite' by NaOH - Selective Dissolution Analysis (SDA)</u> :

The kaolinite plus halloysite contents are based on SiO_2% and Al_2O_3 % (Hashimoto and Jackson, 1960).

The Kaolinite plus halloysite content is calculated using the following equation based on SiO_2%, Al_2O_3%, and Fe_2O_3% content of the extracts of the dehydroxylated samples.

(i) If SiO_2/Al_2O_3 molar ratio is $\leqslant$ 2.0

$$\text{then, } \%\ (\text{KI} + \text{Hly}) = \frac{\%\ SiO_2}{46.5} \times 100 \qquad \ldots\ldots (9)$$

(ii) If SiO_2/Al_2O_3 molar ratio is $\geqslant$ 3.0

$$\text{then, } \%\ (\text{KI} + \text{Hly}) = \frac{\%Al_2O_3}{39.5} \times 100 \qquad \ldots\ldots (10)$$

(iii) If SiO_2/Al_2O_3 molar ratio is between 2 and 3

$$\text{then } \%(\text{KI} + \text{Hly}) = \frac{\frac{\%\ SiO_2}{46.5} + \frac{\%\ Al_2O_3}{39.5}}{2} \times 100 \ldots\ldots (11)$$

2.5 <u>Determination of Amorphous Material by NaOH Selective Dissolution Analysis or SDA</u> :

The amount of amorphous material present in each individual soil sample was determined by the SDA (Hashimoto and Jackson,1960). A 0.1 gm sample was boiled exactly for 2.5 minutes in 0.5(N) NaOH to dissolve the amorphous Al_2O_3 and SiO_2.

Fe_2O_3 was determined from the residue by treating it with Citrate - Bicarbonate - Dithionite (CBD) as described by Mehra and Jackson (1960).

The amorphous material is based on the quantity of SiO_2, Al_2O_3, and Fe_2O_3%per cent dissolved by the above method considering 21%percent water for Smectite clays.

The cation exchange capacity or CEC of the amorphous material was determined by the method described by Alexiades and Jackson (1966) as follows .

2.5.1 Determination of CEC of Soil Clays and Amorphous Materials (Krishna Murti *et al.* 1976):

The CEC (K/NH_4) of the original clays (without the removal of amorphous material) was determined following the procedure described by Krishna Murti *et al.*(1976).

The CEC of the amorphous material was calculated by the following procedure:

$$\text{CEC of the amorphous material(me/100 gm)} = \frac{\text{CEC}(K/NH_4)\text{ of the original clay-CEC}(K/NH_4)\text{ of the AF* clay calculated to the original clay basis}}{\text{Amount of amorphous material}} \times 100 \qquad \ldots\ldots\ (12)$$

* AF = Amorphous Free

2.6 Mineralogical Analysis of Clay Fractions by X-ray Diffraction Technique :

2.6.1 Preparation of Homoionic Clays :

Potassium and Magnesium clay systems were prepared separately by repeated washing of the clays separated by the methods described in 10.2 with 0.1(N) KCl and 0.1(N) $MgCl_2$ respectively.

2.6.2 Treatment of Clays prior to X-ray analysis:

2.6.2.1 Removal of Free Iron Oxide :

Removal of free iron oxide was done by the method recommended by Mehra and Jackson (1956).

2.6.2.2 Use of Organic Swelling Agent:

Wherever presence of montmorillonite or other expanding lattice mineral in the sample was expected, the sample was treated with glycerol according to the technique advocated by Mac-Ewan (1944, 1948) to study their expansion characteristics as an aid to their identification.

2.6.2.3 Heat Treatment :

Samples were heated to 550°C for about 2 hours. Minerals like montmorillonite, vermiculite, degraded illite, hydro-biotite, hydro-muscovite, etc., collapse to 9.9 to 10 Å spacing on this treatment and kaolinite gets completely distintegrated, and after this treatments, does not given any peak at 7 Å. Normal chlorites are not usually affected by this treatment, but in prochlorite and degraded chlorite minerals, the 7 Å peak becomes fairly weak. In fact some soil chlorite may be decomposed at temperatures as low as 550°C (Grim and Johns, 1954; Murray and Sayyab, 1955).

2.6.3 X-ray Diffraction Analysis :

K-saturated, Mg-saturated glycerol solvated, and K-saturated heated to 550°C for 2 hrs. soil clays were used for X-ray diffraction analysis. The Philips Holland X-ray Diffractometer (Model No.1140) using Ni-filtered $Fe_{K\alpha_1}$ radiation obtained at 40 KV and 20 MA, with a scanning speed of 1° (one degree) 2θ per minute, and a time constant of 4, was used for the X-ray analysis purpose.

A semi-quantitative estimation of the minerals of all the soil clays has been attempted according to the method described by Gjems (1967).

2.7 Frequency Distribution Curves and Weathering Means :

According to the formula described by Jackson and Sherman (1953) "Weathering Mean" is calculated as :

$$M = \frac{\Sigma(PS)}{\Sigma(P)} \qquad \ldots\ldots\ldots \quad (13)$$

where, M = weathering mean,
P = % mineral,
and S = weathering index or, stage of weathering of respective mineral.

Frequency distribution curves for the soil clays were drawn by plotting stages of weathering of minerals against the percentage of minerals.

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

Results of the field study (Reconnaissance soil survey) carried out for morphological observations, correlation and classification and the subsequent physical, chemical, physico-chemical, and mineralogical analysis for vindicating and supplementing the field data are enumerated in this chapter. Based on the preliminary study of landscape features coupled with the morphological data and field correlation while surveying, the soils of the area were classified tentatively into five soil series, viz., Leprijot Series, Rangapani Series, Amkishrajot Series, Bandargoj Series, and Bagdogra Series. Mapping was done at the soil association level of the five soil series thus established.

These five soil series were further classified into the taxonomic level of sub-group, great group, sub-order, and order. The data needed for establishing these five soil series at the higher level of classification have been obtained by morphological study of the profiles in the field complemented with a systematic laboratory analyses of the soils of five (one from each series) typical representative profiles collected. This physical, chemical, physico-chemical, and mineralogical analyses also served the foundation for not only attempting at the genesis of the soils in question but also helped in the identification and quantification of the minerals present, the nature and amount of amorphous constituents and also the stages of weathering.

Furthermore, the data collected and obtained were also illuminating enough to shed light on some utility aspects of soil taxonomy viz., land capability classification, land irrigability classification, soil fertility management, land use, and suggested land use.

Thus, the results alongwith discussion, wher-ever necessary, are given under the following heads.

1. Soil Classification

    1.1 Soil series.

    1.2 Land capability sub class.

    1.3 Land Irrigability sub class.

    1.4 Soil Fertility Management.

    1.5 Land Use.

    1.6 Suggested Land Use.

2. Studies on Physical, Chemical, and Physico-chemical Properties of the soils.

3. Studies on soil clay mineralogy and amorphous constituents of the soil clays.

    3.1 Chemical composition and CEC of the soil clays.

    3.2 Amount and composition of "Kaolinite + Halloysite" in amorphous free clays.

    3.3 Study of non-crystalline Amorphous Ferri-Alumino-Silicate (AFAS) constituents in the soil clays.

    3.4 X-ray diffraction studies of the soil clays.

4. Study of Genesis of Clay Minerals of the Classified Soils.
5. General Discussion on the soils of the five soil series.

1. SOIL CLASSIFICATION

Soil classification and delineation of the mapping units were based on morphological, physical, chemical, physico-chemical, and mineralogical study. Soil series has been the fundamental unit of classification and as such the soils have been classified as per USDA (United States Department of Agriculture) soil taxonomy at the sub-group level of the hierarchy.

The area represent soils belonging to two orders viz., Entisols with no diagnostic horizon and Inceptisols with 'ochric' epipedon followed by 'cambic' sub-surface diagnostic horizons. Four sub-groups have been established viz., Typic Fluvaquents, Aeric Haplaquepts, Mollic Udifluvents, and Typic Udipsamments. The five distinct soil series identified are Leprijot Series, Rangapani Series, Amkishrajot Series, Bandargoj Series, and Bagdogra Series. However, a soil map (Fig.5) at the association level has been prepared showing three soil associations viz., Amkishrajot - Leprijot soil association, Bagdogra - Rangapani soil association, and Bandargoj - Amkishrajot soil association. A detailed description of each soil series is given in the following pages.

1.1 Soil Series: (Fig.5)

1.1.1 Leprijot Series (Photograph 1):

The Leprijot series is a member of the coarse loamy, mixed, hyperthermic family of Typic Fluvaquents. Leprijot soils have dark gray colour, strong to medium acidic sandy loam to loamy sand A horizons and gray to pale brown, slightly acidic sandy loam to loam C horizons. They have developed on weathered alluvium. They occur on undulating and rolling alluvial plain with 3-6% slope at an elevation of 10-100 metres above MSL. The climate is subhumid subtropical with the mean daily maximum and minimum air temperature for summer months are 34°C and 25°C and winter months 23°C and 4°C respectively. The average annual rainfall is 3132 mm.

Typifying Pedon: Leprijot sandy loam - cultivated.

Horizon		Description
A_p	0-18 cm ---	Dark Gray (10YR4/1)sandy loam; massive; yellowish brown (10YR5/6)rusty specks; slightly hard, moderately firm,non-sticky;few medium roots; few common pores; weak biological activity; pH 5.3; gradual wavy boundary.
A_c	18-32 cm ---	Dark gray (10 YR 4/1) sandy loam; moderate medium sub-angular blocky structure; few

Photograph 1 : LEPRIJOT SERIES: Coarse Loamy,
A Typic Fluvaquent(0-130 cm depth)

Photograph 2 : RANGAPANI SERIES: Coarse Loamy over
Sand, A Typic Fluvaquent(0-150 cm depth)

1

2

Photograph 3 : AMKISHRAJOT SERIES: Fine Loamy,
An Aeric Haplaquept (0-130 cm depth)

3

fine faint yellowish brown (10 YR 5/8) mottles; slightly firm, slightly sticky, non-plastic; few fine roots; common coarse, common medium pores; weak biological activity; pH 5.4; gradual smooth boundary.

C_1 32-76 cm --- Dark reddish gray (10 YR 5/1) sandy loam; weak medium sub-angular blocky structure; few medium distinct yellowish brown (10 YR 5/8) mottles; slightly firm, slightly sticky, slightly plastic; few fine roots; common coarse, few fine pores; weak biological activity; pH 5.8; gradual smooth boundary.

C_2 76-108 cm --- Light gray (10 YR 6/1) sandy loam; weak coarse sub-angular blocky structure; few fine faint yellowish brown (10 YR 5/8) mottles; slightly firm, slightly sticky, slightly plastic; few fine roots; common coarse, few fine pores; weak biological activity; pH 5.9; gradual smooth boundary.

C_3 108-130 cm --- Pale brown (10 YR 6/3) sandy loam; weak fine sub-angular blocky structure;

slightly firm, slightly sticky; common medium pores; 2-4 cm size gravel about 10% by volume; pH 6.0.

Range in Characteristics :

The thickness of the solum in all the 7 profiles studied is more than 100 cm. The A horizon is 33 cm in thickness. The colour of the A horizon is dark gray (10 YR 4/1), texture being sandy loam to loam. The C horizon is more than 90 cm thick, gray to pale brown (10 YR 5/1 to 6/3) sandy loam. Moisture regime is aquic. The organic carbon content is more than 0.2% at a depth of 125 cm.

Drainage and Permeability :

Very poorly drained with moderate permeability.

Use and Vegetation :

Cultivated to paddy; natural vegetation - *Zizyphus jujuba*, *Bambusa sp*.

Distribution and Extent :

It occupies an area of 6.42 thousand hectares i.e., 16.54% of the total area.

Type Location :

Mouza : - Leprijot; P.S. Siliguri; Dist- Darjiling; W.B., 88° 17' E longitude and 26° 43' N latitude.

1.1.2 Rangapani Series (Photograph 2):

The Rangapani series is a member of the coarse loamy over sandy, mixed, hyperthermic family of Typic Fluvaquents. Rangapani soils are very deep with colour ranging between very dark grayish brown to dark grayish brown, strongly acidic sandy loam A horizons and very dark gray to dark grayish brown C horizons which are slightly acidic and sand in texture. These soils have developed on weathered alluvium. They occur on undulating and rolling alluvial plain with less than 5% slope at an elevation of (7-100) metres above MSL. The climate is sub-humid sub-tropical with mean daily maximum and minimum air temperature for summer months are 34°C and 25°C and winter months 23°C and 4°C respectively. The average annual rainfall is 3132 mm.

Typifying Pedon : Rangapani sandy loam - cultivated.

Horizon		Description
A_p	0-14 cm ---	Very dark grayish brown (10 YR 3/2) sandy loam; weak medium sub-angular blocky structure; few fine faint yellowish brown (10 YR 5/8) mottles; slightly sticky, slightly plastic; few medium roots; common coarse, common fine pores; few fine coarse fragments; weak biological activity; pH 5.1; gradual smooth boundary.

A_{12} 14-44 cm --- Dark grayish brown (10 YR 4/2) sandy loam; weak medium sub-angular blocky structure; very few fine faint yellowish brown (10 YR 5/8); mottles; slightly sticky, non-plastic; few fine roots; common coarse, few fine pores; few fine coarse fragments; weak biological activity; pH 5.4; gradual smooth boundary.

A_C 44-78 cm --- Dark grayish brown (10 YR 4/2) sandy loam; weak medium sub-angular blocky structure; very few fine distinct yellowish brown (10 YR 5/8) mottles; slightly firm, slightly sticky, slightly plastic; few fine roots; common coarse, few fine pores; few prominent coarse fragments; weak biological activity; pH 5.6; diffuse smooth boundary.

C_1 78-104 cm --- Very dark gray (10 YR 3/1) sand ; single grain; very few fine faint yellowish brown (10 YR 5/8) mottles; non-sticky, non-plastic; very few fine roots; few fine pores; few prominent coarse fragments; weak biological activity; pH 6.3; diffuse smooth boundary.

C_2 104-130 cm --- Very dark grayish brown (10 YR 3/2) sand; single grain; common abundant, few fine pores; few prominent coarse fragments; pH 6.5; gradual smooth boundary.

C_3 130-150 cm --- Very dark grayish brown (10 YR 3/2) coarse sand; single grain; common abundant, few fine pores; abundant coarse fragments; pH 6.6.

<u>Range in Characteristics</u> :

The thickness of the solum in all the 15 profiles studied is more than 100 cm. The A horizon ranges from 0-80 cm in thickness. The colour of the A horizon varies from very dark grayish brown to dark gray brown (10 YR 3/2 to 10 YR 4/2) sandy loam. The C horizon is more than 70 cm thick. The colour ranges from very dark gray to very dark grayish brown (10 YR 3/1 to 10 YR 3/2) fine to coarse sandy. The moisture regime is aquic. The organic carbon content of soil is more than 0.2% at the depth of 125 cm.

<u>Drainage and Permeability</u> :

Poorly drained with moderate permeability.

<u>Use and Vegetation</u> :

Cultivated to paddy, jute; natural vegetation - <u>Ficus benghalensis</u>; <u>Zizyphus jujuba</u>; <u>Bambusa sp</u>.

Distribution and Extent :

It occupies an area of 4.98 thousand hectares, i.e., 12.83 per cent of the total area.

Type Location :

Mouza - Rangapani; P.S. Phansidewa; Dist-Darjiling; W.B.; 88° $21\frac{1}{2}$'E longitude and 26° $33\frac{1}{2}$' N latitude.

1.1.3 Amkishrajot Series (Photograph 3):

The Amkishrajot series is a member of the fine loamy, mixed, hyperthermic family of Aeric Haplaquepts. Amkishrajot soils have dark gray to light olive brown, strong to medium acidic sandy loam A horizons. The B horizons colour ranges from dark grayish brown to grayish brown strong to medium acidic sandy loam to sandy clay loam. They occur on undulating and rolling alluvial plain with 2-4% slope at an elevation of (25-100) metres above MSL. These soils have developed on weathered alluvium. The climate of the area is sub-humid sub-tropical with mean daily maximum and minimum air temperature for summer months are 34°C and 25°C and winter months 23°C and 4°C respectively. The average annual rainfall is 3132 mm.

Typifying Pedon : Amkishrajot sandy loam - cultivated.

Horizon		Description
A_p	0-13.5 cm ---	Dark gray (2.5 Y 4/0) sandy loam; moderate medium sub-angular blocky structure; few fine faint yellowish brown(10 YR 5/8)

mottles; slightly sticky; common fine roots; few fine pores; weak biological activity; pH 5.4; gradual wavy boundary.

B_1 13.5-48 cm--- Dark grayish brown (2.5 Y 4/2) sandy loam; moderate medium sub-angular blocky structure; few fine distinct yellowish brown (10 YR 5/6) mottles; slightly firm, slightly sticky, slightly plastic; few fine roots; few fine pores; weak biological activity; pH 5.3; clear smooth boundary.

B_2 48-101 cm --- Grayish brown (2.5 Y 5/2) sandy clay loam; moderate medium sub-angular blocky structure; common fine distinct yellowish brown (10 YR 5/6) mottles; slightly firm, moderately sticky, moderately plastic; very few fine roots; few fine pores; weak biological activity; pH 5.8; gradual smooth boundary.

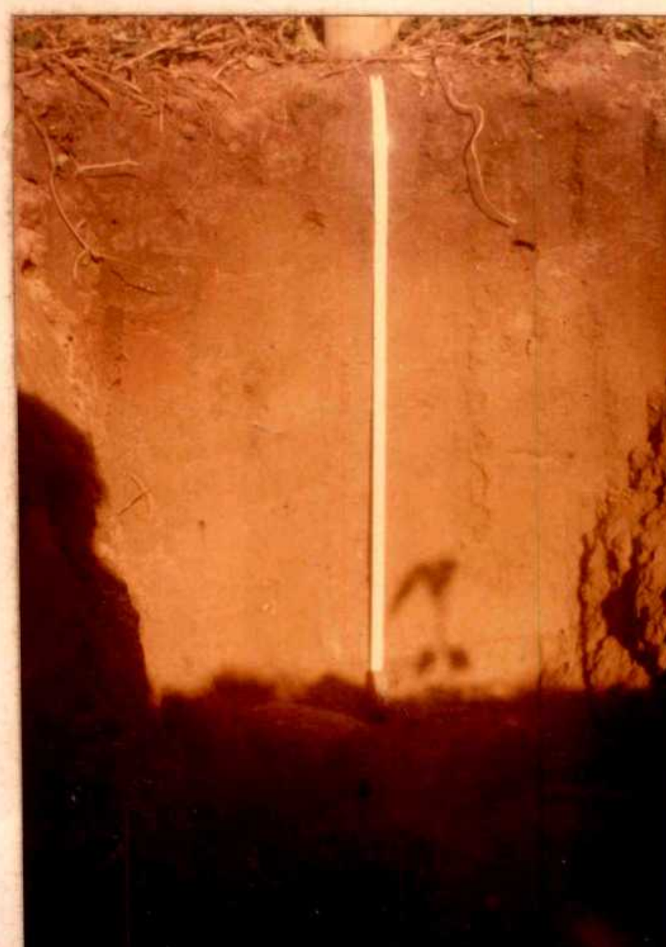
B_3 101-130 cm --- Grayish brown (2.5 Y 5/2) sandy clay loam; moderate medium sub-angular blocky structure; few fine distinct yellowish brown (10 YR 5/6) mottles; slightly firm, slightly sticky, moderately plastic; few fine pores; medium few coarse fragments; pH 6.2.

Photograph 4 : BANDARGOJ SERIES: Coarse Loamy, A Mollic Udifluvent (0-120 cm depth)

Photograph 5 : BAGDOGRA SERIES: A Typic Udipsamment (0-133 cm depth)

4

5



Range in Characteristics :

The thickness of the solum in all the 14 profiles studied is more than 100 cm. The A horizon ranges from 0-15 cm in thickness. The colour of the A horizon is dark gray (2.5 Y 4/0) sandy loam. The B horizon is more than 75 cm in thickness, colour being dark grayish brown to grayish brown (2.5 Y 4/2 to 2.5 Y 5/2) sandy loam to sandy clay loam. The C horizon is 25 cm in thickness, colour being grayish brown (2.5 Y 5/2) sandy clay loam. The moisture regime is aquic.

Drainage and Permeability :

Poorly drained with moderate to low permeability.

Use and Vegetation :

Cultivated to paddy; natural vegetation - *Bambusa sp.*; *Zizyphus jujuba*; *Musa sp.*; *Mangifera indica*; *Ficus benghalensis*.

Distribution and Extent :

It occupies an area of 7.64 thousand hectares, i.e., 19.68 % of the total area.

Type Location :

Mouza - Amkishrajot; P.S. Siliguri; Dist- Darjiling;W.B., 88° 23'E longitude and 26°39' N latitude.

1.1.4 Bandargoj Series (Photograph 4):

The Bandargoj series is a member of the coarse loamy, mixed, hyperthermic family of Mollic Udifluvents. Bandargoj soils have very dark gray to very dark grayish brown colour with strong to medium acidic sandy loam A horizons. The C horizons are very dark grayish brown to dark grayish brown with strong to medium acidic sandy loam soils. These soils have developed on weathered alluvium. They occur on rolling recent flood plain with more than 5% slope at an elevation of (10-100) metres above MSL. The climate of the area is sub-humid sub-tropical with mean daily maximum and minimum air temperature for summer months are 34°C and 25°C and winter months 23°C and 4°C respectively. The average annual rainfall is 3132 mm.

Typifying Pedon : Bandargoj sandy loam - cultivated.

Horizon		Description
A_{11}	0-11 cm ---	Very dark grayish brown (10 YR 3/2) sandy loam; moderate medium sub-angular blocky structure; slightly sticky, slightly firm, slightly plastic; very few fine roots; weak biological activity; pH 5.6; gradual wavy boundary.
A_{12}	11-31 cm ---	Dark grayish brown (10 YR 4/2) sandy loam; moderate medium sub-angular blocky structure; slightly sticky, non-plastic; few fine roots; weak biological activity; 2-4 cm size gravel about less than 10% by volume; pH 5.6; gradual smooth boundary.

C_1 31-89 cm --- Dark brown (10 YR 4/3) sandy loam; moderate medium sub-angular blocky structure; very few fine roots; 2-4 cm size gravel about 10% by volume; pH 5.8; gradual wavy boundary.

C_2 89-120 cm --- Dark brown (10 YR 4/3); loamy sand; moderate medium sub-angular blocky structure;3-5 cm size gravel about 10% by volume; pH 5.9.

Range in Characteristics :

The thickness of the solum in all the 10 profiles studied is more than 100 cm . The A horizon ranges from 0-32 cm in thickness. The colour of the A horizon is very dark grayish brown to dark grayish brown (10 YR 3/2 to 10 YR 4/2) sandy loam. The C horizon is dark brown (10 YR 4/2 to 10 YR 4/3) sandy loam. The thickness of this horizon is more than 90 cm. Soil moisture regime is udic. The content of organic carbon decreases irregularly with increase in depth and moreover at a depth of 125 cm it is more than 0.2%.

Drainage and Permeability :

Well drained with moderate permeability.

Use and Vegetation :

Vegetable cultivated, mostly settlement area; natural vegetation - *Ficus benghalensis*; *Mangifera indica*; *Zizyphus jujuba*.

Distribution and Extent :

It occupies an area of 4.18 thousand hectares, i.e.,10.77 % of the total area.

Type Location :

Mouza - Bandargoj; P.S. Phansidewa; Dist - Darjiling; W.B., 88°18'E longitude and 26°38$\frac{1}{2}$' N latitude.

1.1.5 Bagdogra Series (Photograph 5):

The Bagdogra series is a member of the mixed, hyperthermic family of Typic Udipsamments. These soils have very dark grayish brown to dark brown, strong to medium acidic sandy loam A horizons. The C horizons are gray to very dark gray brown strong to medium acidic loamy sand to sandy soils. They occur on undulating and rolling alluvial plain with 2-3% slope at an elevation of (17-50) metres above MSL. These soils have developed on weathered alluvium. The climate of the area is sub-humid sub-tropical with mean daily maximum and minimum air temperature for summer months are 34°C and 25°C and winter months 23°C and 4°C respectively. The average annual rainfall is 3132 mm.

Typifying Pedon: Bagdogra sandy loam - cultivated.

Horizon		Description
A_p	0-15 cm ---	Very dark grayish brown (10 YR 3/2) sandy loam; massive; slightly sticky; few fine roots; weak biological activity; pH 5.5; clear wavy boundary.

A_c 15- 100 cm --- Light gray (10 YR 7/1) loamy sand; single grain; slightly sticky, slightly firm, slightly plastic; very few fine roots; few fine pores; weak biological activity; pH 5.6; clear smooth boundary.

C_1 100-123 cm --- Gray (10 YR 5/1) loamy sand; single grain; slightly firm, slightly sticky, slightly plastic; very few fine pores; pH 5.6; clear smooth boundary.

C_2 123-133 cm --- Very dark gray (10 YR 3/1) sand; single grain; 3-5 cm size gravel about 10% by volume; pH 5.8.

Range in Characteristics :

The thickness of the solum in all the 8 profiles studied is more than 100 cm. 'A' horizon ranges from 0-100 cm in thickness. The colour of the A horizon is very dark grayish brown to light gray (10 YR 3/2 to 10 YR 7/1) sandy loam to loamy sand. The C horizon is more than 30 cm thick below which ground water is found. The colour of this horizon is gray to very dark gray (10 YR 5/1 to 10 YR 3/1) loamy sand to sandy. Moisture regime is udic.

Drainage and Permeability:

Very poorly drained with moderate to low permeability.

Use and Vegetation:

Cultivated to paddy; natural vegetation- *Bambusa sp.*; *Zizyphus jujuba*.

Distribution and Extent :

It occupies an area of 2.49 thousand hectares, i.e., 6.41% of the total area.

Type Location:

Mouza - Upper Bagdogra; P.S. Bagdogra; Dist-Darjiling; W.B., 88°20'E longitude and 26°44'N latitude.

1.2 Land Capability (Fig.6):

Land capability classification is a systematic classification of different kinds of land according to those properties which determine the ability of the land to produce common cultivated crops and pasture plants virtually on permanent basis. This classification enables the farmer to use the land according to its capability and treat it according to its need.

The land capability classification system provides eight capability classes which are numbered from I to VIII. These are based on the soil type, drainage or erosion and the intensity of limitation for use.

Land capability classes grouped to sub-classes depending on the specific limitations e.g., e for erosion, w for excess water, s for soil limitation within the rooting zone, c for climatic limitation.

Thus land capability sub-class enables the farmer and the planner to separate out the problems and to plan accordingly. The sub-class also enables the planner to evaluate the kinds and amounts of conservation problems.

The surveyed area has the following land capability sub-classes IIw, IIs, IIIs, and IVs. The sub-classes are described in the following lines.

1.2.1 Land capability sub-class IIw :

The land has moderate limitation that reduce the choice of crops. Gently to moderately sloping land with very deep soil of good texture. It needs simple soil and water conservation practices and requires some attention to soil management. The soil conservation practices are simple and easy to apply. These include contour cultivation, graded contour terraces (field lands with land levelling) with suitable safe water disposal arrangements due to excessive wetness during some part of the year. Conservation, crop rotation, stuble mulching and other improved farming practices viz., use of manures and fertilizers, cover and green manure crops, crop rotation, conservation of crop residue to maintain high productivity. This sub-class is mostly represented by Amkishrajot - Leprijot soil association.

1.2.2 Land capability sub-class IIs :

This land has moderate limitation and the characteristics are similar to that of capability sub-class IIw except the dominant limiting factor 'soils' which have low moisture holding sub-class also enables the planner to evaluate the kinds and amounts of conservation problems.

The surveyed area has the following land capability sub-classes IIw, IIs, IIIs, and IVs. The sub-classes are described in the following lines.

1.2.1 Land capability sub-class IIw :

The land has moderate limitation that reduce the choice of crops. Gently to moderately sloping land with very deep soil of good texture. It needs simple soil and water conservation practices and requires some attention to soil management. The soil conservation practices are simple and easy to apply. These include contour cultivation, graded contour terraces (field lands with land levelling) with suitable safe water disposal arrangements due to excessive wetness during some part of the year. Conservation, crop rotation, stuble mulching and other improved farming practices viz., use of manures and fertilizers, cover and green manure crops, crop rotation, conservation of crop residue to maintain high productivity. This sub-class is mostly represented by Amkishrajot - Leprijot soil association.

1.2.2 Land capability sub-class IIs :

This land has moderate limitation and the characteristics are similar to that of capability sub-class IIw except the dominant limiting factor 'soils' which have low moisture holding capacity, and droughtiness often due to light texture. Conservation of moisture is the major consideration. Soil Conservation measure include contour bunding, levelling, crop rotation, mixed farming, selection of drought resistant short duration variety, stuble mulching etc. This capability sub-class is represented by Bandargoj - Amkishrajot soil association.

1.2.3 Land capability sub-class IIIs :

Land with moderate limitations. Soils are deep to very deep, moderately coarse to moderately fine textured, with droughtiness and root zone limitation, low productive potential. Intensive soil conservation measures like contour bunding and levelling may be taken up. Adequate safe disposal drains may be constructed for elimination of excess water during times of heavy precipitation. Cultivation with careful selection of crops adapted to soil limitations. Intensive treatment to offset or overcome soil limitation needs attention. This sub-class is represented by Bandargoj - Amkishrajot soil association.

1.2.4 Land capability sub-class IVs :

This land has severe limitations. Moderately to strongly sloping, deep to moderately deep soil. This soil is susceptible to severe erosion, moderately coarse texture. There is severe adverse effect of drought.

Contour bunding with drainage system for safe disposal of excess run-off is to be provided. Moisture conservation measures need adequate attention. Good farming practices like fertilizing, manuring, crop rotation, conservation of crop residues, stuble mulching are needed. This sub-class is represented by Bagdogra - Rangapani soil association.

1.3 Land Irrigability (Fig. 7):

The present land use data show that the major part of the area is used for rainfed agriculture during Kharif season whereas a very small percentage of land is put to irrigated agriculture (10 % approx.) during Rabi season.

Irrigability classification is made taking note of the fact that temperature and sunshine conditions are favourable throughout the growing period for climatically adapted crops. Soil irrigability classification is made on the basis of important soil characteristics namely depth, soil texture, available moisture holding capacity, inherent infiltration and permeability and salinity-alkalinity conditions. Four (4) land irrigability classes (1 to 4) are recognized. Sub-classes are defined as limiting factors namely, soil problems(s), drainage(d), topography(t), and climate (c). Class 1,2, and 3 lands are mapped (Fig.7) in the area. Land irrigability units in a sub-class are also identified. Lands have been classified into irrigability units based on the intensity of major limitations. Irrigability class 1 lands do not have any limitations and hence they are not grouped into sub-classes and units. These include soil mapping units that have good available moisture capacity and which do not pose problems of drainage and salinity.

Assumption made in classifying the lands are that within an irrigability sub-class or unit, soils have similar limitations or hazards.

Response to practices taken in an irrigability unit will be generally uniform for the soils provided irrigation water is assumed to be adequate.

Quality of irrigation water where ground water is used is not taken into account. Such ground waters are to be considered on the basis of individual situation with respect to soil-water relationships, crop selection and management. Canal waters are of good quality.

Major factors considered in classifying lands into irrigability units are soil textures, available moisture capacity, overflow, stagnation, and high ground water. These limitations are described with appropriate symbols under 2 , 2d, and 3s.

1.3.1 <u>Land Irrigability sub-class 1</u> :

These include soils which are deep with available moisture capacity of about 6.0 to 9.3 cm/60 cm and 13.3 to 15.1 cm/100 cm depth with no hazards of drainage. Under irrigation these lands can support all the crops and orchard plants climatically adapted to the region. They will respond to the recommended average irrigation schedule. Some lands under this class may need initial levelling which is not going to pose any difficulty. These soils are expected to have the most favourable interaction to management.

1.3.2 <u>Land Irrigability sub-class 2s</u> :

These include soils which are deep with available moisture capacity of about 5.0 to 8.5 cm/60 cm and 6.1 to 12.3 cm/100 cm depth with moderate limitation for irrigation due to low available water holding capacity and fairly rapid permeability. These limitations restrict the choice of crops and the land need conservation measures to increase the availability of moisture. Crop rotation, selection of drought resistant short duration variety and stuble mulching are some of the effective measures that can be undertaken.

1.3.3 <u>Land Irrigability sub-class 2d</u> :

These soils are deep with available moisture capacity of about 8 to 9.4 cm/60 cm and 9.6 to 11.8 cm/100 cm depth with restricted permeability and susceptible to seasonal water stagnation and high ground water table. These limitations restrict the choice of crops and the lands need proper surface drainage. Adequate safe disposal drains may be constructed for elimination of excess water during times of heavy precipitation.

1.3.4 <u>Land Irrigability sub-class 3s</u> :

These include soils that are deep with available moisture capacity of about 3.5 to 6 cm/60 cm and 5.1 to 8.3 cm/100 cm depth with low available moisture and excess leaching of nutrients and susceptible to seasonal flooding. These soils present problems due to heavy percolation losses and frequent irrigation needs. Low fertility retention capacity and percolation losses of fertilizers are obvious. Choice of crops are restricted and selecting crops to use moisture and fertilizer at deeper depths of soil profile is necessary.

1.4 <u>Soil-Fertility Management (Fig.8)</u> :

Soil fertility variations are broadly distinguished on soil textures which affect the fertility holding capacity, clay mineralogy and proportions of unweathered minerals being the same. Sandy soils are less retentive whereas loams and clay loams have better capacity to hold nutrients with good base saturation ratio in all the soils. Some soils pose the problem of calcium carbonate, within the 50 cm depth profile that might affect phosphate fixation and hinder the availability of zinc which is recognized as a limiting factor. Similarly soils that are wet are expected to pose the problems of zinc availability and loss of nitrogen.

Still low fertility levels and infiltration problems are common temporary conditions irrespective of inherent characteristics. This is caused due to past use and management. These are to be corrected through proper application of fertilizers and cultural practices. For example, response to zinc may be expected in a paddy -

wheat rotation even in Irrigability class 1 land whereas it may not be so in a maize - wheat or bajra - wheat rotation. In the case of 2d soils application of zinc may be necessary irrespective of the rotation followed. Fertility management of soils should be made on the basis of inherent soil characteristics. It is assumed that soil testing is done to apply fertilizers to meet the requirement of different crops.

1.4.1 Soils with problems of fertility management due to coarse texture (Area depicted by X in Fig. 8):

These include soils (Fig.8) that are sand and sandy loams (coarse texture) throughout the profile depth. Soils of associations Bagdogra - Rangapani and Amkishrajot - Bandargoj are the examples of this kind. These soils are recommended for green manuring, deep-rooted legume crops and split application of fertilizers.

1.4.2 Soils with problems of fertility management due to wetness (Area depicted by Y in Fig.8):

These include soils (Fig.8) that are comparatively fine textured and includes mostly Amkishrajot - Leprijot soil association. These soils are subjected to stagnation, over-flow and high ground water table problems. Proper surface drainage will mitigate the problem of high ground water and/or over flow and stagnation. Paddy may be grown with supplemental irrigation followed by wheat and mustard. Besides, on site problems will have to be tackled for individual fields.

1.4.3 Soils with problems of low moisture retentivity (Area depicted by Z in Fig. 8):

These soils (Fig.8) are represented by some parts of the Amkishrajot - Leprijot soil association. They have fertility problems due to low available moisture holding capacity and fairly rapid permeability. Proper selection of crops, drought resistant short duration varieties and stuble mulching with split application of fertilizers are some of the effective measures that can be undertaken.

1.5 Land Use (Fig.9) :

The area is not put to intensive agricultural use as indicated by information collected during the survey. A sizeable part viz., 16.63 % of the area is under tea plantations. Forests occupy about 9.29 % and horticultural crops a meagre 3.30 % of the total area. Net area available for cultivation is 20.85 % of the total geographical area in which paddy (aman and aus) are the predominant crops cultivated under rainfed conditions. Jute, wheat, oilseeds,and potato are cultivated where irrigation is assured and this comprises a very small percentage of the total area cultivated. More than 10 % of the total cultivable area is under irrigation.

Fig.9 depicts the distribution of tea plantations, forests, and horticultural crops (orchards) throughout the area. The net area sown is 25.77 thousand hectares and the gross cropped area is 45.6 thousand hectares. Area sown more than once is 19.83 thousand hectares and the intensity of cropping is 176.94 %.

1.6 Suggested Land Use (Fig.10):

Soil survey has provided information on the distribution of different soils in the area and their inherent characteristics and qualities. Based on these, land evaluation has been made for rainfed and irrigated agriculture. However, detailed information and productivity and yield production should make it possible to choose package of practices for projected yields or to make contingency plans.

Crops to be grown are listed below for various land classes. The recommendations given furnish general guideline for cropping practices. However, these do not take the place of detailed recommendation made by Extension Agronomists. The recommendations refer to the identified and mapped soil units.

1.6.1 Good uplands with irrigation facilities :

Where irrigation facilities are available the following rotations are recommended.

Jute-Rice-Mustard/Wheat/Potato. The above rotation can be profitably cultivated in most of the area belonging to the Amkishrajot - Leprijot soil association.

1.6.2 Good uplands under rainfed conditions :

Under rainfed conditions the following rotation of crops in good uplands are recommended.

Jute-Paddy; Paddy-Paddy.

1.6.3 Bad lands with irrigation facilities :

Parts of Bagdogra - Rangapani and Bandargoj - Amkishrajot soil associations comes under this category. These lands can be profitably cultivated with the following crop rotation. Jute - Paddy - Pulse (*Phaseolus mungo*).

1.6.4 Medium lands under rainfed conditions :

Jute-Paddyrotation is recommended for these lands but wheat/ potato can also be included in the rabi season with assured irrigation facilities.

Potato/Cucurbits/French bean can also be cultivated in these lands. Fruit crops like Mango, Pineapple, Arecanut,Root crops(to be late Aug. -Sept.) are also recommended.

1.6.5 Low lands under rainfed conditions :

Monocropping with local variety of paddy is best suited for these soils.

2. STUDIES ON PHYSICAL,CHEMICAL, AND PHYSICO-CHEMICAL PROPERTIES OF THE SOILS

The studies included in this section is a corollary to the preceding as well as the following section, which provides the basic informations of the five soil series comprising chemical, and physico-chemical properties like pH, organic matter (O.M) content, C/N ratio, free iron oxide, available phosphate, total nitrogen content, exchangeable cations, cation exchange capacity (C.E.C.), per cent base saturation, and the exchangeable iron and aluminium accompanying with the physical properties, viz., distribution of mechanical separates in different horizons in each of the five soil series, bulk density, particle density, porosity, and water holding capacity. The results, thus obtained, are enumerated below under five sub-sections corresponding to the five soil series identified.

2.1 Leprijot Series :

As mentioned in the preceding section that the profile of this series comprises of five different horizons. Accordingly, the important physical, chemical, and physico-chemical properties of soils are presented in Tables 1.1, 1.2, and 1.3.

The percentage distribution of mechanical separates is presented in Table 1.1. It is observed that the soil of all the horizons contain a very small to fairly good amount of clay varying from 2.58 to 18.13% . The soils of the second horizon contains the highest amount of clay and it is slightly higher than that of the first horizon and nearly double than that of the third horizon. This may be the result of transportation of clay (illuviation) from surface (0-18 cm) to the immediate sub-surface horizon (18-32 cm).

TABLE 1.1: Particle Size Distribution and Textural Class of Leprijot Series

Name of Horizon	Depth (cm)	Size-class and Particle Diameter (mm): Coarse Sand (%) (2.0-0.5)	Fine Sand (%) (0.5-0.05)	Coarse Silt (%) (0.05-0.02)	Fine Silt (%) (0.02-0.002)	Clay (%) (<0.002)	Coarse Fragments (%) (> 2mm)	Ratio of Fine/Coarse sand	Ratio of Fine/Coarse silt	Textural Class
A_p	0-18	38.10	23.60	17.59	4.68	15.67	-	0.61	0.26	Sandy Loam
A_c	18-32	27.31	12.21	33.73	7.85	18.13	-	0.44	0.23	Loam
C_1	32-76	46.89	24.43	13.05	6.47	9.17	-	0.52	0.49	Sandy Loam
C_2	76-108	34.60	19.39	27.45	11.65	6.92	-	0.41	0.42	Sandy Loam
C_3	108-130	49.10	14.20	18.10	15.73	2.58	-	0.28	0.87	Sandy Loam

In all the horizons of this series, coarse and fine sand are the dominant mechanical separates which is indicative of the immaturity of the soils of the area under this series. The ratio of fine sand to coarse sand is important for the determination of the transportation of the material from surface to sub-surface horizon (Ruhe and Walker, 1968). The ratio is relatively high in the surface soil (0-18 cm) and the third horizon (32-76 cm)due to high content of fine sand whereas it is lowest in the last horizon (108-130 cm) indicating high content of coarse sand. The ratio of fine silt to coarse silt is three times more in the soils of the last horizon than that of the first two horizons.

From Table 1.2 it appears that the bulk density of the different horizons show an uniform trend of decreasing down the depth ranging from 1.62 to 1.56 g/cc whereas the trend of particle density is just the reverse varying from 2.64 to 2.56 g/cc. The porosity is observed to vary from 36.72 to 42.21% which shows an increasing trend with depth.

pH of all the horizons is in the acidic range with less variation among them. The pH increases with depth from 5.3 to 6.0 (soil : distilled water, 1:2.5) and in 1(N) KCl similar trend is observed with values ranging from 4.4 to 5.1. This indicates that the acidity of the profile gradually decreases down the profile perhaps due to leaching of bases from the surface to sub-surface horizons.

TABLE 1.2: Important Physical and Chemical Properties of Leprijot Series

Name of Horizon	Depth (cm)	pH		Bulk Density (g/cc)	Particle Density (g/cc)	Porosity (%)	Water Holding capacity (%)	O.C. (%)	O.M. (%)	Total N(%)	C:N Ratio
		With Distilled H_2O	With 1(N) KCl								
A_p	0–18	5.3	4.4	1.62	2.56	36.72	36.00	0.37	0.65	0.023	18.84
A_c	18–32	5.4	4.5	1.58	2.60	39.24	39.02	0.29	0.51	0.026	14.52
C_1	32–76	5.8	4.7	1.55	2.60	40.39	38.89	0.29	0.51	0.022	14.83
C_2	76–108	5.9	4.9	1.52	2.63	42.21	41.46	0.27	0.47	0.023	11.73
C_3	108–130	6.0	5.1	1.56	2.64	40.91	39.20	0.27	0.47	0.021	12.85

The organic matter percentage (Table 1.2) is observed to be the highest viz., 0.65% at the surface and decreases down the depth to 0.47% in the last horizon. However, the organic matter content is considered low. From the data in Table 1.2 it is evident that the total nitrogen % is also very low throughout the profile ranging from 0.026 to 0.021. The C : N ratio ranges from 18.84 to 11.73. The ratio is highest in the surface and lowest in the fourth horizon, which indicates that the accumulation of un-decomposed matter is more on the surface soil than that of the sub-surface layers.

The values of C.E.C. and exchangeable bases of different horizons are presented in Table 1.3. It is observed that the C.E.C. of the different horizons are relatively low varying from 7.02 me/100 g in the second horizon to 4.10 me/100 g in the last horizon. The percentage base saturation has been found to increase from 28.94 in the surface to 61.70% down the depth. This increase of Ca, Mg, K and Na may be attributed to the leaching and percolation from surface to sub-surface horizons. The increasing trend of pH down the profile is in good agreement with the percentage base saturation of the soils of subsequent horizons. The percentage of Free Iron Oxide is maximum (1.21 %) in the third horizon whereas it is minimum (0.31%) in the last horizon of this profile.

The values of exchangeable iron and aluminium and available phosphate are also presented in Table 1.3. It is noteworthy that the

TABLE 1.3 : Important Chemical and Physico-chemical Properties of Leprijot Series

Name of Horizon	Depth (cm)	C.E.C. (me/ 100g)	Exchangeable Cations (me/100 g)				Free Iron Oxide (%)	Exchange -able Iron 'Fe' (%)	Exchange -able Aluminium 'Al' (%)	Available 'P_2O_5' (%)	Base saturation (%)
			Ca	Mg	K	Na					
A_p	0-18	6.91	1.33	0.33	0.22	0.12	0.89	0.0046	0.0043	0.0025	28.94
A_c	18-32	7.02	1.36	0.33	0.24	0.12	0.93	0.0038	0.0062	0.0021	29.20
C_1	32-76	4.84	1.54	0.46	0.19	0.23	1.21	0.0026	0.0036	0.0013	50.04
C_2	76-108	4.78	1.57	0.48	0.16	0.21	0.94	0.0018	0.0023	0.0011	52.71
C_3	108-130	4.10	1.59	0.51	0.14	0.18	0.31	0.0011	0.0023	0.0001	61.70

exchangeable iron is gradually decreasing with depth varying from 0.0046 % in the first horizon to 0.0011 % in the last, whereas, in case of exchangeable aluminium the second horizon containing 0.0062 % has the maximum accumulation and the last horizon containing 0.0023 % is the lowest in the profile. In case of available phosphate, it is evident from the data that the first horizon contains the highest amount (0.0025 %) and the last horizon the lowest (0.0001 %). This high amount of phosphate in the surface layer might be due to the accumulation and deposition played by different grass sp ., surface addition of fertilizers, and/or the effect of liming for correcting soil acidity.

2.2 Rangapani Series :

Tables 2.1, 2.2, and 2.3 show the important physical, chemical, and physico-chemical properties of the Rangapani soils. It is observed that the profile has six distinct horizons.

From Table 2.1, it is evident that the percentage distribution of clay is low varying from 0.2 in the last horizon (130-150 cm) to 9.1 in the surface horizon (0-14 cm). The C horizon (C_1, C_2 and C_3) contains a meagre 1.2 to 0.2% of clay only whereas the clay percentage varies in the first three horizons from 9.1 to 7.6.

The soils of this area are young and immatured as is demonstrated by the high percentage of distribution of coarse and

TABLE 2.1: Particle Size Distribution and Textural Class of Rangapani Series

Name of Horizon	Depth (cm)	Size-class and Particle Diameter (mm)					Coarse Fragments (%) (>2mm)	Ratio of Fine/Coarse sand	Ratio of Fine/Coarse silt	Textural Class
		Coarse Sand (%) (2.0-0.5)	Fine Sand (%) (0.5-0.05)	Coarse Silt (%) (0.05-0.02)	Fine Silt (%) (0.02-0.002)	Clay (%) (< 0.002)				
A_p	0-14	41.75	32.25	14.11	2.67	9.17	-	0.78	0.19	Sandy Loam
A_{12}	14-44	50.25	25.64	11.83	6.57	3.68	-	0.50	0.55	Loamy Sand
A_c	44-78	50.80	20.57	13.58	6.91	7.60	-	0.40	0.51	Sandy Loam
C_1	78-104	64.07	28.73	3.18	2.85	1.21	-	0.45	0.90	Sand
C_2	104-130	67.09	20.09	7.52	3.91	0.81	-	0.29	0.52	Sand
C_3	130-150	70.63	18.12	7.30	4.11	0.22	-	0.26	0.56	Sand

fine sand. The ratio of fine to coarse sand is significantly high in the first horizon (0.78) whereas it is lowest in the last two horizon (0.26). The ratio of fine to coarse silt is significantly high in the sub-surface layers which is maximum in the fourth horizon (0.90). However, the ratio varies from 0.19 to 0.90.

The bulk density of different horizons shown in Table 2.2 indicates an increase in its value down the depth. It ranges from 1.45 g/cc to 1.63 g/cc. The particle density, on the other hand depicts a more or less reverse trend varying from 2.63 g/cc in the surface to 2.45 g/cc in the last horizon (130-150 cm), with the exception of the fourth horizon (2.43 g/cc). The percentage porosity values follow the same trend varying from 41.07 to 33.88 with the fourth horizon giving the lowest value of 32.22.

pH measured with distilled water ranges from 5.1 to 6.6 and with 1(N)KCl 4.5 to 5.7 showing the distinct acidic nature of the soils of this profile. Furthermore, the pH values have been found to show an increasing trend down the profile (Table 2.2). This increase can be attributed to leaching of bases from the surface layer. The o.m. percentage shows a decreasing trend with depth, the highest being at the surface horizon (0.62%) and the lowest in the last two horizons (0.47%). The total

TABLE 2.2: Important Physical and Chemical Properties of Rangapani Series

Name of Horizon	Depth (cm)	pH		Bulk Density (g/cc)	Particle Density (g/cc)	Porosity (%)	Water Holding capacity (%)	O.C. (%)	O.M. (%)	Total N(%)	C:N Ratio
		With Distilled H_2O	With 1(N) Kcl								
A_p	0-14	5.1	4.5	1.45	2.63	41.07	40.62	0.36	0.62	0.026	18.12
A_{12}	14-44	5.4	4.7	1.56	2.60	40.00	39.00	0.31	0.54	0.024	15.60
A_c	44-78	5.6	4.8	1.58	2.51	37.06	36.21	0.30	0.51	0.021	14.88
C_1	78-104	6.3	5.4	1.63	2.43	32.22	31.83	0.29	0.50	Trace	-
C_2	104-130	6.5	5.7	1.61	2.45	34.29	34.00	0.29	0.47	Trace	-
C_3	130-150	6.6	5.7	1.62	2.45	33.88	33.34	0.27	0.47	Trace	-

nitrogen is observed to be maximum (0.026%) in the surface soil and minimum (0.021%) in the soils of third horizon, whereas the values for the last three horizons are observed to be trace and considered negligible. Consequently, the C:N ratio varies from 18.12 in the surface soils to 15.60 and 14.58 in the soils of second and third horizons respectively. This suggests more accumulation of undecomposed material in the surface layer.

Table 2.3 presents the C.E.C. and exchangeable base values of the soils of this profile. The C.E.C. values of the soils of last three horizons are exceptionally low ranging from 0.89 me/100 g to 1.0 me/100 g. However, the soils of the first three horizons show an increase in C.E.C. values (2.67 to 4.33 me/100 g) than that of the underlying horizons. The per cent base saturation varies from 48.26 % for the soils of the surface horizon to nearly double in that of the fifth horizon (86.59%). The percentage base saturation of the soils is observed to increase down the profile with increase in the pH values. Further, the free iron oxide varies from 0.11 to 1.01%. And, the soils of the first three horizons show an increase in its content than that of the remaining last three.

The exchangeable iron and aluminium values show a more or less decreasing trend with increasing depth. Exchangeable iron varies from 0.0011 to 0.0034% and the exchangeable aluminium from

TABLE 2.3: Important Chemical and Physico-chemical Properties of Rangapani Series

Name of Horizon	Depth (cm)	C.E.C. (me/100 g)	Exchangeable Cations (me/100 g)				Free Iron Oxide (%)	Exchange-able 'Fe' (%)	Exchahge-able 'Al' (%)	Available 'P_2O_5'	Base saturation (%)
			Ca	Mg	K	Na					
A_p	0–14	4.33	1.04	0.67	0.21	0.17	0.88	0.0034	0.0032	0.0029	48.26
A_{12}	14–44	2.67	0.83	0.27	0.12	0.20	1.01	0.0021	0.0030	0.0028	53.18
A_c	44–78	4.08	1.21	0.40	0.26	0.23	0.89	0.0023	0.0029	0.0028	51.47
C_1	78–104	1.00	0.42	0.12	0.11	0.15	0.22	0.0011	0.0016	0.0002	80.00
C_2	104–130	0.97	0.43	0.11	0.14	0.16	0.12	0.0013	0.0014	Trace	86.59
C_3	130–150	0.89	0.41	0.11	0.12	0.10	0.11	0.0011	0.0015	Trace	83.15

0.0014 to 0.0032%. Available phosphate is present in trace quantities (negligible) in the soils of the last two horizons whereas the availability varies from 0.0002 to 0.0029% in the soils of the above four horizons. The layers of the A horizon (A_p,A_{12},A_c) show a uniformity in the distribution of available phosphate indicating the chances of the surface soil being manipulated with addition of fertilizers and/or effect of liming for correcting soil acidity.

2.3 Amkishrajot Series :

Amkishrajot soils have four different horizons. The results of the important physical, chemical, and physico-chemical properties are presented in Tables 3.1, 3.2, and 3.3.

It appears from Table 3.1 that the coarse and fine sands are the dominant mechanical separates of the soils of this profile. The amount of coarse silt exceeds that of the fine silt values in all the soils of the four horizons and the clay percent varies from 8.6 in the soils of first horizon (0-13.5 cm) to 32.0 in that of the third horizon (48-101 cm). Consequently, the soils of the first two horizons are sandy loam and the last two are sandy clay loam in nature. Distribution of clay shows an increasing trend down upto the third horizon. However, the soils of the last horizon (101-130 cm) contains 24.0% clay.

TABLE 3.1 : Particle Size Distribution and Textural Class of Amkishrajot Series

Name of Horizon	Depth (cm)	Size-class and Particle Diameter (mm)					Coarse Fragments (%) (>2mm)	Ratio of Fine/Coarse Sand	Ratio of Fine/Coarse Silt	Textural Class
		Coarse Sand (%) (2.0-0.5)	Fine Sand (%) (0.5-0.05)	Coarse Silt (%) (0.05-0.02)	Fine Silt (%) (0.02-0.002)	Clay (%) (< 0.002)				
A_p	0-13.5	44.16	22.21	14.21	10.83	8.6	-	0.50	0.76	Sandy Loam
B_1	13.5-48.0	38.52	18.40	12.36	11.78	16.7	-	0.48	0.95	Sandy Loam
B_2	48.0-101.0	32.00	16.01	10.70	9.11	32.0	-	0.50	0.85	SandyClay Loam
B_3	101.0-130.0	45.13	20.87	5.43	4.51	24.0	-	0.46	0.83	SandyClay Loam

The ratio between fine to coarse sand is maximum in the soils of the first and third horizons (0.50) whereas the same is observed to be less in that of the second (0.48) and fourth (0.46) horizons. On the contrary the ratio between fine and coarse silt of the soils of the second and third horizons are observed to be 0.95 and 0.85 respectively and that of the first and third horizons are 0.76 and 0.83 respectively.

The bulk density values of the soils of this profile as presented in Table 3.2 varies from 1.50 g/cc to 1.61 g/cc whereas the particle density shows an increasing trend down the profile varying from 2.58 g/cc to 2.67 g/cc (Table 3.2). The percentage porosity (Table 3.2) values varies from 39.30 to 43.57% indicating the increase in micro pores with the fineness of the texture down the profile, the value being highest for the soils of the last horizon (101-130 cm).

The pH values (Table 3.2) of the soils in distilled water and in 1(N)KCl ranges from 5.3 to 6.2 and 4.0 to 5.9 respectively. In both the cases pH value increases with increase in depth. This increase might be attributed to leaching and accumulation of exchangeable cations in the sub-surface layers.

The organic matter content of the soils (Table 3.2) show a decreasing trend down the horizons with maximum (1.12 % and 1.10%) in the first two horizons and minimum in the last two (0.84% and

TABLE 3.2: Important Physical and Chemical Properties of Amkishrajot Series

Name of Horizon	Depth (cm)	pH		Bulk Density (g/cc)	Particle Density (g/cc)	Porosity (%)	Water Holding capacity (%)	O.C. (%)	O.M. (%)	Total N(%)	C:N Ratio
		With Distilled H_2O	With 1(N) KCl								
A_p	0-13.5	5.4	4.1	1.55	2.58	39.93	38.29	0.65	1.12	0.035	18.3
B_1	13.5-48	5.3	4.0	1.52	2.60	41.54	40.86	0.64	1.10	0.033	19.1
B_2	48-101	5.8	4.5	1.61	2.65	39.30	38.00	0.49	0.84	0.035	14.0
B_3	101-130	6.2	5.9	1.50	2.67	43.57	40.16	0.32	0.55	0.023	13.6

0.55%). Total nitrogen percentage values are 0.035 in the soils of the first and third horizons and 0.033 and 0.023 in the soils of the second and fourth horizons respectively. The C:N ratio is observed to vary between 13.6 to 19.1. The values are highest in the first two layers are indicative of the accumulation of undecomposed organic materials.

The C.E.C. values of the soils of different horizons presented in Table 3.3 show an abrupt increase right from the second horizon (8.10 me/100 g) to the third (12.0 me/100 g) and fourth (13.6 me/100 g) horizons. This increase provides additional support to the earlier assumption that there is considerable leaching and accumulation of mineral nutrients from the surface layer. The percentage base saturation of the soils (Table 3.3) ranges from 42.23 in the second horizon to 57.79 in the last horizon. There is an increase in the base saturation values of the soils of the last two horizons (55.41 and 57.79%). All the exchangeable cations show remarkable accumulation, as indicated by the increase in values in the last horizon as compared to the first two horizons. Percentage free iron oxide value ranges from 0.32 for the soils of the first horizon to 1.29 for the second horizon which is observed to be three to four times more than that of the soils of other three horizons. An accumulation of free iron oxide in this subsurface layer (13.5 - 48 cm) is well indicated in this profile.

TABLE 3.3: **Important** Chemical and Physico-Chemical Properties of Amkishrajot Series

Name of Horizon	Depth (cm)	C.E.C. (me/100 g)	Exchangeable Cations (me/100 g)				Free Iron Oxide (%)	Exchange-able 'Fe' (%)	Exchange-able 'Al' (%)	Available 'P_2O_5' (%)	Base saturation (%)
			Ca	Mg	K	Na					
A_p	0-13.5	7.3	1.44	1.17	0.66	0.38	0.32	0.0042	0.0039	0.0022	50.0
B_1	13.5-48	8.10	1.23	0.96	0.82	0.42	1.29	0.0073	0.0031	0.0023	42.23
B_2	48-101	12.0	2.63	1.62	1.32	1.08	0.44	0.0012	0.0032	0.0011	55.41
B_3	101-130	13.6	3.19	1.98	1.30	1.39	0.41	0.0011	0.0018	0.0001	57.79

The exchangeable iron and aluminium, and available phosphate content of the soils of this profile is given in Table 3.3. The exchangeable iron content ranges from 0.0011% to 0.0073% whereas the exchangeable aluminium content varies from 0.0018% to 0.0039% . The percentage of exchangeable aluminium is highest in the soil of the surface horizon whereas the value of exchangeable iron is highest in the soil of the second horizon. The available phosphate values are also maximum in the soils of the second horizon (0.0023%) and minimum in the last horizon(0.0001%). As the surface layer shows a significant amount of available phosphate it is suggested that the probable reason for this may lie in addition of fertilizers and/or the effect of liming as is usually done very often for correcting soil acidity.

2.4 Bandargoj Series :

The four different horizons of this profile show a dintinct dominance of sand over other finer particles. Table 4.1 presents the data of percentage distribution of various textural classes.

In the soils of all the horizons sand is the dominant particle within which the amount of coarse sand has a definite edge over its finer counterpart. The same is true for coarse silt. The amount of clay varies from 2.67% in the soils of the lowest horizon(89-120 cm) to 5.61% in the third horizon (31-89 cm). The soils of the surface horizon (0-11cm) contain 4.12% clay. A significant characteristic of this profile is the presence of a low amount of

TABLE 4.1 : Particle Size Distribution and Textural Class of Bandargoj Series

Name of Horizon	Depth (cm)	Size-class and Particle Diameter (mm)					Coarse Fragments (%) (>2mm)	Ratio of Fine/Coarse Sand	Ratio of Fine/Coarse Silt	Textural Class
		Coarse Sand (%) (2.0-0.5)	Fine Sand (%) (0.5-0.05)	Coarse Silt (%) (0.05-0.02)	Fine Silt (%) (0.02-0.002)	Clay (%) (< 0.002)				
A_{11}	0-11	40.12	28.91	18.51	6.23	4.12	2.21	0.72	0.34	Sandy Loam
A_{12}	11-31	43.46	23.62	17.32	7.81	5.03	4.11	0.54	0.45	Sandy Loam
C_1	31-89	45.40	22.83	14.29	7.93	5.61	5.06	0.50	0.55	Sandy Loam
C_2	89-120	54.46	17.81	12.43	5.99	2.67	8.13	0.32	0.48	Loamy Sand

coarse fragments (2.21 to 8.13%) all along the profile.

The ratio between fine to coarse sand is maximum (0.72) in the surface and minimum (0.32) in the last horizon of this profile. The trend is decreasing down the profile. On the other hand the ratio between fine and coarse silt shows no such trend and as such is highest in the soils of the third horizon (0.55) and lowest in that of the surface horizon (0.34).

Bulk density values of the soils are presented in Table 4.2 show an increasing trend down the profile. It ranges from 1.55 g/cc to 1.61 g/cc, whereas, particle density of the soils ranges from 2.46 g/cc in the last horizon to 2.58 g/cc in the surface. However, there is no definite trend in the values of particle density. But it is observed that with the texture becoming lighter (Table 4.1) the bulk density (Table 4.2) increases down the depth. The porosity values of the soils range from 34.56% in the last horizon to 39.93% in the surface horizon.

From Table 4.2 it appears that the pH values in distilled water ranges from 5.6 to 5.9 down the soil profile. In 1(N) KCl it varies from 4.7 to 4.9. In both the cases there is a slight increase in the value of pH with the increase in depth of soil.

The values of organic matter content of the soils of different horizons in Table 4.2 shows that the surface horizon has the maximum accumulation of undecomposed matter whereas the

TABLE 4.2: Important Physical and Chemical Properties of Bandargoj Series

Name of Horizon	Depth (cm)	pH		Bulk Density (g/cc)	Particle Density (g/cc)	Porosity (%)	Water Holding Capacity (%)	O.C. (%)	O.M. (%)	Total N(%)	C:N Ratio
		With Distilled H_2O	With 1(N) KCl								
A_{11}	0-11	5.6	4.7	1.55	2.58	39.93	39.11	0.37	0.64	0.023	18.48
A_{12}	11-31	5.6	4.7	1.58	2.52	37.31	36.26	0.35	0.60	0.022	17.40
C_1	31-89	5.8	4.8	1.59	2.54	37.41	36.54	0.28	0.51	0.022	14.88
C_2	89-120	5.9	4.9	1.61	2.46	34.56	33.89	0.30	0.47	Trace	-

last two horizons show a minimum of such phenomenon. There is a steady increase in the values of o.m. content up the profile ranging from 0.47 to 0.64%. Total nitrogen content is uniform for the first three horizons whereas the last horizon shows a trace or negligible amount of it. The C:N ratio decreases from 18.48 to 14.88 down the profile.

It is evident from Table 4.3 that the C.E.C. values of the soils are relatively low ranging from 2.54 me/100 g to 5.22 me/100 g. The values decrease with the increase in depth. The surface horizon shows the maximum C.E.C. whereas the lowest horizon the minimum. Percentage base saturation is also highest (72.98%) in the surface layer and lowest in the last horizon (45.66%). Among the exchangeable cations calcium is abundant in comparison to others viz., Mg, K, and Na. The free iron oxide content is observed to be highest in the soils of the second (0.92%) and third (0.81%) horizons in comparison to that of the surface (0.11%) and last sub-surface horizon (0.24%).

Table 4.3 also presents the values of exchangeable iron and aluminium, and available phosphate in terms of percentage. Exchangeable iron content of the soils of this profile varies from 0.0011 to 0.0047% whereas, the exchangeable aluminium ranges from 0.0020 to 0.0032%. Both the values are maximum in the soils of second and third horizons and minimum in the fourth or last

TABLE 4.3: Important Chemical and Physico-Chemical Properties of Bandargoj Series

Name of Horizon	Depth (cm)	C.E.C. (me/100g)	Exchangeable Cations (me/100g)				Free Iron Oxide (%)	Exchangeable 'Fe' (%)	Exchangeable 'Al' (%)	Available 'P_2O_5' (%)	Base saturation (%)
			Ca	Mg	K	Na					
A_{11}	0-11	5.22	1.65	0.85	0.53	0.78	0.11	0.0032	0.0021	0.0031	72.98
A_{12}	11-31	3.50	0.90	0.34	0.42	0.29	0.92	0.0047	0.0028	0.0034	56.00
C_1	31-89	3.10	0.93	0.33	0.43	0.36	0.81	0.0043	0.0032	0.0029	65.80
C_2	89-120	2.54	0.62	0.22	0.11	0.21	0.24	0.0011	0.0020	0.0012	45.66

horizon. Percentage available phosphate is also minimum (0.0012%) in the soils of the last horizon and maximum (0.0034%) in that of the second horizon. However, the soils of the surface horizon also contain 0.0031% of available phosphate.

2.5 Bagdogra Series :

The physical, chemical, and physico-chemical properties of soils of Bagdogra series are presented in Table 5.1, 5.2, and 5.3. The profile, it is observed, has four distinct horizons which are all dominated by the distribution of sand.

Table 5.1 reveals that the distribution of coarse sand is nearly twice than that of fine sand throughout the profile with the exception of the soils of the first horizon (0-15 cm). The same is true for the distribution of the coarse silt which is approximately three times more in the second (15-100 cm), third (100-123 cm) and fourth (123-133 cm) horizons than that of the fine silt. The ratio between fine and coarse sand is observed to be the highest in the surface and lowest in the last horizon ranging from 0.35 to 0.86. Fine and coarse silt ratio follows the same pattern with a range of 0.33 in the third horizon to 0.75 in the surface. Here, the last horizon has a value of 0.45 which is more than that of the above-lying horizons (15-100 cm and 100 -123 cm).

The clay percentage is maximum 13.02 % in the soils of the surface and minimum in that of the last horizon (3.19%). The

TABLE 5.1: Particle Size Distribution and Textural Class of Bagdogra Series

Name of Horizon	Depth (cm)	Size-class and Particle Diameter(mm) Coarse Sand (%) (2.0-0.5)	Fine Sand (%) (0.5-0.05)	Coarse Silt (%) (0.05-0.02)	Fine Silt (%) (0.02-0.002)	Clay (%) (< 0.002)	Coarse Fragments (%) (>2mm)	Ratio of Fine/Coarse sand	Ratio of Fine/Coarse silt	Textural Class
A_p	0-15	38.01	32.86	9.42	7.05	13.02	-	0.86	0.75	Sandy Loam
A_c	15-100	49.16	26.15	14.23	5.30	5.16	-	0.53	0.37	Loamy sand
C_1	100-123	53.21	27.32	10.20	3.41	6.43	-	0.51	0.33	Loamy Sand
C_2	123-133	68.83	24.19	3.79	1.71	3.19	-	0.35	0.45	Sand

textural class in which the horizons belong (from surface downwards) is sandy loam, loamy sand, loamy sand, and sand respectively (Table 5.1).

The values of bulk density vary from 1.57 g/cc to 1.61 g/cc down the profile (Table 5.2). An increase in the values is justified and is in accordance with the textural class which is changing to the lighter side with increasing depth. The particle density of the soils ranges from 2.49 to 2.57 g/cc, the lowest being in the last horizon and the highest shown by that of the surface horizon. The porosity (Table 5.2) of the soils ranges from 35.35 to 38.92% . The surface soil has a higher value in comparison to that of the sub-surface layers.

pH values (Table 5.2) of all the soils of different horizons of this profile is observed to be acidic in nature. The values in distilled water and in 1(N)KCl range from 5.5 to 5.8, and 4.6 to 4.9, respectively. pH increases with depth along the profile. The o.m. distribution varies from 0.21 to 1.14% . The second horizon contains the largest amount (1.14%) whereas the last horizon the lowest (0.21%). However, the first two horizons show the presence of considerable amount of undecomposed material. The total nitrogen content varies from 0.009 to 0.031% showing no uniform pattern of distribution. The accumulation of undecomposed matter is also evident from the C:N ratio values which is maximum in the first two horizons. The ratio ranges from 13.1 to 21.93.

TABLE 5.2 : Important Physical and Chemical Properties of Bagdogra Series

Name of Horizon	Depth (cm)	pH		Bulk Density (g/cc)	Particle Density (g/cc)	Porosity (%)	Water Holding capacity (%)	O.C. (%)	O.M. (%)	Total N(%)	C:N Ratio
		With Distilled H_2O	With 1(N) KCl								
A_p	0-15	5.5	4.6	1.57	2.57	38.92	38.00	0.40	0.70	0.022	20.18
A_c	15-100	5.6	4.7	1.60	2.52	36.51	36.11	0.66	1.14	0.031	21.93
C_1	100-123	5.6	4.9	1.61	2.53	36.37	35.29	0.15	0.26	0.012	13.60
C_2	123-133	5.8	4.9	1.61	2.49	35.35	34.21	0.12	0.21	0.009	13.10

TABLE 5.3: Important Chemical and Physico-Chemical Properties of Bagdogra Series

Name of, Horizon	Depth (cm)	C.E.C. (me/100g)	Exchangeable Cations (me/100 g)				Free Iron Oxide (%)	Exchange-able 'Fe' (%)	Exchange-able 'Al' (%)	Available 'P_2O_5' (%)	Base saturation (%)
			Ca	Mg	K	Na					
A_p	0-15	8.56	2.10	0.94	1.94	0.48	0.61	0.0039	0.0042	0.0024	63.78
A_3	15-100	4.10	0.98	0.64	0.42	0.28	1.21	0.0066	0.0051	0.0024	56.58
C_1	100-123	3.92	1.03	0.52	0.54	0.13	0.76	0.0042	0.0046	0.0019	56.63
C_2	123-133	2.32	0.83	0.18	0.12	0.29	0.52	0.0013	0.0029	0.0011	61.20

From Table 5.3 it is evident that the C.E.C. is maximum (8.56 me/100 g) for the soils of the surface and minimum (2.32 me/100 g) for that of the last horizon. There is a decreasing trend with increasing depth. Percentage base saturation, as a consequence, is maximum (63.78%) in the surface and minimum (56.58%) in the second horizon. The content of free iron oxide varies from 0.52 to 1.21% , the second horizon showing maximum accumulation (1.21%) of it.

Exchangeable iron and aluminium ranges from 0.0013 to 0.0066% and 0.0029 to 0.0051% respectively. In both the cases the second and third horizons show the abundance of these elements. Available phosphate is observed to be the highest in the soils of first two horizons and lowest in the last horizon. The value ranges from 0.0011 to 0.0024% .

3. STUDIES ON SOIL CLAY MINERALOGY AND AMORPHOUS CONSTITUENTS OF THE SOIL CLAYS

To investigate the clay mineralogy of the soil clays from five soil series, a two Ponged study was undertaken viz., (i) study of the chemical composition and C.E.C. of the soil clays; and (ii) X-ray diffraction analysis of the soil clays. The use of the latter technique is resorted to identify, characterize, and quantify the clay minerals since it is generally recognized as the most powerful tool till date. However, the study of chemical composition, C.E.C., and 'Kaolinite + Halloysite' determinations were used to supplement and confirm the mineralogy of the soil clays obtained from X-ray diffraction analysis. Besides, the amount of amorphous constituents in the clay fractions of all the soil clays have also been determined and presented in this section.

3.1 <u>Chemical Composition and C.E.C. of Soil clays</u> :

3.1.1 <u>Leprijot Soil clays</u> :

Table 6.1 shows the amount of chemical constituents analysed and the CEC of the soil clays. Table 6.2 gives the molar ratios of the constituents. The SiO_2/Al_2O_3 molar ratios of the five horizons from surface downwards are 3.51, 3.48, 3.57, 3.50, and 3.54 (Table 6.2) respectively and the corresponding SiO_2/R_2O_3 molar ratio values are 2.94, 3.04, 3.16, 3.07, and 3.12. Comparing these values with those of the standard clay values (Table 6) it is observed that there is an overwhelming dominance of 2:1 mineral throughout the profile. The total K_2O% of the above clays are observed to be 2.47, 2.98, 3.01, 3.21, and 3.47 down the profile. These values in itself indicate the presence of a good amount of illite in all the horizons, the highest proportion being expected in the last horizon. Non-exchangeable MgO content of the clays vary from 1.72 to 2.92. These values indicate the possible presence of a fairly good amount of Mg-containing 2:1 type of clay

TABLE 6: Molar ratios of Standard clay minerals calculated from the data published by Grim (1968)

Serial No.	Name of the clay minerals	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Al_2O_3}{MgO}$	$\frac{Al_2O_3}{K_2O}$
1	Kaolinite (Anna, Illinois)	2.01	2.05	Infinity	Infinity
2	Smectite (Otay, California)	5.17	5.35	0.95	32.7
3	Illite (Fithian, Illinois)	3.22	3.36	3.58	3.93
4	Chlorite (Pennsylvania)	2.82	3.50	0.17	Infinity
5	Vermiculite (Pilot, Maryland)	3.46	5.74	0.19	Infinity

minerals in the profile. Corresponding CEC values at pH 7 of the soil clays are (Table 6.1) 16.24, 17.32, 17.20, 16.51, and 16.36 me/100 g down the profile. Correlating the MgO % with CEC values it is inferred that there is 2:1 type of non-expanding Mg-containing clays.

A trace quantity of CaO (0.53 to 0.68 %) is present in these clays. As this Ca could not be removed by repeated leaching of the clays with dilute HCl, it is probable that the clay

TABLE 6.1: Chemical Composition and CEC of Leprijot soil clays

Name of Horizon	Depth (cm)	Constituents Extracted (%)							CEC (me/100 g clay)
		SiO_2	Al_2O_3	Fe_2O_3	R_2O_3	CaO	MgO	K_2O	
A_p	0-18	44.24	21.38	6.51	27.89	0.68	2.92	2.47	16.24
A_c	18-32	46.10	22.53	5.08	27.61	0.63	2.68	2.98	17.32
C_1	32-76	48.72	23.19	4.67	27.86	0.65	1.72	3.01	17.20
C_2	76-108	52.21	25.36	5.47	30.83	0.61	1.78	3.21	16.51
C_3	108-130	53.80	25.80	5.43	31.23	0.53	2.68	3.47	16.36

TABLE 6.2: Molar Ratios of Leprijot Soil Clays

Name of Horizon	Depth (cm)	SiO_2/Al_2O_3	SiO_2/R_2O_3	Al_2O_3/MgO	Al_2O_3/K_2O
A_p	0-18	3.51	2.94	2.90	8.01
A_c	18-32	3.48	3.04	3.33	6.99
C_1	32-76	3.57	3.16	5.34	7.13
C_2	76-108	3.50	3.07	5.64	7.31
C_3	108-130	3.54	3.12	3.81	6.87

contains trace of primary minerals. Moreover, the Fe_2O_3 content (4.67 to 6.51%) signifies the presence of structural iron associated with clays.

3.1.2 Rangapani soil clays :

The data presented in Tables 7.1 and 7.2 are the amount of the constituents extracted alongwith the CEC of soil clays and various molar ratios respectively. The percentage distribution of K_2O in the soil clays isolated from all the horizons of the profile indicate the possible presence of a considerable amount of illitic mineral. This is again confirmed from the SiO_2/Al_2O_3 and SiO_2/R_2O_3 molar ratios which vary from 3.36 to 3.55 and 2.99 to 3.13 respectively. Comparing these values with those of standard clay values

TABLE 7.1: Chemical Composition and CEC of Rangapani soil clays

Name of Horizon	Depth (cm)	Constituents Extracted (%)							CEC(me/100g clay)
		SiO_2	Al_2O_3	Fe_2O_3	R_2O_3	CaO	MgO	K_2O	
A_p	0-14	50.48	24.12	5.14	29.36	0.56	2.93	1.44	15.41
A_{12}	14-44	50.86	24.50	5.24	29.74	0.69	2.85	2.12	18.89
A_c	44-78	52.09	25.03	6.15	31.18	0.60	1.84	2.41	14.23
C_1	78-104	53.40	26.62	4.26	30.88	0.52	1.36	2.46	14.01
C_2	104-130	54.12	27.40	5.27	32.67	0.59	1.18	2.49	13.89
C_3	130-150	54.81	27.42	5.18	32.60	0.59	2.82	2.51	13.63

(Table 6) the dominance of illite throughout the horizon is noticed. The MgO % content of the soil clays of this profile varies from 1.18% to 2.93% . These values indicate the presence of a fairly good amount of Mg-containing 2:1 type of clay minerals in the soils of this profile. The corresponding CEC

TABLE 7.2: Molar Ratios of Rangapani Soil Clays

Name of Horizon	Depth (cm)	SiO_2/Al_2O_3	SiO_2/R_2O_3	Al_2O_3/MgO	Al_2O_3/K_2O
A_p	0-14	3.55	3.13	3.26	15.57
A_{12}	14-44	3.53	3.10	3.40	10.68
A_c	44-78	3.53	3.06	5.38	9.63
C_1	78-104	3.41	3.09	7.75	10.00
C_2	104-130	3.36	2.99	9.20	10.18
C_3	130-150	3.39	3.03	3.84	10.11

values are 15.41, 18.89, 14.23, 14.01, 13.89, and 13.63 me/100 g clay down the profile. Interpreting the MgO % values alongwith the CEC values, it point to the presence of 2:1 non-expanding Mg-containing clays.

The CaO content varies from 0.52 to 0.69% which is considered very trace. This presence of CaO might be due to the presence of traces of clay sized primary minerals in the soil clays of this profile.

Fe_2O_3 % is considered high (4.26 to 6.15%) indicating the association of iron oxides with the clays.

3.1.3 Amkishrajot soil clays :

The SiO_2/Al_2O_3 molar ratios of the clays from four horizons of this profile are 3.42, 3.56, 3.68, and 3.54, and the corresponding SiO_2/R_2O_3 molar ratios are 2.93, 3.10, 3.07, and 3.06 (Table 8.2) down the profile. These values when compared with those of standard clays (Table 6) it is observed that the profile is dominating in 2:1 lattice type of minerals. The per cent K_2O values are indicative of possible presence of illite in the soil clays (Table 8.1). The K_2O % values are 2.13, 2.62, 2.32, and 3.01 down the profile suggesting that the relatively highest proportion of illite mineral is present in the last horizon. The per cent MgO content varies from 2.32 to 3.21 which indicates the possible presence of a fairly good amount of Mg-containing clays. If the CEC values (Table 8.1) are correlated with the total MgO content of clays then it can be inferred that the Mg-containing 2:1 non-expanding minerals are present in association with traces of expanding minerals. Again, it is noted

TABLE 8.1: Chemical Composition and CEC of Amkishrajot soil clays

Name of Horizon	Depth (cm)	Constituents Extracted (%)							CEC (me/100g clay)
		SiO_2	Al_2O_3	Fe_2O_3	R_2O_3	CaO	MgO	K_2O	
A_p	0-13.5	44.56	21.90	6.13	28.03	0.31	2.32	2.13	22.32
B_1	13.5-48	46.83	22.36	5.18	27.54	0.44	2.36	2.62	23.31
B_2	48-101	44.80	20.67	6.49	27.16	0.29	3.21	2.32	26.62
B_3	101-130	48.26	23.13	5.79	28.92	0.21	3.16	3.01	27.41

that the CEC values of the soil clays increase down the profile and is relatively higher in the soil clays of the last two horizons which suggests that these layers possibly contain more of 2:1 minerals than the above-lying horizons. However, the Mg content was not due to smectite or vermiculite minerals only, because under such situations the CEC of the clays should have yielded much higher values.

TABLE 8.2: Molar Ratios of Amkishrajot Soil Clays

Name of Horizon	Depth (cm)	SiO_2/Al_2O_3	SiO_2/R_2O_3	Al_2O_3/MgO	Al_2O_3/K_2O
A_p	0-13.5	3.42	2.93	7.73	9.50
B_1	13.5-48	3.56	3.10	3.75	7.89
B_2	48-101	3.68	3.07	2.54	8.24
B_3	101-130	3.54	3.06	2.89	7.11

Very small amount of CaO is observed (0.21 to 0.44 %) in the clay fraction of the soils of all the horizons of this profile which can be accounted by the presence of clay size calcium bearing unweathered primary minerals in the clays. Fairly high content of Fe_2O_3 (5.18 to 6.49 %) in the clay fraction may be due to the isomorphous substitution of iron for aluminium in the octahedral region.

3.1.4 Bandargoj soil clays :

As shown in Table 9.2, the SiO_2/Al_2O_3 molar ratios of the soil clays of this profile are 3.44, 3.49, 3.52, and 3.49 down the profile, and the corresponding SiO_2/R_2O_3 molar ratios are 3.03, 3.09, 3.03, and 3.13 respectively. All these ratios when compared with the ratios of Table 6, it appears that all the soil clays contain a fairly good amount of 2:1 expanding lattice minerals.

The increasing trend in the content of K_2O%(Table 9.1) in the soil clays with depth (1.63 to 3.12) further suggests the presence of increasing amount of illitic mineral with increasing depth. But no such trend in the content of MgO was found with increasing depth. It is observed to vary from 1.96 to 2.38% . The clays isolated from the horizon (first) contains 2.38% of MgO is indicative of the presence of relatively increased amount of 2:1 type of minerals. The MgO values when compared with the CEC values at pH 7, which are 19.23, 18.64, 14.41, and 13.89 me/100 g clay down the profile, it is inferred that there is 2:1 type of non-expanding Mg-containing minerals in this profile. However, from the CEC and MgO content values of the clays it is evidenced that the proportion of expanding lattice mineral if at all present is relatively more in the first two horizons. Fairly high content of Fe_2O_3 (4.74 to 6.02 %) seems to be due

TABLE 9.1: Chemical Composition and CEC of Bandargoj soil clays

Name of Horizon	Depth (cm)	Constituents Extracted (%)							CEC (me/100g clay)
		SiO_2	Al_2O_3	Fe_2O_3	R_2O_3	CaO	MgO	K_2O	
A_{11}	0-11	44.36	21.87	4.68	26.55	0.31	2.38	1.63	19.23
A_{12}	11-31	48.21	23.44	4.74	28.18	0.44	1.98	2.74	18.64
C_1	31-89	49.18	23.75	6.02	29.77	0.58	1.96	2.98	14.41
C_2	89-120	54.29	26.43	4.76	31.19	0.42	2.11	3.12	13.89

TABLE 9.2: Molar Ratios of Bandargoj Soil Clays

Name of Horizon	Depth (cm)	SiO_2/Al_2O_3	SiO_2/R_2O_3	Al_2O_3/MgO	Al_2O_3/K_2O
A_{11}	0-11	3.44	3.03	3.64	12.40
A_{12}	11-31	3.49	3.09	4.68	7.93
C_1	31-89	3.52	3.03	4.79	7.37
C_2	89-120	3.49	3.13	4.96	7.83

to the presence of structural iron in the clays. Traces of (0.31 to 0.58 %) non-exchangeable CaO in the clays of all the horizons may be accounted for by the presence of some amount of clay sized primary minerals.

3.1.5 Bagdogra soil clays :

In Tables 10.1 and 10.2, the chemical composition and CEC, and the molar ratios of Bagdogra soil clays are presented. The molar ratios of SiO_2/Al_2O_3 of the soil clays isolated from different horizons are 3.47, 3.42, 3.54, and 3.58 down the profile. The corresponding SiO_2/R_2O_3 molar ratio of the soil clays of different horizons are 3.08, 2.97, 3.00, and 3.16 (Table 10.2). These values when compared with the values of standard clays (Table 6), it appears that the clays of the profile under

TABLE 10.1: Chemical Composition and CEC of Bagdogra soil clays

Name of Horizon	Depth (cm)	Constituents Extracted (%)							CEC (me/100g clay)
		SiO_2	Al_2O_3	Fe_2O_3	R_2O_3	CaO	MgO	K_2O	
A_p	0–15	52.21	25.58	5.11	30.69	0.82	2.11	2.36	18.23
A_c	15–100	48.23	23.95	5.75	29.70	0.84	1.62	1.69	19.36
C_1	100–123	49.86	23.90	6.73	30.63	0.58	2.16	1.65	21.20
C_2	123–133	53.83	25.57	5.22	30.79	0.53	2.13	2.33	22.81

investigation have 2:1 non-expanding type of mineral as the most widely-spread one in all the horizons. Among these minerals, the presence of illitic mineral finds further support as the dominant clay, from the non-exchangeable K_2O % values of the soil clays presented in Table 10.1, which ranges from 2.36, 1.69, 1.65 and 2.33 down the profile. These values also suggests the possible presence of illite in the first and last horizons to be relatively more.

TABLE 10.2: Molar Ratios of Bagdogra Soil Clays

Name of Horizon	Depth (cm)	SiO_2/Al_2O_3	SiO_2/R_2O_3	Al_2O_3/MgO	Al_2O_3/K_2O
A_p	0-15	3.47	3.08	10.04	4.80
A_c	15-100	3.42	2.97	13.13	5.86
C_1	100-123	3.54	3.00	13.40	4.38
C_2	123-133	3.58	3.16	10.15	4.75

The non-exchangeable MgO content of soil clays varies from 1.62 to 2.16% . These values point to the presence of a fairly good amount of Mg-containing 2:1 type of clay minerals in the profile. The relative abundance of this mineral is possibly more in the third (2.16% MgO) and fourth (2.13% MgO) horizons of this profile. The CEC values of the soil clays at pH 7 are 18.23, 19.36, 21.20, and 22.81 me/100 g and increases with the increasing depth of the profile. Since the CEC values are not relatively high, it is indicative of the possible presence of 2:1 type of non-expanding Mg-containing mineral in this profile.

Fe_2O_3 content varies from 5.11 to 6.73% signifying the presence of structural iron in the soil clays, which is indicative of high isomorphous substitution in the clays. Presence of traces of CaO in the soil clays may be due to the possible presence of some clay sized primary minerals in the soil clays of all the horizons.

3.2 Amount and Composition of 'Kaolinite + Halloysite' in AFAS* -free clays from five soil series :

3.2.1 Leprijot soil clays :

The analytical data on 'Kaolinite + Halloysite' content based on SiO_2% , Al_2O_3%, and Fe_2O_3% (Hashimoto & Jackson, 1960) of the AFAS*-free clay fractions is given in Table 11. The SiO_2/Al_2O_3 molar ratio of 'Kaolinite + Halloysite' in the AFAS-free clays isolated from the soils of five horizons of this soil profile vary over a narrow range, viz., 1.78 to 1.92. Among these the third (32-76 cm) horizon has the relatively higher value and the lowest is observed in the soil clays of the surface horizon (0-18 cm). This indicates that the nature of kaolinite in the clay fractions are almost similar so far the

* AFAS - Amorphous Ferri-Aluminosilicates

TABLE 11 : Amount and Composition of 'Kaolinite + Halloysite' in AFAS*- free clays of Leprijot series

Name of Horizon	Depth (cm)	Constituents Extracted(%)				Molar Ratio		'Kaolinite + Halloysite' (%)
		SiO_2	Al_2O_3	Fe_2O_3	R_2O_3	SiO_2/Al_2O_3	SiO_2/R_2O_3	
A_p	0–18	9.86	8.87	1.29	10.16	1.78	1.63	21.20
A_c	18–32	8.37	7.64	0.53	8.17	1.86	1.78	18.03
C_1	32–76	8.27	7.40	2.16	9.56	1.92	1.62	17.78
C_2	76–108	8.31	7.60	1.76	9.36	1.87	1.63	17.87
C_3	108–130	7.44	6.68	1.24	7.12	1.89	1.69	16.00

* AFAS = Amorphous Ferri-Aluminosilicates

substitution is concerned. Significant amount of iron (Fe) has been extracted by the citrate-bicarbonate-dithionite (CBD) treatment (Mehra and Jackson, 1960) of the residues after 0.5(N) NaOH treatment of the AFAS - free clays. This is indicative of a possible presence of Fe in (1:1 lattice minerals) octahedral layer alongwith 'Al'.

The semiquantitative data (Table 11) of the mineralogy of the AFAS-free clays indicates that the amount of 'Kaolinite + Halloysite' varies from 16.0 to 21.20%. The distribution of this mineral in the clay fractions all along the profile shows a decreasing trend downwards with the surface horizon containing a maximum of 21.20% and the soil clays of last horizon(108-130 cm) containing 16.00% only.

3.2.2 <u>Rangapani soil clays</u> :

The 'Kaolinite + Halloysite' content of the AFAS-free clays of the soils of this series is presented in Table 12. The SiO_2/Al_2O_3 and SiO_2/R_2O_3 molar ratios of 'Kaolinite + Halloysite' in the AFAS-free clay fractions in all the six horizons varies from 1.70 to 1.96 and 1.46 to 1.68 respectively. The SiO_2/Al_2O_3 molar ratio is observed to be relatively higher (1.96)for the said minerals of the last horizon(130-150 cm) and lowest (1.70) in the fifth horizon (104-130 cm). The second (14-44 cm) and third (44-78 cm) horizons have molar ratios of SiO_2/Al_2O_3 which

TABLE 12: Amount and Composition of 'Kaolinite + Halloysite' in AFAS* - free clays of Rangapani series

Name of Horizon	Depth (cm)	Constituents Extracted (%)				Molar Ratio		'Kaolinite + Halloysite' (%)
		SiO_2	Al_2O_3	Fe_2O_3	R_2O_3	SiO_2/Al_2O_3	SiO_2/R_2O_3	
A_p	0-14	8.83	7.56	2.00	9.56	1.87	1.66	18.99
A_{12}	14-44	9.37	8.18	1.91	9.99	1.93	1.68	20.15
A_c	44-78	9.32	8.31	2.26	10.57	1.90	1.62	20.04
C_1	78-104	7.54	7.34	1.79	9.13	1.72	1.49	16.21
C_2	104-130	6.04	6.03	1.49	7.52	1.70	1.47	12.98
C_3	130-150	4.75	4.01	1.11	5.12	1.96	1.46	10.21

* AFAS = Amorphous Ferri-Aluminosilicates

is more or less same (1.93 and 1.90 respectively). The fourth and fifth horizons, though show a decrease in the molar ratio in comparison to the above-lying horizons, the variation among them is negligible (1.70 and 1.72 respectively). A significant amount of iron (Fe) has been extracted by the CBD treatment of the residues after 0.5 (N) NaOH treatment of the AFAS-free clays. The values range from 1.11 to 2.26%. The third horizon has the maximum amount of Fe and the last horizon the minimum. This is indicative of probable occurrence of Fe in the (1:1 lattice minerals) octahedral layer alongwith 'Al' after necessary substitution of Fe for Al.

The 'Kaolinite + Halloysite' content varies from 10.21% in the soil clays of the last horizon to 20.15% in that of the second horizon. The second and third horizons show the relative abundance of the mineral (20.04 and 20.15%) whereas the last horizon contains the minimum amount (10.21 %). With the exception of the surface horizon (18.99%) there is an overall trend of decrease in the mineral content down the profile.

3.2.3 <u>Amkishrajot soil clays</u> :

Table 13 reveals the analytical data of the selective dissolution analysis for 'Kaolinite + Halloysite'. The SiO_2/Al_2O_3 and SiO_2/R_2O_3 molar ratios vary from 1.79 to 1.98 and 1.48 to 1.72 respectively. The molar ratios of SiO_2/Al_2O_3 have the relatively

TABLE 13: Amount and Composition of 'Kaolinite + Halloysite' in AFAS* - free clays of Amkishrajot series

Name of Horizon	Depth (cm)	Constituents Extracted(%)				Molar Ratio		'Kaolinite + Halloysite' (%)
		SiO_2	Al_2O_3	Fe_2O_3	R_2O_3	SiO_2/Al_2O_3	SiO_2/R_2O_3	
A_p	0-13.5	10.11	8.54	3.35	11.89	1.85	1.48	21.74
B_1	13.5-48	8.83	7.14	1.69	8.83	1.98	1.72	18.99
B_2	48-101	10.23	9.24	2.44	11.68	1.88	1.54	22.02
B_3	101-130	7.84	7.05	1.17	8.22	1.79	1.62	16.86

*AFAS = Amorphous Ferri-Aluminosilicates higher value for the said minerals of soil clays in the second horizon (13.5-48 cm) and the lowermost value for that of the last horizon(101-130 cm). However, with the exception of the surface horizon's (0-13.5 cm) molar ratio (SiO_2/Al_2O_3) value, the rest three horizons show a decreasing trend in their values down the profile. The iron (Fe) extracted by the CBD treatment of the residues is relatively high in the surface horizon. All other horizons also show a fair amount of Fe. This indicates the chance of Fe occurring in the octahedral layer alongwith'Al' after the necessary substitution of Fe for Al.

Semiquantitative data of 'Kaolinite + Halloysite' minerals in the soil clays shown in Table 13 suggests maximum presence of the same in the third (22.02%) and first (21.74%) horizons and the relatively minimum in the last (16.86%) horizon.

3.2.4 Bandargoj soil clays :

From Table 14 it is quite evident that the analytical data of 'Kaolinite + Halloysite' of AFAS-free clays of Bandargoj soils have molar ratios (SiO_2/Al_2O_3 and SiO_2/R_2O_3) varying from 1.76 to 1.96 and 1.51 to 1.78 respectively. The SiO_2/Al_2O_3 molar ratio is maximum (1.96) for the 'Kaolinite + Halloysite' in the second horizon (11-31 cm) and relatively minimum (1.76) for that of the last horizon (89-120 cm). A fairly good amount of iron (Fe) is observed in all the horizons which is found in other soil series

TABLE 14: Amount and Composition of 'Kaolinite + Halloysite' in AFAS* - free clays of Bandargoj series

Name of Horizon	Depth (cm)	Constituents Extracted (%)				Molar Ratio		'Kaolinite + Halloysite' (%)
		SiO_2	Al_2O_3	Fe_2O_3	R_2O_3	SiO_2/Al_2O_3	SiO_2/R_2O_3	
A_{11}	0-11	8.33	7.36	1.28	8.64	1.92	1.73	17.91
A_{12}	11-31	8.47	7.26	1.14	8.40	1.96	1.78	18.22
C_1	31-89	8.00	7.33	2.43	9.76	1.83	1.51	17.20
C_2	89-120	6.04	5.82	1.45	7.27	1.76	1.52	12.52

* AFAS = Amorphous Ferri-Aluminosilicates

as well. Fe in (1:1 lattice minerals) the octahedral layer alongwith 'Al' after necessary substitution of Fe for Al is observed to be present in these soil clays. The presence of structural Fe of the 'Kaolinite + Halloysite' of the 3rd horizon of this profile is observed to be maximum (2.43%) and the same is minimum in that of the second horizon (1.14%).

The semiquantitative data of the AFAS-free clay for 'Kaolinite + Halloysite' reveals that the second horizon has the maximum content of the mineral (18.22%) and the last horizon the minimum (12.52%). However, no uniform pattern of the distribution of the minerals along the profile could be established, though the last three horizons show a gradual and then an abrupt decrease of the mineral content.

3.2.5 <u>Bagdogra soil clays</u> :

In Table 15 the analytical data for 'Kaolinite + Halloysite' of AFAS-free clays of Bagdogra soils is presented. The 'Kaolinite + Halloysite' content is based on SiO_2 and Al_2O_3 per centage of the AFAS-free clay fractions of the four horizons of this soil series. The SiO_2/Al_2O_3 and SiO_2/R_2O_3 molar ratios of 'Kaolinite+ Halloysite' in AFAS-free clays of the four horizons ranges from 1.84 to 1.99 and 1.58 to 1.71 respectively. The SiO_2/Al_2O_3 molar ratios of the 'Kaolinite + Halloysite' present in the first three horizons increases down the profile whereas the last horizon is an exception

TABLE 15: Amount and Composition of 'Kaolinite + Halloysite' in AFAS* - free clays of Bagdogra series

Name of Horizon	Depth (cm)	Constituents Extracted (%)				Molar Ratio		'Kaolinite + Halloysite' (%)
		SiO_2	Al_2O_3	Fe_2O_3	R_2O_3	SiO_2/Al_2O_3	SiO_2/R_2O_3	
A_p	0-15	8.43	7.37	1.43	8.80	1.92	1.71	18.13
A_c	15-100	9.76	8.45	2.22	10.67	1.96	1.68	20.98
C_1	100-123	8.37	7.14	1.90	9.04	1.99	1.70	18.00
C_2	123-133	7.44	6.87	1.78	8.65	1.84	1.58	16.01

* AFAS = Amorphous Ferri-Aluminosilicates

in this regard. The iron (Fe) content of the 'Kaolinite + Halloysite' of the AFAS-free clays of the four horizons vary from 1.43 to 2.22% . The said minerals of the first horizon (0-15 cm) has the lowest content of structural Fe whereas the immediate horizon below (15-100 cm) shows the maximum amount of Fe present. This indicates that Fe is considered to be present in the octahedral layer alongwith 'Al' after necessary substitution of Fe for Al.

The percentage distribution of 'Kaolinite + Halloysite' in the four horizons varies from 16.01 to 20.98%. The second horizon has the highest amount of (20.98%) whereas the last horizon contains only 16.01%.

3.3 <u>Study of non-crystalline Amorphous Ferri-aluminosilicate (AFAS) constituents in the soil clays</u> :

It is an established fact that in the study of soil properties and its genesis, the identification, characterization, and quantification of mineral species in soil clays is of utmost significance. The clay fraction besides containing the crystalline part also constitute of a significant amount of non-crystalline or amorphous material in it. The widely recognized and accepted forms of these amorphous inorganic materials occurring in association with the clays are, the free and combined oxides and hydroxides of iron and aluminium, and silicates of aluminium and iron, all in various combinations with water. However, due to non availability or difficultly available pure soil amorphous material their identification and characterization is very difficult.

In this study, the composition and amount of these amorphous constituents in the five soil series have been determined by the Selective Dissolution Analysis (SDA) of Hashimoto and Jackson (1960) and the CEC was determined by the procedure described by Alexiades and Jackson (1966).

3.3.1 Leprijot soil clays :

The chemical composition of the amorphous ferri-alumino-silicates (AFAS) in the soil clays isolated from different horizons of this profile was analysed for Al_2O_3, SiO_2, and Fe_2O_3 and is presented in Table 16.1. The amount of AFAS material is observed to be relatively higher in the soil clays of the lowest (108-130 cm) and immediate above-lying (76-108 cm) horizons than that of the first three horizons. The content of AFAS minerals for the five horizons are 15.28, 15.05, 15.27, 16.91, and 18.94 % respectively down the profile. The SiO_2/Al_2O_3 molar ratios of all the horizons vary from 4.11 to 4.80. The molar ratios of the AFAS minerals of soil clay of the lowest horizon is relatively higher (4.80) than that of the four horizons overlying them (4.69, 4.27, 4.43, and 4.11) which indicates a relatively higher quantity of silica in the AFAS material associated with soil clays of the last horizon. It is also being observed that

TABLE 16.1: Composition, Amount and Molar Ratios of Amorphous Materials in Leprijot Soil Clays

Name of Horizon	Depth (cm)	Constituents Extracted (%)				Molar Ratio		$(Al_2O_3/SiO_2 + Al_2O_3)$ (%)	Amorphous material (%)
		SiO_2	Al_2O_3	Fe_2O_3	R_2O_3	SiO_2/Al_2O_3	SiO_2/R_2O_3		
A_p	0-18	8.16	3.03	1.44	4.47	4.69	3.58	17.57	15.28
A_c	18-32	8.21	3.01	1.22	4.23	4.27	3.80	17.46	15.05
C_1	32-76	8.02	3.05	1.55	4.60	4.43	3.41	18.40	15.27
C_2	76-108	8.90	3.68	1.40	5.08	4.11	3.36	19.56	16.91
C_3	108-130	10.08	3.63	1.94	5.57	4.80	3.57	17.24	18.94

the SiO_2/R_2O_3 molar ratios of this material are 3.58, 3.80, 3.41, 3.36, and 3.57 down the profile. The CEC (K/NH_4) values of total clay, amorphous free clay, and the amorphous material is shown in Table 16.2. It appears from the data that the CEC of the AFAS-materials is increasing down the profile upto the fourth horizon, the values being 46.08, 49.65, 53.61, 54.70 me/100 g of clay. A sudden and abrupt decrease in the CEC of AFAS minerals is observed for the last horizon. So, it becomes evident from the result that the AFAS material available in different horizons have a different composition and different CEC.

TABLE 16.2: CEC of Clay and Amorphous Material of Leprijot Soil Clays

Name of Horizon	Depth (cm)	CEC(K/NH_4) of Total clay (me/100 g)	CEC(K/NH_4) of AF* - clay (me/100 g)	CEC(K/NH_4) of Amorphous material (me/100 g)
A_p	0-18	16.24	7.98	46.08
A_c	18-32	17.32	8.56	49.65
C_1	32-76	17.20	7.82	53.61
C_2	76-108	16.51	6.21	54.70
C_3	108-130	16.36	6.16	47.69

* AF = Amorphous Free

However, the CEC values of the AFAS component in different horizons does not show any definite relationship with the molar ratios or CEC values of total clay. The relatively low CEC values of the original clays (16.24 to 17.32 me/100 g) indicates the relatively lower abundance of amorphous minerals in the soils of this series. Although no regular trend could be established between CEC and molar ratios and the $(Al_2O_3/SiO_2 + Al_2O_3)$% values but the latter values does indicate to the components of the tetrahedral and octahedral core of the composition.

3.3.2 Rangapani soil clays :

The soil clays separated from the six horizons of this soil series contain low amounts of amorphous ferri-aluminosilicates (AFAS) minerals (12.50 to 17.76%) as is evident from Table 17.1. It appears from the data that the soil clays of the last three horizons and the first horizon (0-14 cm) contain 15.95, 16.72, 17.76, and 15.52% of AFAS minerals, whereas, the second and third horizons contain relatively lower amount, viz., 13.13 and 12.50% respectively. With the exception of the first two horizons, the profile in general shows an increasing pattern of distribution of the AFAS minerals in the clay fraction with increasing depth. Both SiO_2/Al_2O_3 and SiO_2/R_2O_3 molar ratios are relatively higher for AFAS minerals of soil clays in the third (44-78 cm) and fifth (104-130 cm) horizons than that of the other four horizons. Though the amount of silica in the

TABLE 17.1 : Composition, Amount and Molar Ratios of Amorphous Materials in Rangapani Soil Clays

Name of Horizon	Depth (cm)	Constituents Extracted (%)				Molar Ratio		(Al_2O_3/ SiO_2 + Al_2O_3) (%)	Amorphous material (%)
		SiO_2	Al_2O_3	Fe_2O_3	R_2O_3	SiO_2/Al_2O_3	SiO_2/R_2O_3		
A_p	0-14	7.22	3.53	2.08	5.61	3.48	2.53	22.34	15.52
A_{12}	14-44	6.32	2.97	1.56	4.53	3.62	2.71	21.65	13.13
A_c	44-78	6.09	2.83	1.41	4.24	3.65	2.77	21.50	12.50
C_1	78-104	7.46	3.54	2.18	5.72	3.58	2.57	21.82	15.95
C_2	104-130	7.81	3.62	2.39	6.01	3.67	2.58	21.42	16.72
C_3	130-150	8.29	3.96	2.43	6.39	3.55	2.55	21.96	17.76

composition of AFAS mineral is higher in the last horizon but the molar ratios are comparatively lower because of the higher percentage of aluminium and iron in relation to other horizons. However, no regular trend is observed (Table 17.1) between the molar ratios and $(Al_2O_3/SiO_2 + Al_2O_3)\%$ and the content or magnitude of the amorphous materials.

TABLE 17.2: CEC of Clay and Amorphous Material of Rangapani Soil Clays

Name of Horizon	Depth (cm)	$CEC(K/NH_4)$ of Total clay (me/100 g)	$CEC(K/NH_4)$ of AF* - clay (me/100 g)	$CEC(K/NH_4)$ of Amorphous material (me/100 g)
A_p	0-14	15.41	6.20	53.14
A_{12}	14-44	18.89	8.73	68.65
A_c	44-78	14.23	6.11	58.85
C_1	78-104	14.01	6.16	43.05
C_2	104-130	13.89	5.25	46.42
C_3	130-150	13.63	5.20	42.27

* AF = Amorphous Free

From Table 17.2 it is apparent that the second horizon (14-44 cm) has relatively high CEC value of AFAS-material (68.65 me/100 g) followed by the third horizon (58.85 me/100 g). The last horizon shows relatively low CEC value of AFAS minerals i.e., 42.27 me/100 g. The CEC values of the soil clays isolated from different soils of this profile range from 13.63 to 18.89 me/100 g. Here also, the last horizon has relatively the lowest CEC value. Notwithstanding, the similarity in yielding the lowest CEC values by the last horizon of both the soil clay and AFAS material, there is no other generalized relationship that could be established from the present study.

3.3.3 Amkishrajot soil clays :

From Table 18.1 it is quite evident that the amorphous ferri-aluminosilicates (AFAS) found in the soil clays of this series have a relatively higher percentage of distribution throughout the profile. The percentage AFAS content varies from 27.32 to 30.34 and it shows an overall decreasing trend of distribution of this mineral down the profile. The surface horizon (0-13.5 cm) contains relatively higher amount of this mineral in the clay fraction (30.34%) whereas the last horizon contains relatively the lowest amount (27.32%). The surface horizon contributes more amount of silica in the composition of the AFAS mineral than that of the other three horizons.

Further, Table 18.1 also reveals that the SiO_2/Al_2O_3 molar ratio of this mineral has a decreasing trend (5.71 to 4.63) down the profile whereas the SiO_2/R_2O_3 molar ratio has

TABLE 18.1: Composition, Amount and Molar Ratios of Amorphous Materials in Amkishrajot Soil Clays

Name of Horizon	Depth (cm)	Constituents Extracted (%)				Molar Ratio		$(Al_2O_3/SiO_2 + Al_2O_3)$ (%)	Amorphous material (%)
		SiO_2	Al_2O_3	Fe_2O_3	R_2O_3	SiO_2/Al_2O_3	SiO_2/R_2O_3		
A_p	0-13.5	16.82	4.98	3.28	8.26	5.71	4.06	14.89	30.34
B_1	13.5-48	16.09	4.87	2.65	7.52	5.58	4.18	15.18	28.56
B_2	48-101	15.32	5.21	3.12	8.33	5.00	3.64	16.67	28.61
B_3	101-130	14.48	5.28	2.82	8.10	4.63	3.49	17.74	27.32

no such definite trend. The AFAS minerals of the clays of second horizon shows relatively the highest value (4.18) and the same of the last horizon is observed to be the lowest (3.49). On the other hand, the ($Al_2O_3/SiO_2 + Al_2O_3$)% values of the said mineral increases steadily with the increase in depth and this is in conformation with the increase of AFAS-mineral down the profile.

TABLE 18.2: CEC of Clay and Amorphous Material of Amkishrajot Soil Clays

Name of Horizon	Depth (cm)	CEC (K/NH_4) of Total clay (me/100 g)	CEC (K/NH_4) of AF* - clay (me/100 g)	CEC (K/NH_4) of Amorphous material (me/100 g)
A_p	0-13.5	22.32	8.02	39.11
B_1	13.5-48	23.31	8.68	41.73
B_2	48-101	26.62	12.02	39.01
B_3	101-130	27.41	10.92	49.44

* AF = Amorphous Free

The CEC (K/NH_4) values, as shown in Table 18.2, of the AFAS mineral is comparatively low and ranges from 39.01 to 49.44 me/100 g. These values are not apparently correlated to the molar ratios and ($Al_2O_3/SiO_2 + Al_2O_3$)% values, with the only exception of the last horizon (101-130 cm). In this horizon the SiO_2/Al_2O_3 and SiO_2/R_2O_3 molar ratio values are relatively the lowest and the

($Al_2O_3/SiO_2 + Al_2O_3$) % value is the highest. The corresponding AFAS - content (27.32%) is the lowest in this horizon whereas the CEC value (49.44 me/100 g) is relatively the highest.

3.3.4 Bandargoj soil clays :

In the soil clays of this series an appreciable quantity of amorphous ferri-aluminosilicate (AFAS) minerals has been noticed. Table 19.1 shows the percentage of AFAS minerals found in the clays of the four horizons of the profile. The soil clays of the surface horizon (0-11 cm) has 20.90% which is the minimum, and the clays of the last horizon (89-120 cm) contains 25.11% , the maximum among the four horizons. Moreover, there is an increasing trend in the distribution of this mineral down the profile. The SiO_2/Al_2O_3 molar ratio is comparatively higher in all the horizons varying from 5.43 to 7.82. The ratio is highest for the said minerals of the third horizon (31-89 cm) and the lowest for that of the last horizon (89-120 cm). Though the SiO_2/Al_2O_3 molar ratio of the AFAS minerals is lowest for the last horizon, it shows a higher amount of silica possibly associated with the soil clays. The SiO_2/R_2O_3 molar ratio of this amorphous mineral varies from 3.83 to 5.09, the relatively highest value belonging to that of the third horizon and the relatively lowest to that of the surface horizon. The ($Al_2O_3/SiO_2 + Al_2O_3$) % values vary from 11.33 to 15.54 % . No generalized trend has been found among the percentage AFAS mineral distribution in the profile and the molar

TABLE 19.1: Composition, Amount and Molar Ratios of Amorphous Materials in Bandargoj Soil Clays

Name of Horizon	Depth (cm)	Constituents Extracted (%)				Molar Ratio		(Al_2O_3/ SiO_2 + Al_2O_3) (%)	Amorphous material (%)
		SiO_2	Al_2O_3	Fe_2O_3	R_2O_3	SiO_2/Al_2O_3	SiO_2/R_2O_3		
A_{11}	0-11	11.31	3.48	2.49	5.97	5.53	3.83	15.31	20.90
A_{12}	11-31	12.52	2.97	2.57	5.54	7.20	4.64	12.18	21.85
C_1	31-89	13.12	2.94	2.44	5.38	7.82	5.09	11.33	22.38
C_2	89-120	14.32	4.52	1.92	6.44	5.43	4.27	15.54	25.11

ratios and $(Al_2O_3/SiO_2 + Al_2O_3)$ % values for AFAS minerals of different horizons.

TABLE 19.2: CEC of Clay and Amorphous Material of Bandargoj Soil Clays

Name of Horizon	Depth (cm)	$CEC(K/NH_4)$ of Total clay (me/100 g)	$CEC(K/NH_4)$ of AF* - clay (me/100 g)	$CEC(K/NH_4)$ of Amorphous material (me/100 g)
A_{11}	0-11	19.23	6.12	51.97
A_{12}	11-31	18.64	6.63	48.34
C_1	31-89	14.41	6.11	30.97
C_2	89-120	13.89	5.43	28.26

* AF = Amorphous Free

The CEC (K/NH_4) values are presented in Table 19.2. The CEC of the AFAS mineral varies from 28.26 to 51.97 me/100 g. The surface horizon has relatively the highest CEC of the AFAS minerals and gradually the values show a decreasing trend for the minerals of different horizons with the increase in soil depth. The CEC of soil clays also reveal the same trend whose values range from 13.89 to 19.23 me/100 g. These CEC values apparently do not show any relationship with the molar ratio values and $(Al_2O_3/SiO_2 + Al_2O_3)$% values although the latter values suggest to the components of the tetrahedral and octahedral core of the composition.

3.3.5 Bagdogra soil clays :

Amorphous ferri-aluminosilicates (AFAS) found in the soil clays of Bagdogra series show an increasing trend of distribution all along the four horizons down the profile (Table 20.1). The content of AFAS material is observed to be relatively lowest (12.38 %) in the soil clays of the surface horizon (0-15 cm) and relatively highest (19.67 %) in that of the last horizon (123-133 cm). However, the content of AFAS material in the first two horizons vary over a narrow range (12.38 and 12.79 %). The SiO_2/Al_2O_3 and SiO_2/R_2O_3 molar ratios show a decreasing trend down the profile, the values of which range from 3.76 to 3.26 and 2.86 to 2.48 respectively. Interestingly enough, the $(Al_2O_3/SiO_2 + Al_2O_3)$ % values show a reverse trend than that of the molar ratios of this mineral. The values ranging from 21.02 to 23.47 % , increases down the profile with the increase in AFAS mineral content.

The CEC (K/NH_4) values of the AFAS minerals range from 81.10 to 99.20 me/100 g (Table 20.2). The CEC (K/NH_4) of the soil clays varies from 18.23 to 22.81 me/100 g which increases down the depth. But the CEC of the AFAS mineral shows no regular trend though it can be observed that the last horizon which has

TABLE 20.1: Composition, Amount and Molar Ratios of Amorphous Materials in Bagdogra Soil Clays

Name of Horizon	Depth (cm)	Constituents Extracted (%)				Molar Ratio		(Al_2O_3/ SiO_2 + Al_2O_3) (%)	Amorphous materials (%)
		SiO_2	Al_2O_3	Fe_2O_3	R_2O_3	SiO_2/Al_2O_3	SiO_2/R_2O_3		
A_p	0-15	6.11	2.76	1.36	4.12	3.76	2.86	21.02	12.38
A_c	15-100	6.23	2.89	1.45	4.34	3.65	2.77	21.32	12.79
C_1	100-123	7.12	3.51	1.98	5.49	3.45	2.54	22.47	15.26
C_2	123-133	9.14	4.76	2.36	7.12	3.26	2.48	23.47	19.67

the highest amount of AFAS mineral and highest $(Al_2O_3/SiO_2 + Al_2O_3)$%

TABLE 20.2: CEC of Clay and Amorphous Material of Bagdogra Soil clays

Name of Horizon	Depth (cm)	CEC(K/NH_4) of Total Clay (me/100 g)	CEC(K/NH_4) of AF* - clay (me/100 g)	CEC(K/NH_4) of Amorphous material (me/100 g)
A_p	0-15	18.23	6.01	92.69
A_c	15-100	19.36	6.93	90.25
C_1	100-123	21.20	5.26	99.20
C_2	123-133	22.81	5.73	81.10

* AF = Amorphous Free

values give the lowest CEC (81.10 me/100 g) value.

3.4 X-ray diffraction studies of the soil clays :

For the positive identification of mineral species and their quantitative estimation in soil clay systems, it usually requires the application of several complementary qualitative and quantitative analyses, such as, X-ray Diffraction analysis, Differential Thermal analysis, and Thermo-Gravimetric analysis. Of these, one of the most useful methods is X-ray diffraction analysis. Hadding (1923) and Rhine (1924) were the first to apply X-ray to the study of clay minerals; and Hendricks and Fry (1930) and Kelley et al.(1931) were the first to demonstrate that soil clay contain crystalline mineral components that yield X-ray diffraction patterns. In recent times, improvement in X-ray instrumentation techniques, sample preparation and definition of criteria for identification and characterization of clay mineral species has advanced the field of clay mineralogy to a point where mineralogical analysis yield a wealth of information relative to the properties and genesis of soil. And it is unanimously accepted that X-ray diffraction has contributed more to mineralogical characterization of clay fractions of soils than any other single method of analysis.

In this study K and Mg-saturated clays were used for the X-ray diffraction analysis in a Philips Holland X-ray Diffractometer (Model No.1140) using Ni-filtered $Fe_{K\alpha_1}$ radiation obtained at 40 KV and 20 MA, with a scanning speed of 1° (one degree) 2θ per minute, and a time constant of 4. Parallel oriented specimens were used in recording the X-ray diffractograms. A semi-quantitative estimation of the clay mineral of the five soil series has been attempted according to the method described by Gjems (1967). Frequency distribution curves of the minerals of the five soil series have been prepared and the "Weathering Means" calculated according to Eqn. (4).

The results of the X-ray diffraction studies of the clays of the five soil series and their stage of weathering and frequency distribution of minerals are given in the following paragraphs.

3.4.1 Leprijot soil clays :

The clay mineral composition of one soil profile of Leprijot sandy loam of Leprijot series has been studied. The predominent mineral in all the five horizons of the profile is illite as has been identified from the 10.09 Å (001) and 5.00 Å (002) diffraction peaks in K-saturated samples (Figs. 11.1 to 11.2). These peaks (Table 21) are retained in the Mg-saturated glycerolated samples and also in the K-saturated samples heated to 550°C. The possible presence of kaolinite has been identified from the 7.15 Å peak in the diffractograms of K-clay and the disappearance of this peak on heating the samples to550°C confirms the presence of the same. The presence of a strong peak at 14.23 Å (001) alongwith its higher order at 4.73 Å (003) in the diffractograms of K-clay of all the horizons which does not change its position and/ or intensity of glycerol solvation of Mg-saturated clays, may be due to chlorite and vermiculite in the clay fraction. Heating of K-clay to 550°C for 2 hours leads to collapse of a part of the mineral giving a slightly reduced intensity of the 14.23 Å peak. This behaviour confirms that this collapsed part of the 14 Å mineral is vermiculite. The same diffractograms of clays, subjected to 550°C heating, also shows the presence of a peak with reduced

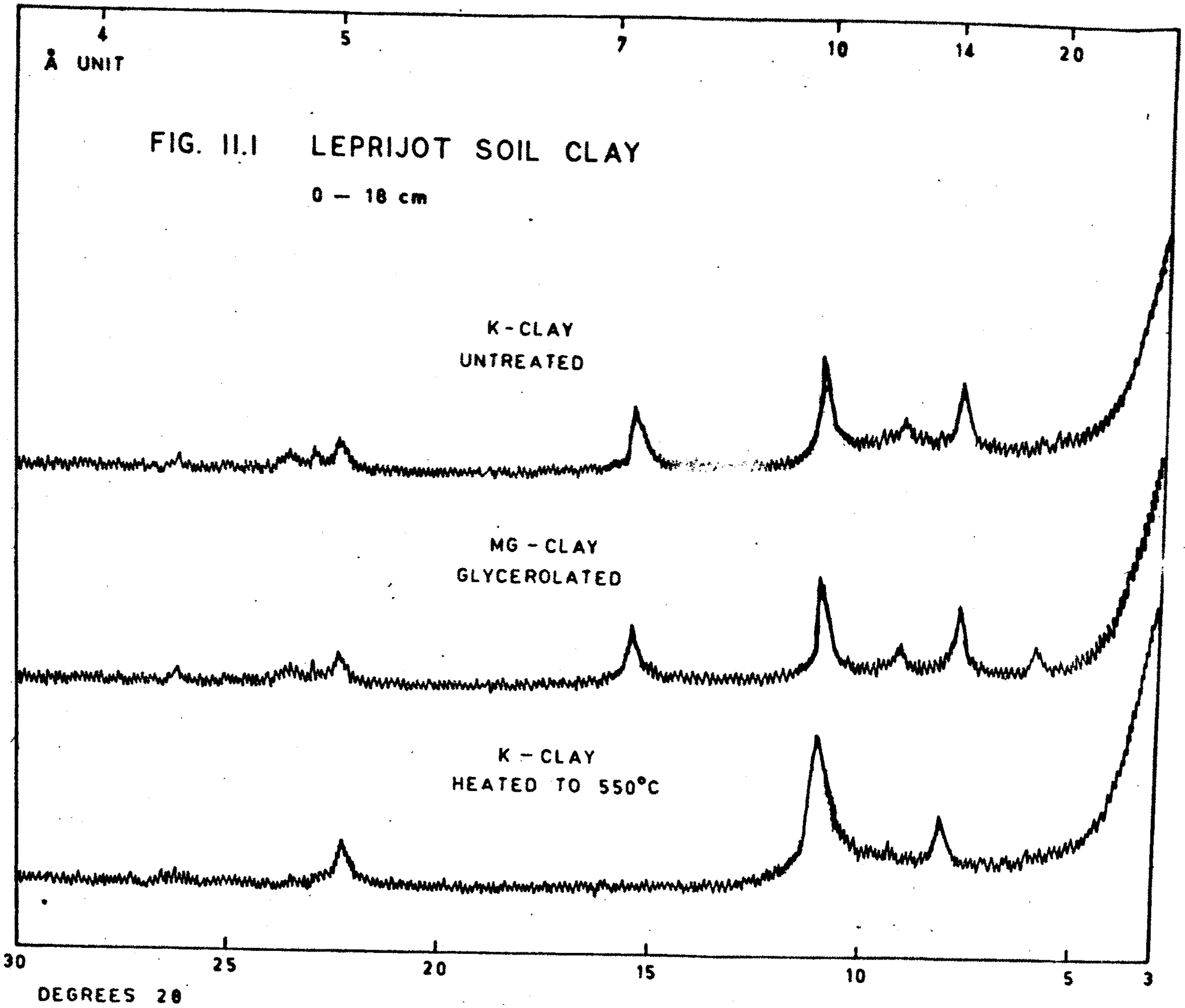


FIG. II.1 LEPRIJOT SOIL CLAY

0 — 18 cm

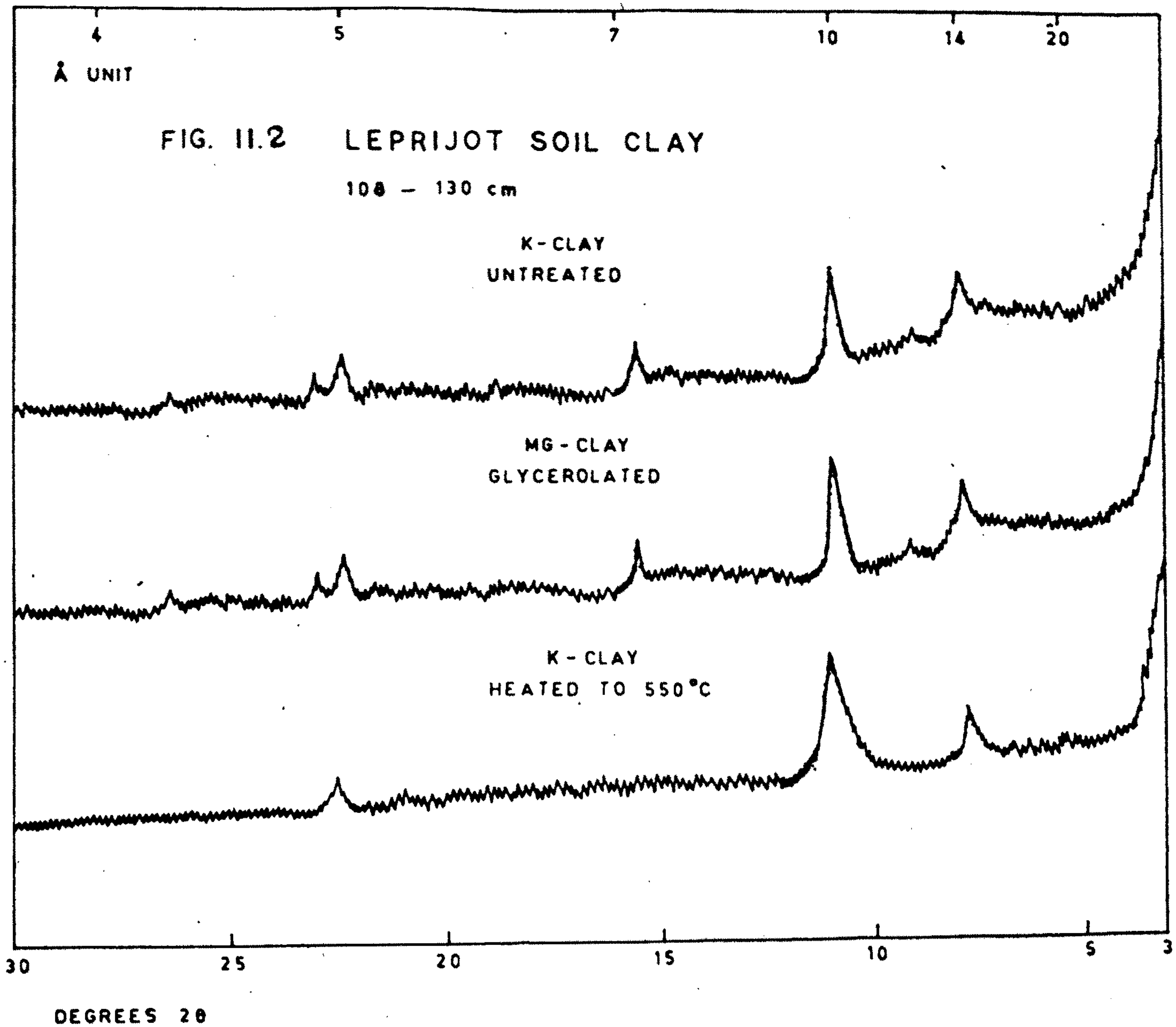


FIG. II.2 LEPRIJOT SOIL CLAY

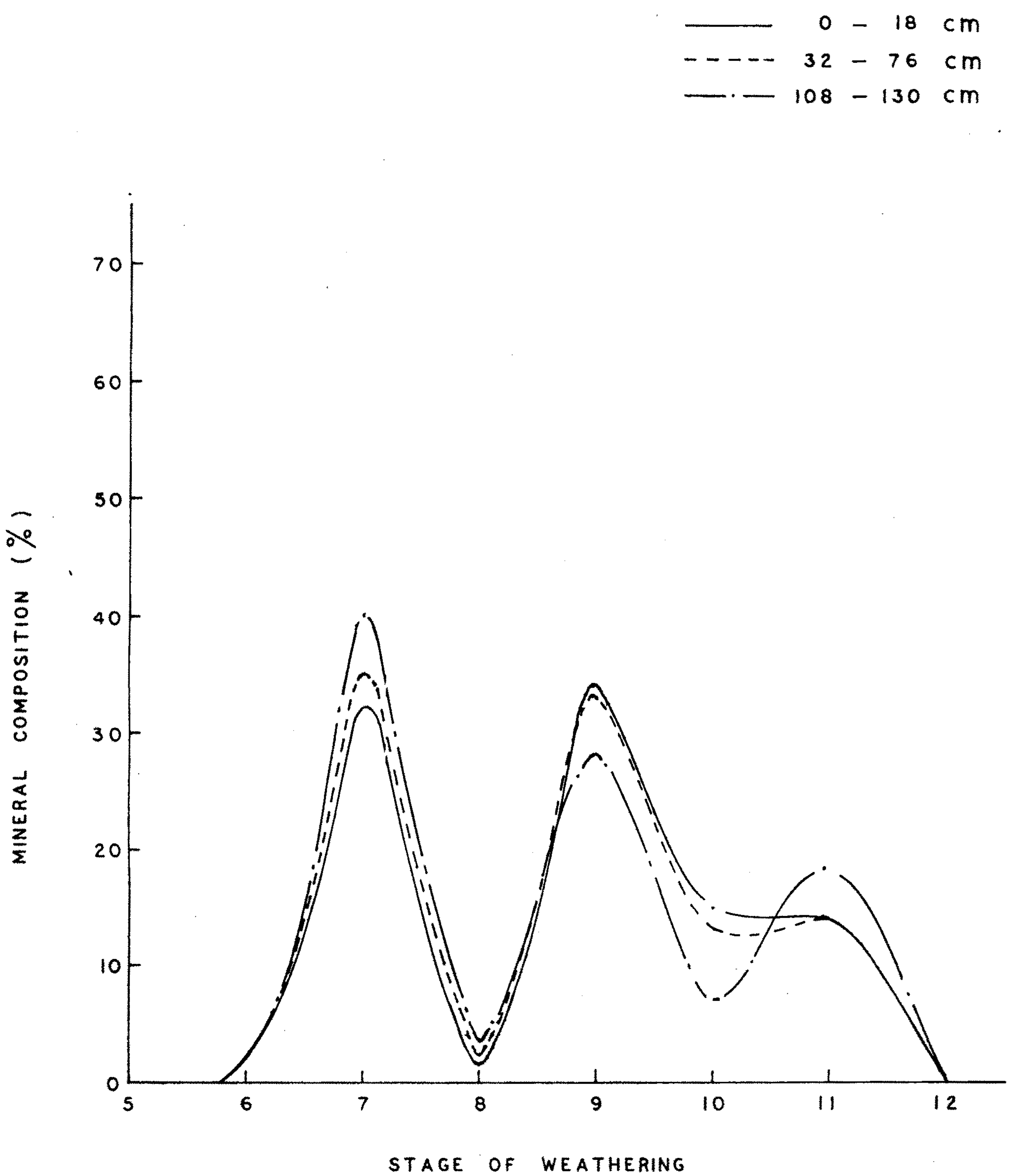
intensity at 14.23 Å, providing sufficient evidence for the presence of chlorite in the soil clay. Very weak peaks observed (in the first three horizons only) in the region of 17.7 Å in the Mg-saturated glycerolated clays were indicative of the presence of traces of smectite mineral in the soil clays.

A very weak peak at 12.0 Å and higher order at 4.85 Å has been found in the diffractograms. With glycerol solvation of Mg-clays these peaks do not change their position, suggesting the possible presence of interstratified mineral in the clay fraction. These indicates possible alternate layering of 10 Å and 14 Å minerals. The (001) peak, to be expected at 24 Å, has not however, been detected due to poor resolution at the low angles in the diffractograms. The 12.0 Å peak shifted to and merged with the 10 Å component on heating the K-saturated clays to 550°C. The 14 Å component in interstratification is possibly the non-swelling type but revealed characteristics of collapsing as heated to higher temperature. This behaviour indicates that the 14 Å component is vermiculite type. The regularly interstratified mineral may, therefore, be considered as a mica-vermiculite one. Moreover, in these diffractograms a very weak peak at 4.27 Å indicate the presence of traces of quartz.

Since the diffractograms of the clays from first (0-18 cm), second (18-32 cm), and third (32-76 cm) horizons depict the presence of similar type of mineralogical composition with difference in their relative abundance, only one diffractograms (Fig.11.1) of the surface horizon is represented and reproduced here. Diffractograms of the fourth (76-108 cm), and fifth (108-130 cm) horizons are similar in composition with difference in relative abundance and they are different from the first three layers by the conspicuous absence of smectite mineral. Diffractogram of the last horizon (108-130 cm) is represented by Fig. 11.2.

The semi-quantitative clay mineralogical composition of the clays has been calculated from the peak area measurement and presented in Table 22. Mica is the dominant mineral in the soils of Leprijot series varying from 32 to 40% and increases down the depth in the profile. But kaolinite content is seen to have a decreasing trend down the profile ranging from 16% at the surface to 7% at the bottom (108-130 cm). The chlorite content varies from 13 to 17% showing almost a more or less homogenous distribution throughout the soil profile. The amount of mixed mineral in the soil clays is relatively high with 14% at the surface to 15% at the lowermost horizon. However, there is a definite decreasing trend of distribution of vermiculite in the soil clay from the second horizon (18-32 cm) downwards, though the amount present is possibly meagre, varying from 2-4%. Smectite also can be traced only in the first three layers of the profile, amounting to 2-3 % of the clays. Quartz is present in all the horizons varying from 3% at the bottom to 2-3% in the rest four horizons as calculated from the diffractograms.

FIG. 11.3 FREQUENCY DISTRIBUTION CURVE OF MINERALS IN SOIL CLAYS OF LEPRIJOT SERIES



Weathering mean has been estimated on the basis of quantitative mineralogical composition of the clay fractions (Table 22). The weathering mean values are 8.74, 8.68, 8.62, 8.58, and 7.82 down the profile. This indicates that the surface and its immediate sub-surface layer is more weathered than the last three sub-surface horizons.

The frequency distribution curve (Fig.11.3)of minerals of this soil series shows more or less the same pattern for the first two horizons (depths). It shows three peaks at the 7th, 9th, and 11th stage of weathering. The two peaks at the 7th and 9th stages are comparatively longer than the peak at the 11th stage of weathering. The last three horizons show a longer peak at the 7th stage and a shorter one at the 9th stage. The peak at the 11th stage of weathering is relatively the shortest of all.

3.4.2 Rangapani soil clays :

Rangapani soil clays show a conclusive dominance of illite minerals as has been evident from medium strong 10.0 Å and 4.9 Å (Table 21) diffraction peaks in the diffractograms of K-saturated, Mg-saturated glycerolated, and heated to 550°C soil clays (Figs. 12.1 to 12.3). The 7.15 Å peak which vanishes on heat treatment (550°C)confirms the presence of kaolinite in the clays. Strong peaks at 14 Å along with peaks at higher order 4.73 Å in the diffractograms (Figs. 12.1 to 12.3) which are retained on glycerol

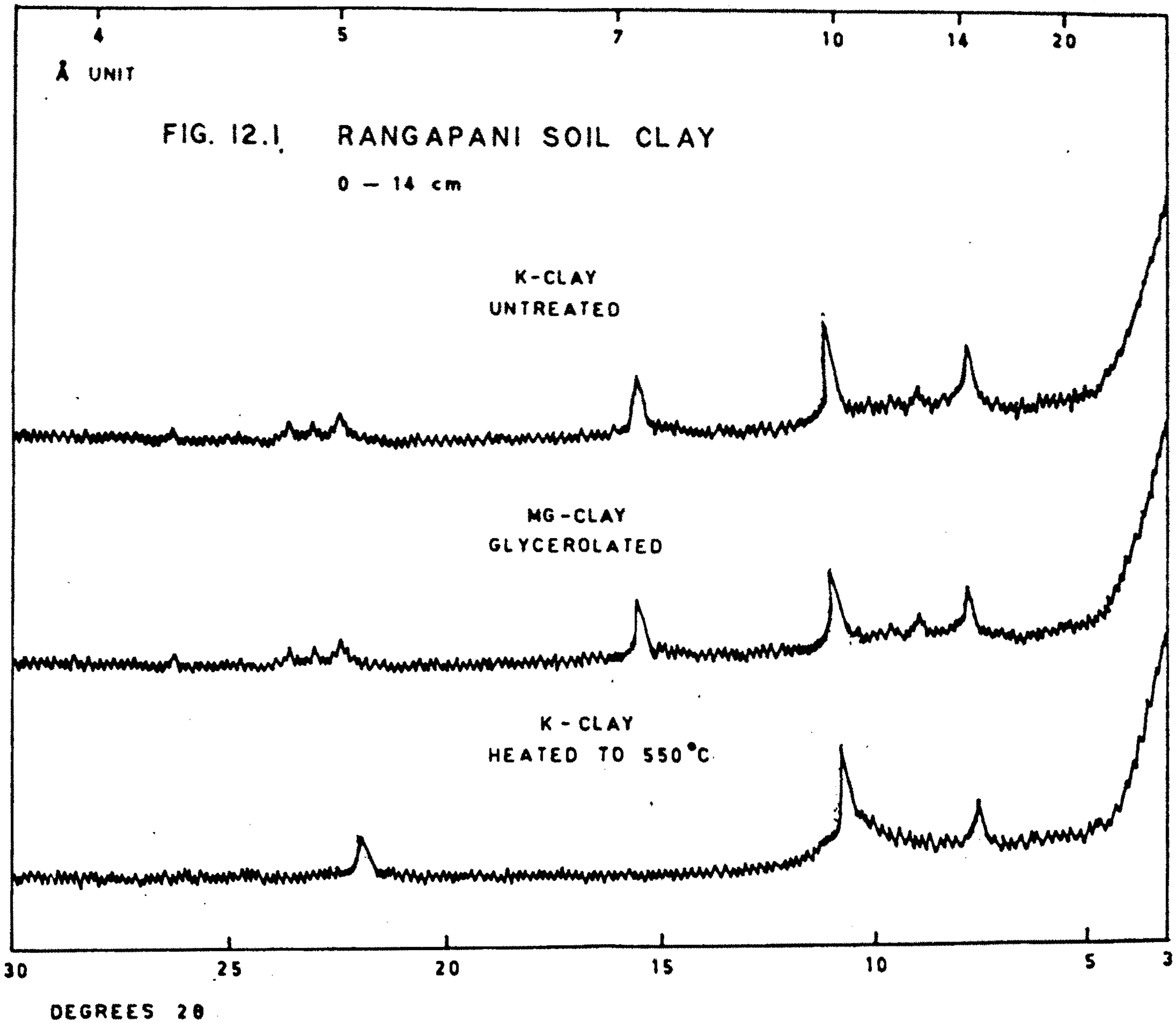
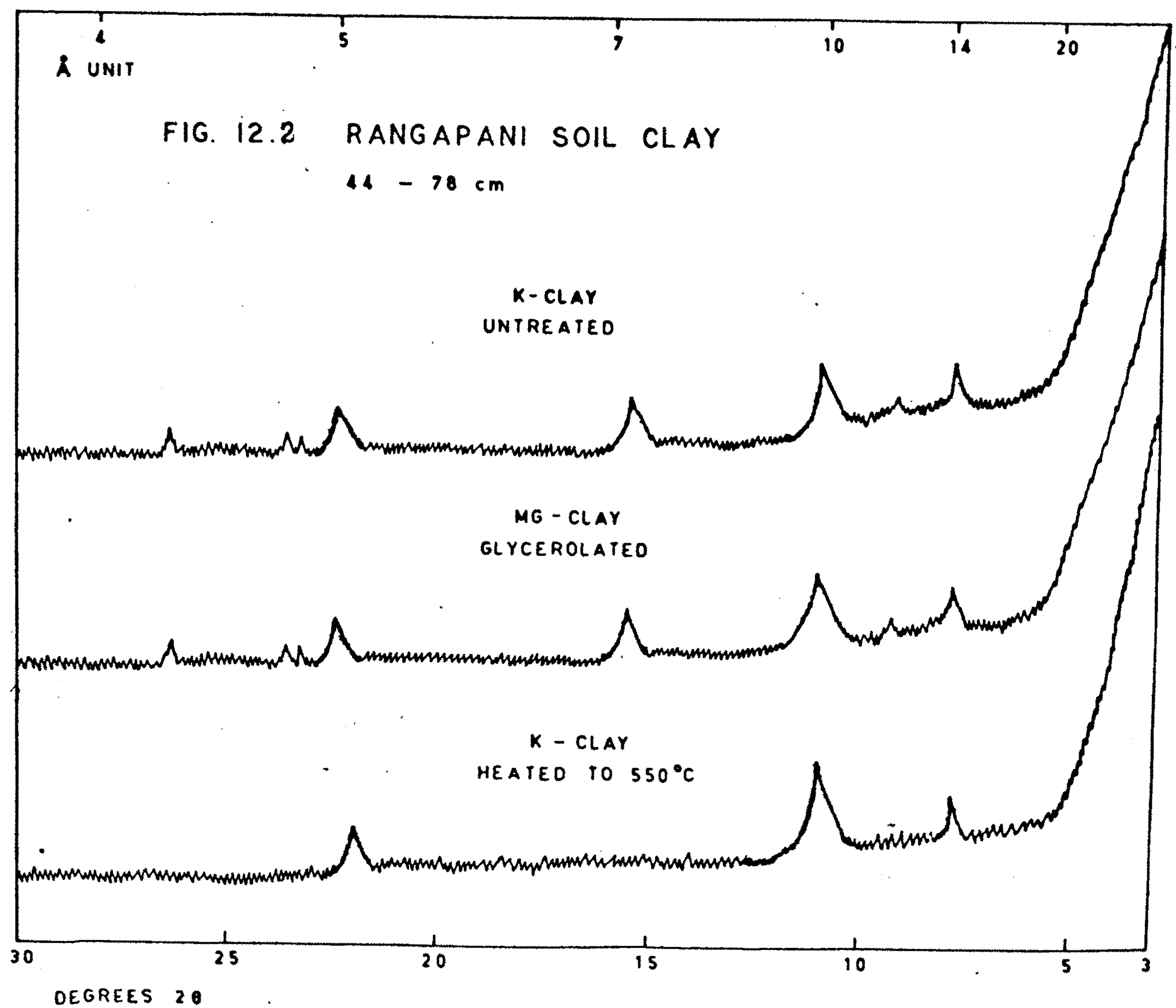


FIG. 12.1 RANGAPANI SOIL CLAY

0 — 14 cm


Å UNIT
4
5
7
10
14
20
FIG. 12.2 RANGAPANI SOIL CLAY
44 - 78 cm
K-CLAY
UNTREATED
MG - CLAY
GLYCEROLATED
K - CLAY
HEATED TO 550°C
30
25
20
15
10
5
3
DEGREES 2θ

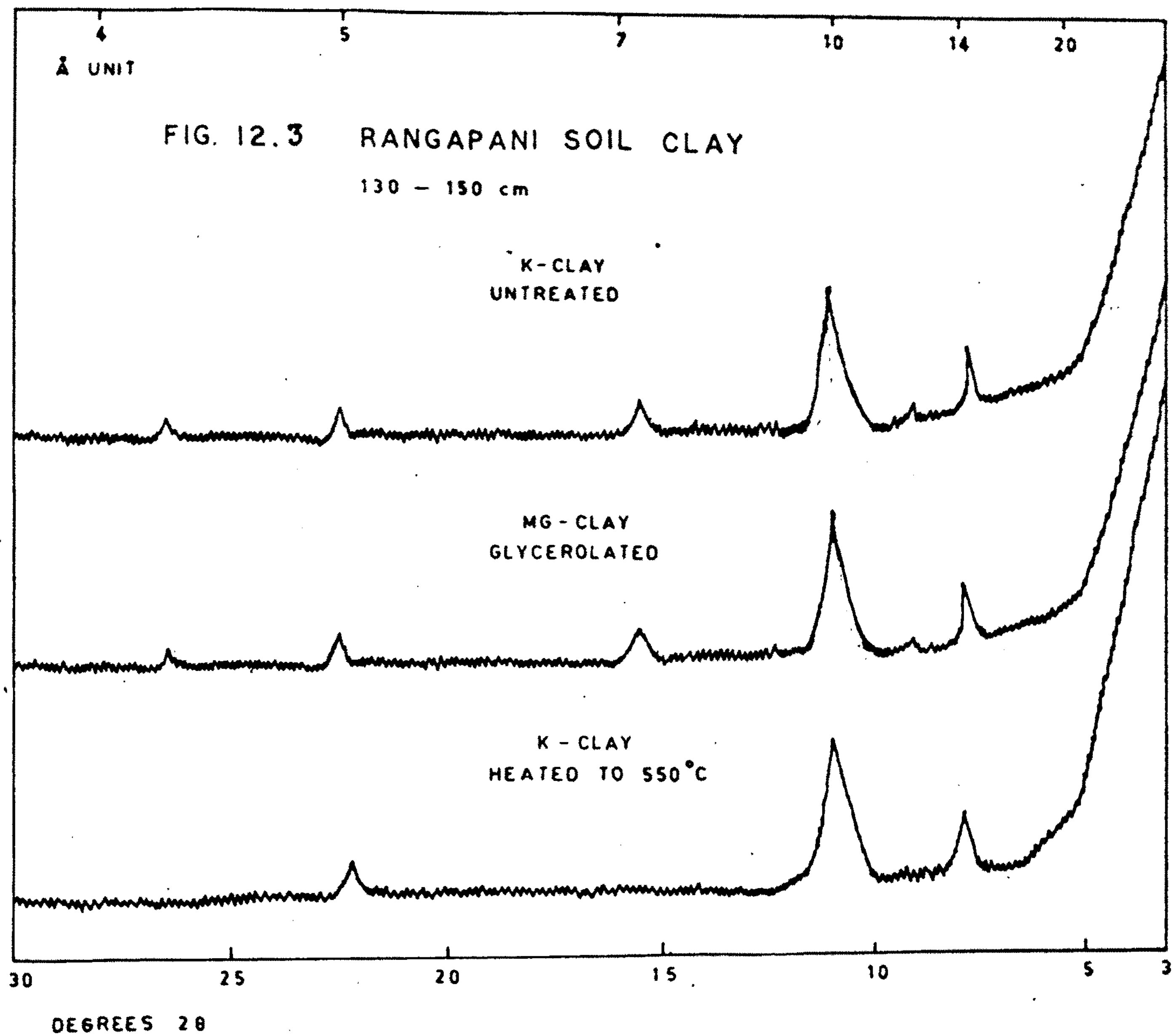


FIG. 12.3 RANGAPANI SOIL CLAY

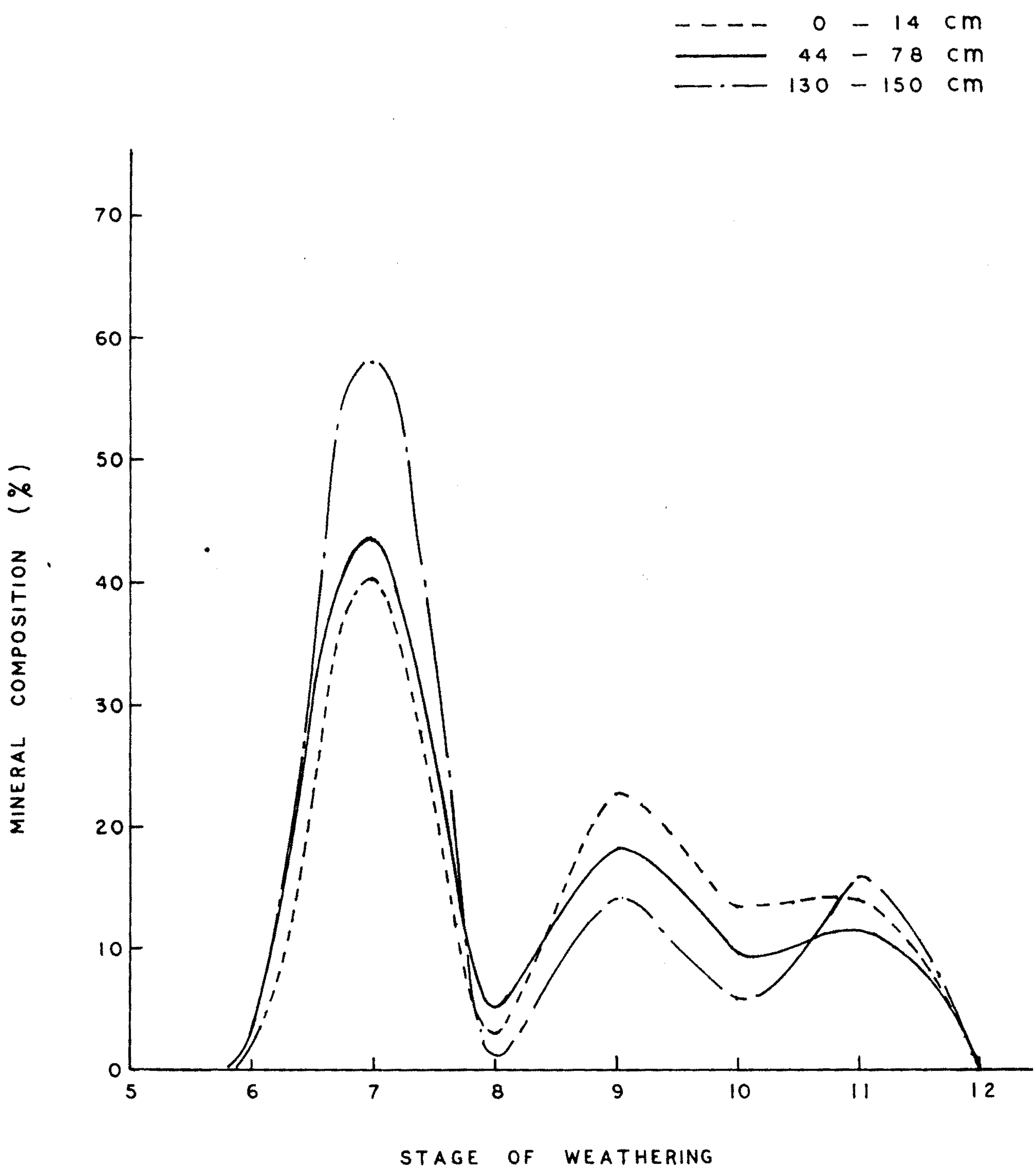
130 – 150 cm

solvation, but remains with a reduced intensity on thermal treatment (550°C) confirms the presence of a good amount of chlorite and a small amount of vermiculite. A very weak peak at 12 Å and 4.85 Å and the area bove the base line between the 10 Å and 14 Å line is considered to be due to mixed layer mineral. On glycerol solvation they do not change their position but on heat treatment (550°C) the 12 Å peak however shifted to and merged with the 10 Å component suggesting interstratification of vermiculite with mica. Moreover, in all the diffractograms a very weak peak at 4.27 Å indicate the presence of small amounts of quartz.

The diffractograms (Figs. 12.1 to 12.3) of the clays of this soil series shows the presence of similar mineralogical composition, at all the six soil depths(horizons) with difference in their relative proportion. Hence, diffractograms of the surface (0-14 cm), third (44-78 cm) and last (130-150 cm) horizons are only reproduced here by Figs. 12.1, 12.2, and 12.3 respectively.

From the semi-quantitative clay mineralogical composition of the clays presented in Table 22 it can be suggested that mica is the predominant mineral throughout the soil profile of Rangapani series ranging from 40% at the surface to 59% at the lowest depth. It has an increasing trend down the profile. However, kaolinite content varies from 5 to 16% and the distribution of this mineral shows a decreasing trend downwards with the exception of the second horizon (14-44 cm). The chlorite content is as high as

FIG. 12.4 FREQUENCY DISTRIBUTION CURVE OF MINERALS IN SOIL CLAYS OF RANGAPANI SERIES



10% in the surface layer and as low as 5% in the fourth and fifth layers. Mixed layer minerals (mica-vermiculite) ranges from 5 to 13% and increases up in the clays of different horizons of this soil profile. Vermiculite is present in traces and it amounts to 1% at the bottom to 4% and 5% at the second and third horizons respectively. Moreover, a small quantity (2-3%) of quartz is available in the horizons (six) of this soil profile.

The weathering means are presented in Table 22. The first five horizons have 8.55, 8.46, 8.12, 8.23, and 8.17 respectively as weathering means, the lowest being 8.13 in the last horizon. However, there is an overall decreasing trend of the weathering mean values down the profile.

The frequency distribution curve (Fig.12.4)of minerals of this soil series depicts a homogenous pattern at all the depths. From Fig.12.4 it is observed that the peaks at the 7th stage are longer than that of the peaks at the 9th stage of weathering for all the soil depths. The peaks at the 11th stage of weathering is the shortest for all the soil depths.

3.4.3 <u>Amkishrajot soil clays</u> :

The diffractograms of the clays from two soil profile depths namely, surface (0-13.5 cm) and last horizon (101-130 cm), of this soil series are presented in Figs. 13.1 and 13.2. The

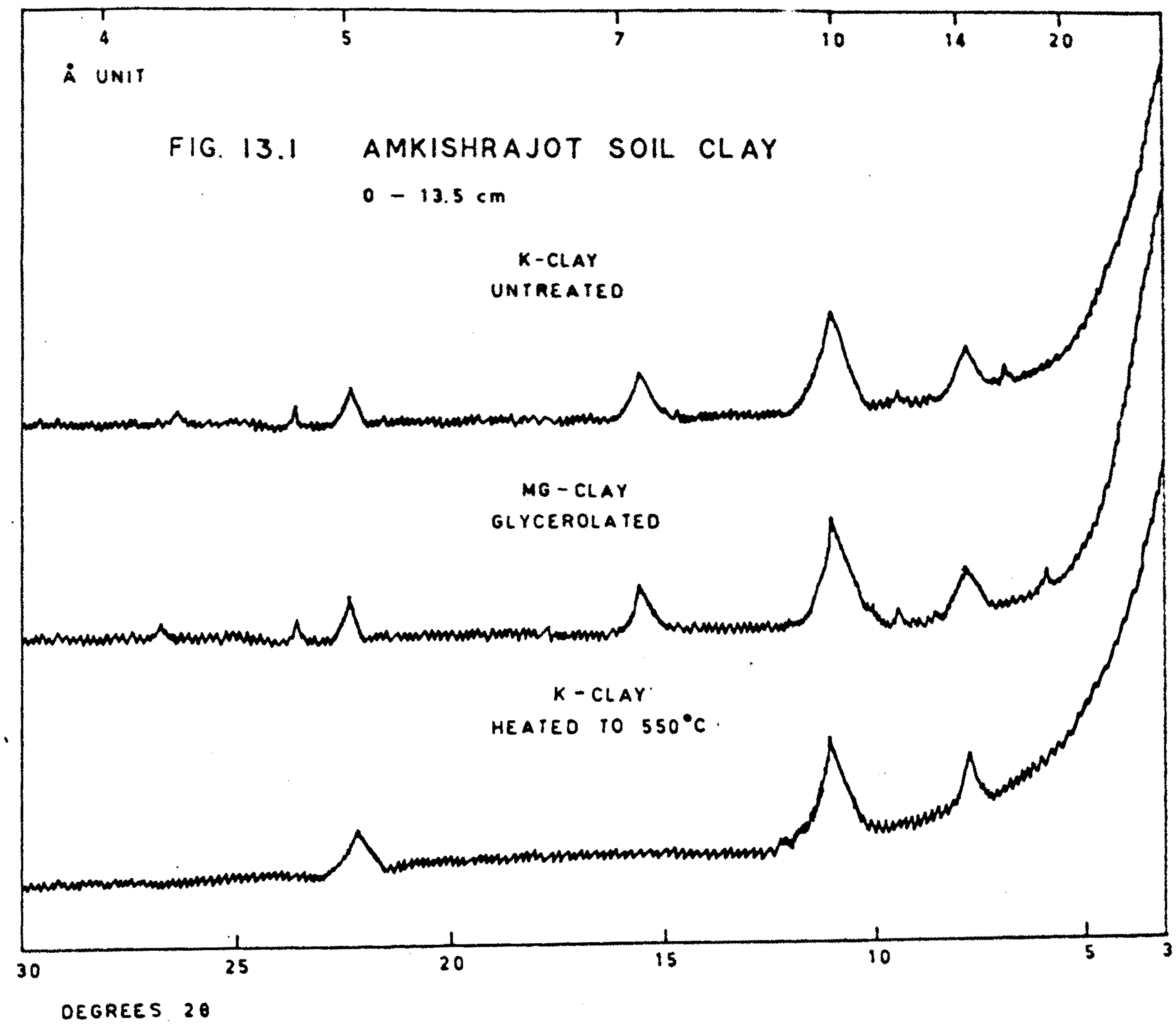


FIG. 13.1 AMKISHRAJOT SOIL CLAY

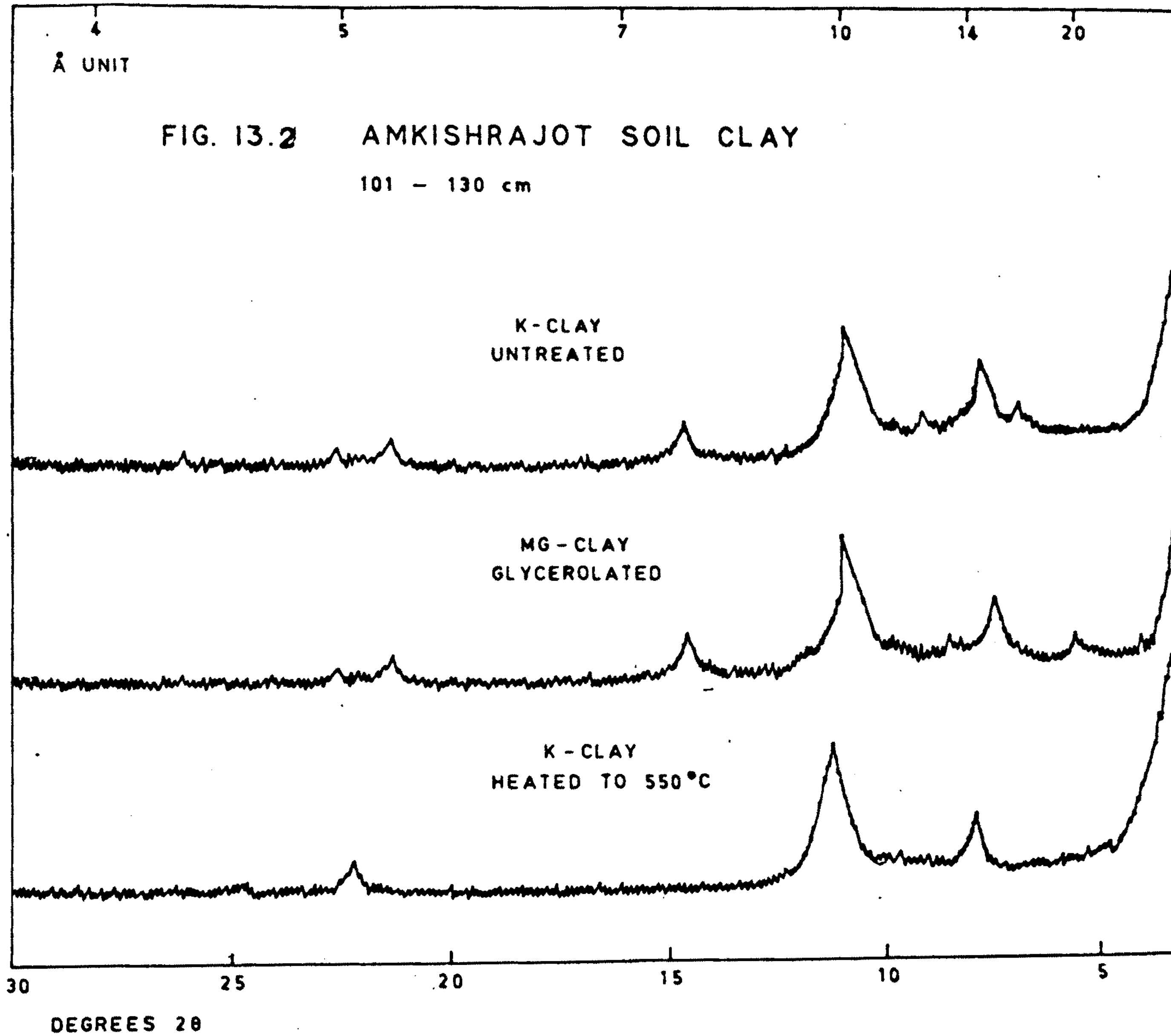
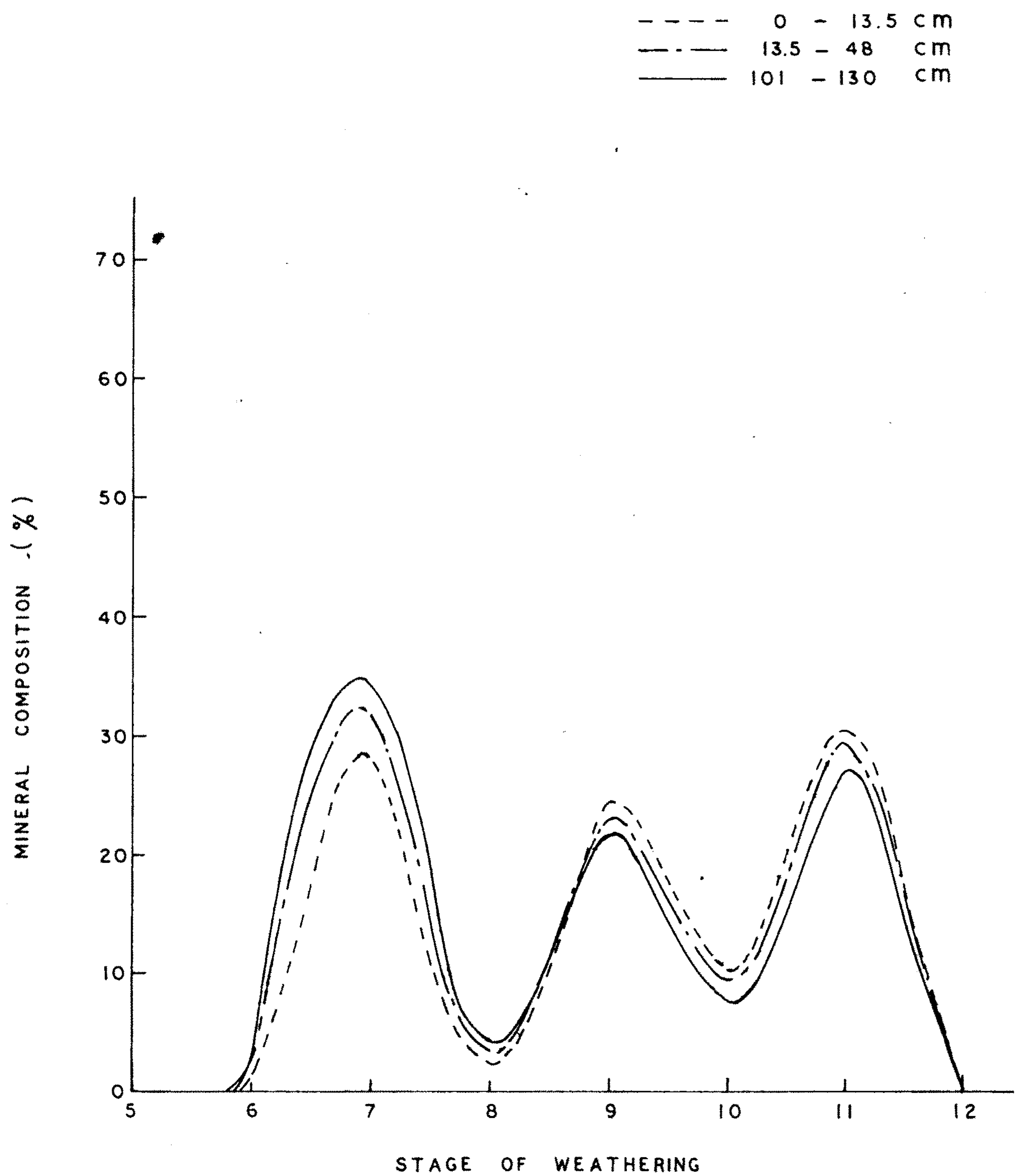


FIG. 13.2 AMKISHRAJOT SOIL CLAY

clays from the four different horizons of this soil series yielded similar diffractograms only differing in the relative intensity of diffraction peaks. A weak peak at 16 Å shifted to 18 Å (Table 21) on glycerol solvation clearly indicates the presence of smectite, although a small amount, in the surface layer as well as in the other three sub-surface horizons of the profile. The difference was only in the intensity of peaks, which increases in the last two layers as compared to the first two. The presence of illite is indicated by the strong diffraction peaks at 10 Å and 4.9 Å in all the horizons. Intensity of the peaks increased with increasing depth. The 7.15 Å peak which vanishes on heat treatment (at 550°C) confirms the presence of kaolinite in all the soil clays isolated from different depths. The presence of a strong peak at 14 Å, with reduced intensity of the same in the heated samples and without any second order peak at 7 Å is indicative of the presence of a good amount of chlorite mineral in all the samples. The intensity of the 14 Å peak reduced on heated samples due to collapse of a part of the 14 Å component to 10 Å suggesting the presence of vermiculite. The area above the base line between the 10 Å and 14 Å line is considered due to mixed layer mineral. This has been found to be true for all the four soil depths. Furthermore, a very weak peak at 4.25 Å in all the diffractograms suggests the presence of a trace amount of quartz mineral in the clays.

FIG. 13.3 FREQUENCY DISTRIBUTION CURVE OF MINERALS IN SOIL CLAYS OF AMKISHRAJOT SERIES



Semi-quantitative clay mineralogical composition presented in Table 22 shows the homogeneity of minerals present with relative abundance in different horizons. Again mica is the dominant mineral varying from 29% in the surface layer to 36% in the lowest horizon. Kaolinite content varies from 7 to 12% . However, no definite trend of distribution of mica and kaolinite could be established. The amount of chlorite present varies from 6% in the soil clay of the third horizon to 10% in that of the surface or first horizon . Mixed layer minerals range from 8 to 13%. Vermiculite has been found to vary from 4 to 6% whereas smectite mineral is 2% in the surface layer and 6% in the third horizon. The percentage of quartz varies from 2-3% all along the profile.

The weathering means (Table 22) of the soil clays vary from 9.02 for the surface horizon to 8.75 for the clays of the lowest horizon. It is revealed from the weathering mean values that the first three horizons from the surface are comparatively more weathered than the soils of the fourth horizon .

The frequency distribution curve (Fig.13.3) of minerals of Amkishrajot soil clays show three prominent peaks at the 7th, 9th, and 11th stage of weathering. The peaks at the 7th stage of weathering are longer than that of the peaks of 9th and 11 th stage of weathering for all the horizons. Again, the peaks at the 11th stage of weathering is longer than the 9th stage for all the soil depths.

3.4.4 Bandargoj soil clays :

X-ray diffractograms of the clay minerals separated from four different horizons of Bandargoj series are almost similar. They differ only in the relative intensity of the peaks (Figs. 14.1 and 14.2). The presence of a strong peak at 14.2 Å alongwith its higher order at 4.77 Å (Table 21) in the diffractograms of K-clay of all the horizons which does not change the position and/or intensity on glycerol solvation of Mg-clay, may be due to chlorite and vermiculite type of minerals in the soil clays. Heating of K-clays to 550°C for 2 hrs. shows the presence of a 14.2 Å peak with a reduced intensity, providing evidence for the presence of chlorite mineral in the soil clays, as the chlorite is not affected by heating of K-saturated clay samples. However, the collapse of the part of the mineral of 14.2 Å spacing to 10 Å with the heat treatment of K-saturated clays confirmed the presence of vermiculite. Illite is identified by the presence of diffraction peaks at 10 Å and 4.9 Å in all the diffractograms of K-clays, Mg-clays glycerolated, and K-clays heated to 550°C. The area above the base line between the 10 Å and 14 Å peaks indicates the possible presence of mixed layer minerals. The 7.15 Å diffraction peak which vanishes on heat treatment (550 °C) confirms the presence of kaolinite. Very weak peaks at 4.27 Å indicate the presence of traces of quartz.

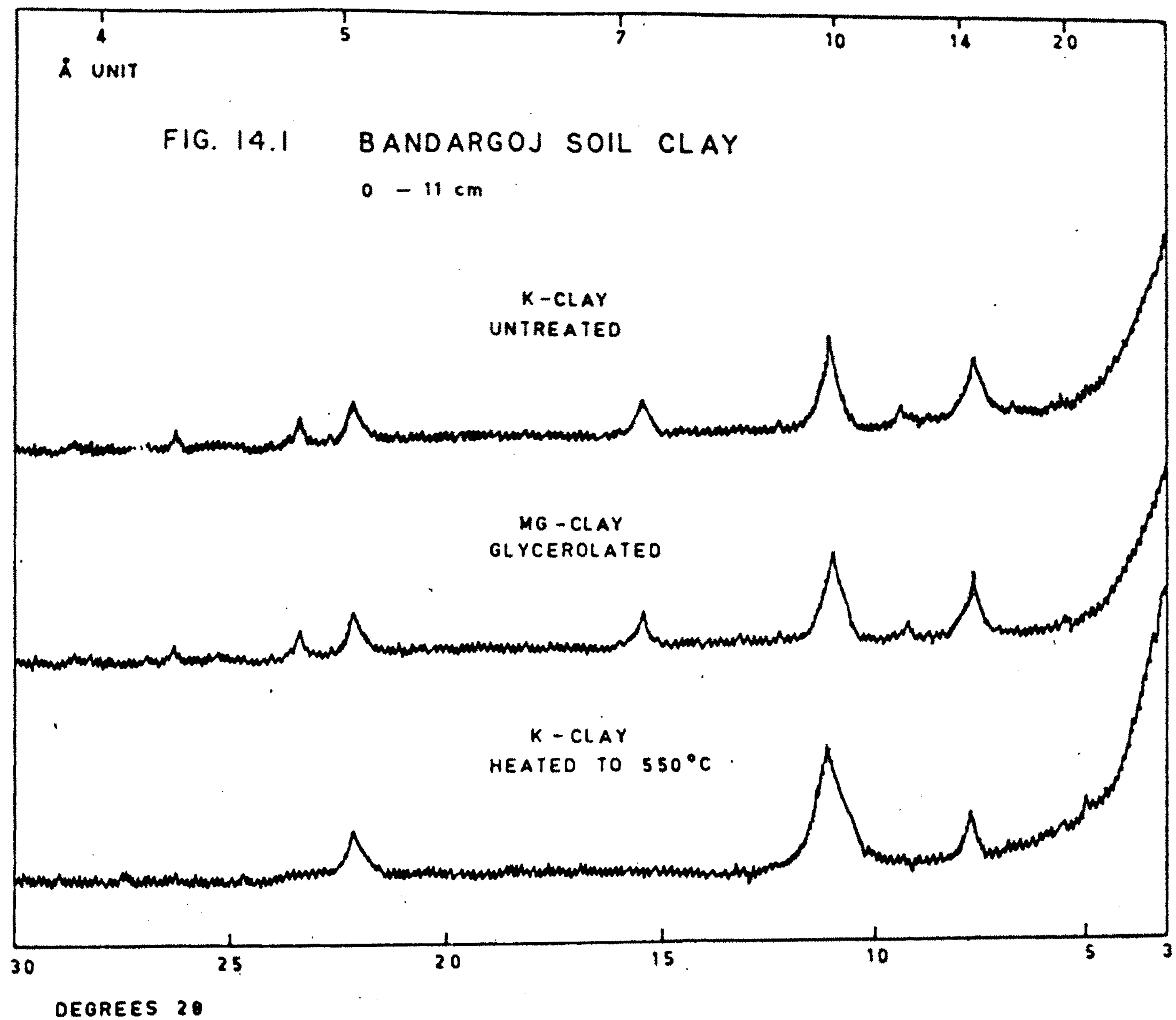


FIG. 14.1 BANDARGOJ SOIL CLAY

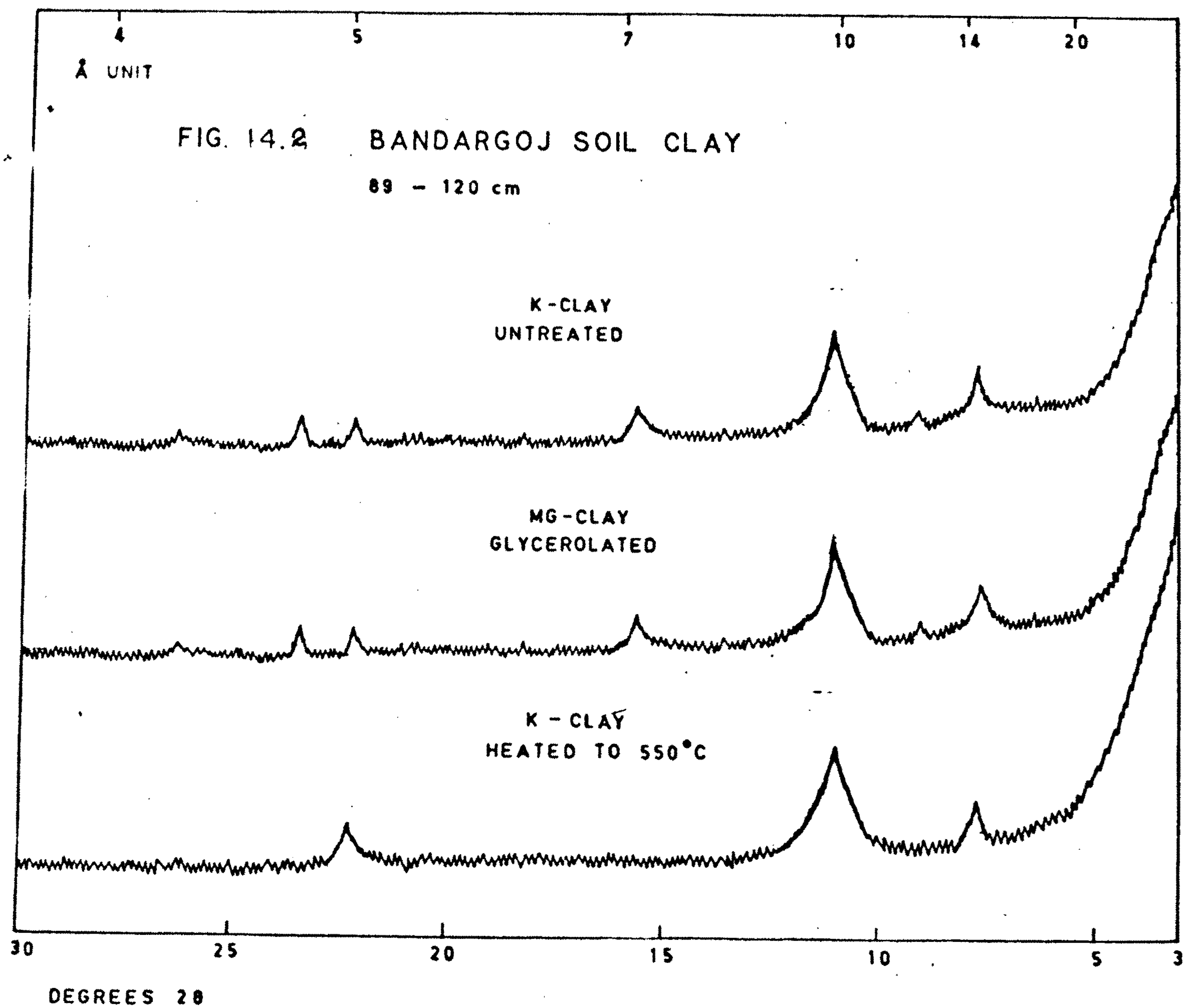


FIG. 14.2 BANDARGOJ SOIL CLAY

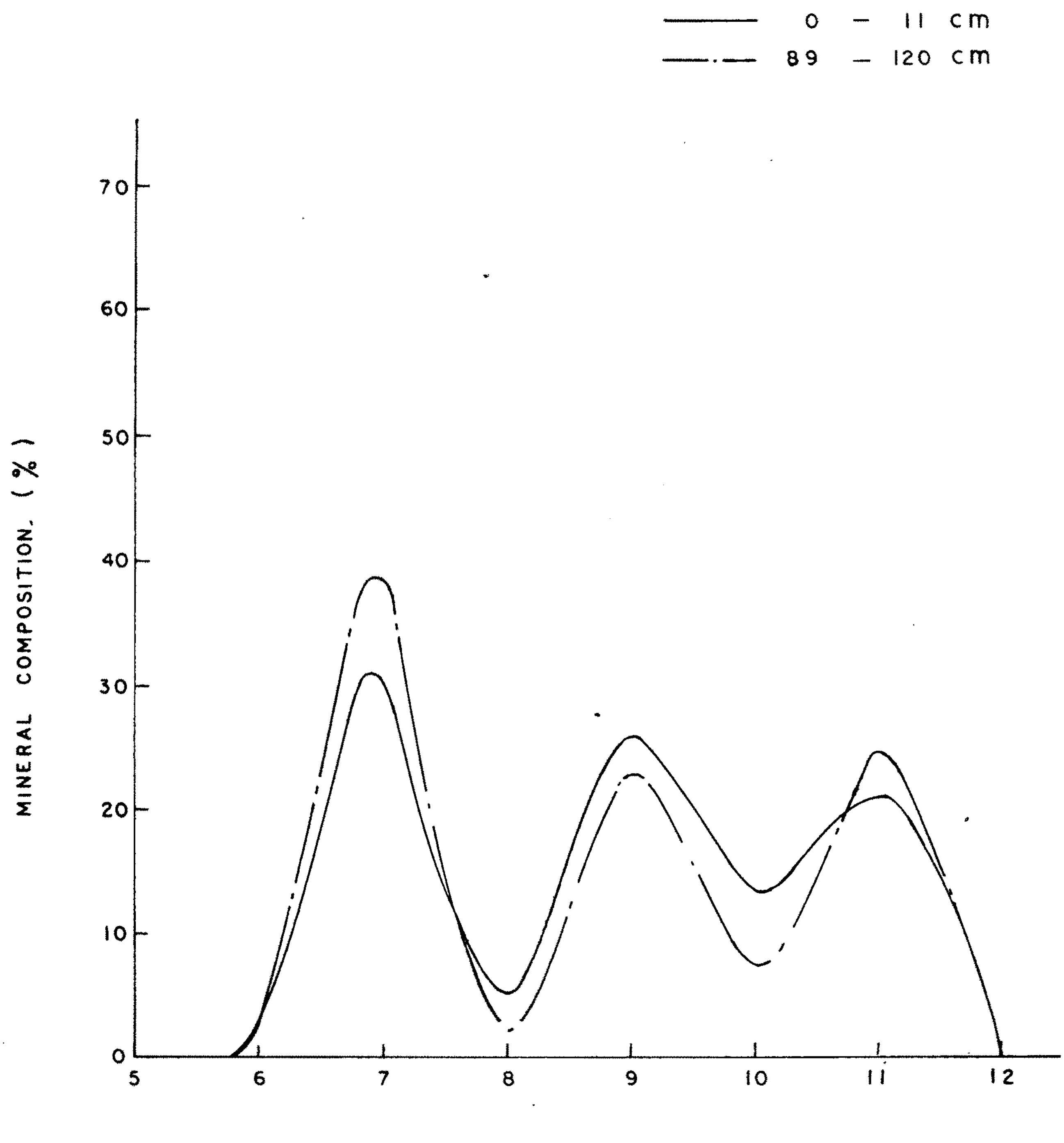
89 - 120 cm

Table 22 presents the data of semi-quantitative clay mineralogical composition which shows that all the horizons of this soil profile comprises of similar minerals with difference in their relative abundance. Mica being the dominant mineral, in all the horizons, varies from 31% to 39%. There is a gradual increase in their distribution down the profile. Chlorite occupies the second position in their relative abundance all along the profile ranging from 12 to 14%. Kaolinite ranges from 8 to 14% in the clays of different horizons. Mixed layer minerals are observed to be present in all the horizons in good proportion which varies from 11 to 13% . There is a decreasing trend of this mineral in the soil clays with increasing depth of the profile. Vermiculite is comparatively meagre in amount and decreases from 5 to 2% down the profile. Moreover, a trace amount of quartz is also present all along the profile (2-3%) which is evident from the small peak at 4.27 Å.

The weathering mean values presented in Table 22 shows that the soil clays of the first two horizons has the relatively higher mean of 8.80 and the clay of the last horizon has 8.69 only. An overall decreasing pattern down the profile is observed indicating thereby that the soils of the surfade layer is more weathered than that of the sub-surface horizons.

Frequency distribution curve (Fig.14.3)of minerals present in these soil clays yields three sharp peaks at the 7th,9th, and

FIG. 14.3 FREQUENCY DISTRIBUTION CURVE OF MINERALS IN SOIL CLAYS OF BANDARGOJ SERIES



11th stage of weathering. The peaks at the 7th stage is longer than that of the 9th and 11th stage of weathering for all the horizons, whereas, the last horizon (89-120 cm) shows the peak at 9th stage of weathering to be shorter than that of the 11th stage of weathering.

3.4.5 <u>Bagdogra soil clays</u> :

Figs. 15.1 and 15.2 show the X-ray diffractograms of the surface (0-15 cm) and last horizon (123-133 cm) only of the soils of Bagdogra series where illite is the most abundant mineral in all the four horizons as evidenced by its strong diffraction peaks at 10 Å and 4.99 Å(Table 21) in the K-clays and Mg-clays (glycerol solvated). The 7.15 Å diffraction peaks in the K-clays and Mg-clays (glycerolated) which vanishes on thermal treatment (550°C) confirms the presence of kaolinite. The presence of vermiculite and chlorite in all the horizons has been confirmed by the diffraction peaks at 14.2 Å alongwith peaks at 4.77 Å. The 14 Å peak is retained with a reduced intensity on heat treatment of K-clay confirming the presence of vermiculite which merges with the 10 Å component. The rest part of the 14 Å peak which persists even after the heat treatment is accounted for the chlorite mineral. Presence of mixed layer minerals is indicated by the area above the base line between the 10 Å and 14 Å component and also weak peaks at 12 Å spacing.

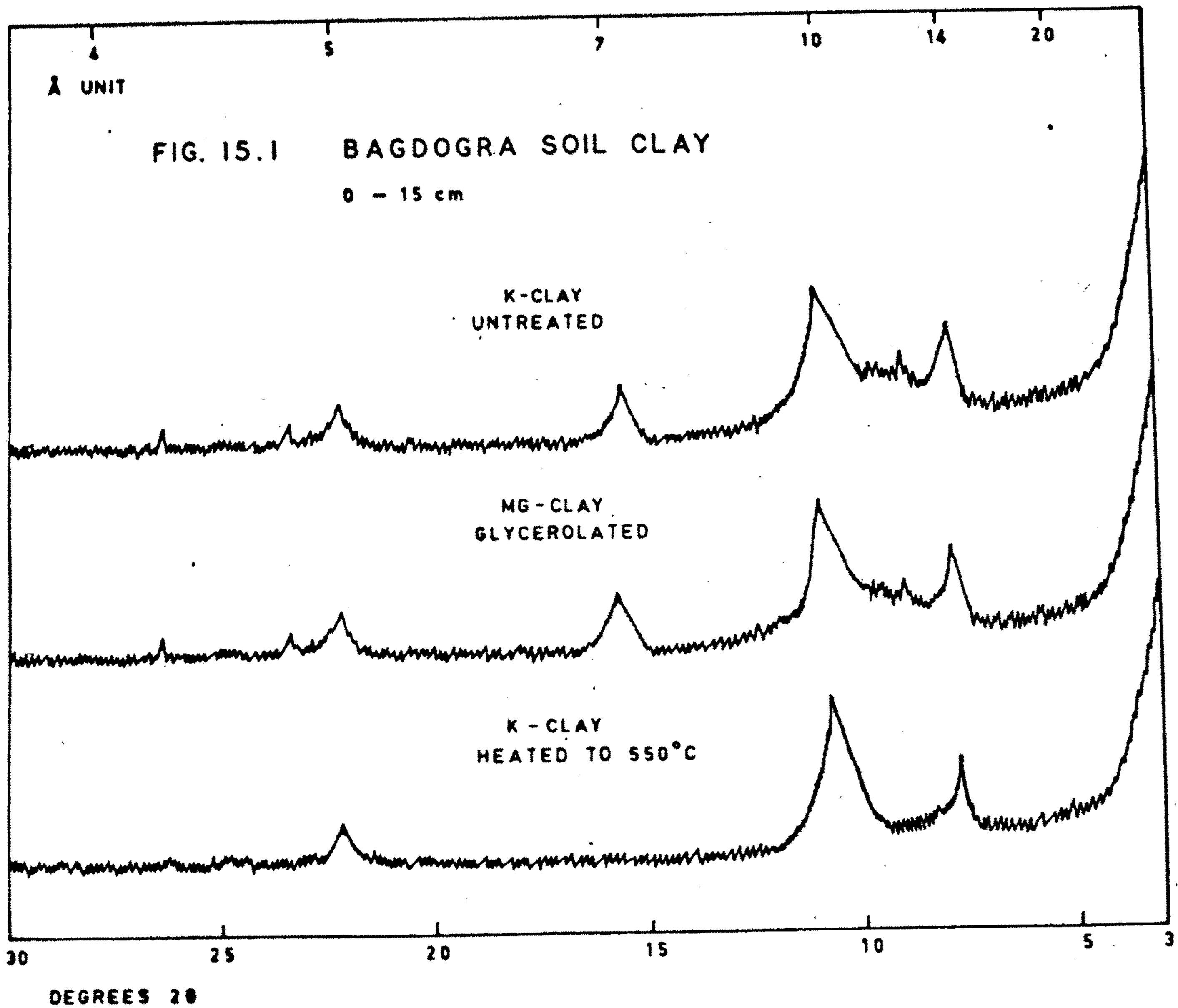


FIG. 15.1 BAGDOGRA SOIL CLAY

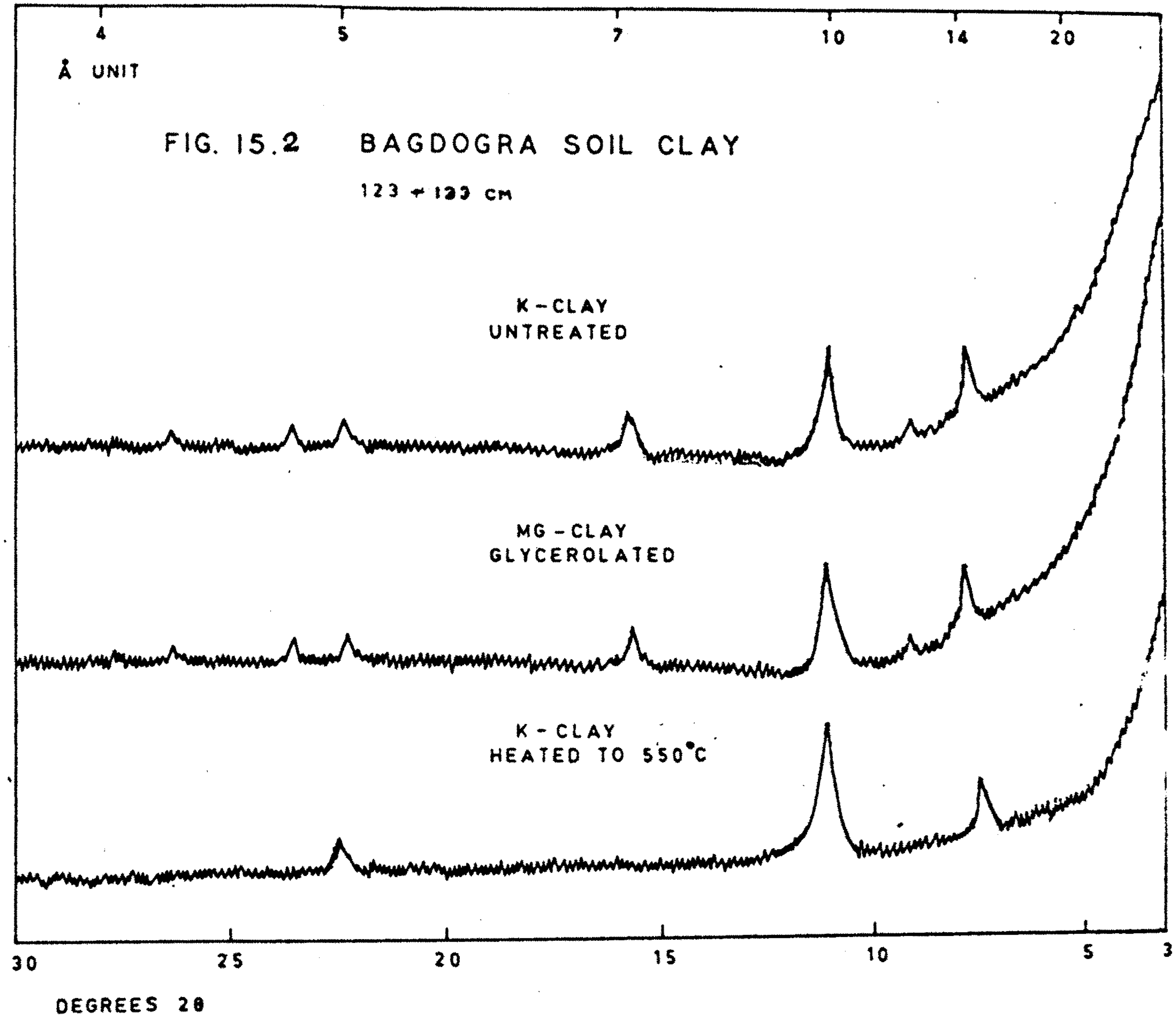


FIG. 15.2 BAGDOGRA SOIL CLAY

Furthermore, very weak peak at 4.27 Å suggests quartz to be present in trace quantities in all the soil clays.

The diffractograms (Figs.15.1 and 15.2) points to the similarity in the mineral make-up of all the horizons of this series with difference in their proportional distribution.

Illite has been found to be the dominant mineral (Table 22) in all the horizons ranging from 48% in the soil clays of the surface horizon to 40% in that of the third horizon. No regular trend could be found in its distribution. Kaolinite is the second in relative abundance varying from 8 to 15 % . The abundance of chlorite is very close to kaolinite, the percentage distribution of which varies from 9-11 % . Mixed layer minerals vary from 8-13% whereas vermiculite ranges from a meagre 2% at the surface to 7% in that of the third horizon. Quartz is also present in trace amounts varying from 2-3% all along the profile.

Weathering means (Table 22) have been calculated from the clay mineralogical information and found to vary from 8.41 in the last horizon to 8.43, 8.44, and 8.28 in the third, second, and first horizons respectively. It is found that the sub-surface layers are more weathered than the surface layer.

The frequency distribution curve (Fig.15.3)of the minerals yielded three sharp peaks at the 7th,9th,and 11th stage of weathering. The peaks at the 7th stage is longer than the peaks at the

FIG. 15.3 FREQUENCY DISTRIBUTION CURVE OF MINERALS IN SOIL CLAYS OF BAGDOGRA SERIES

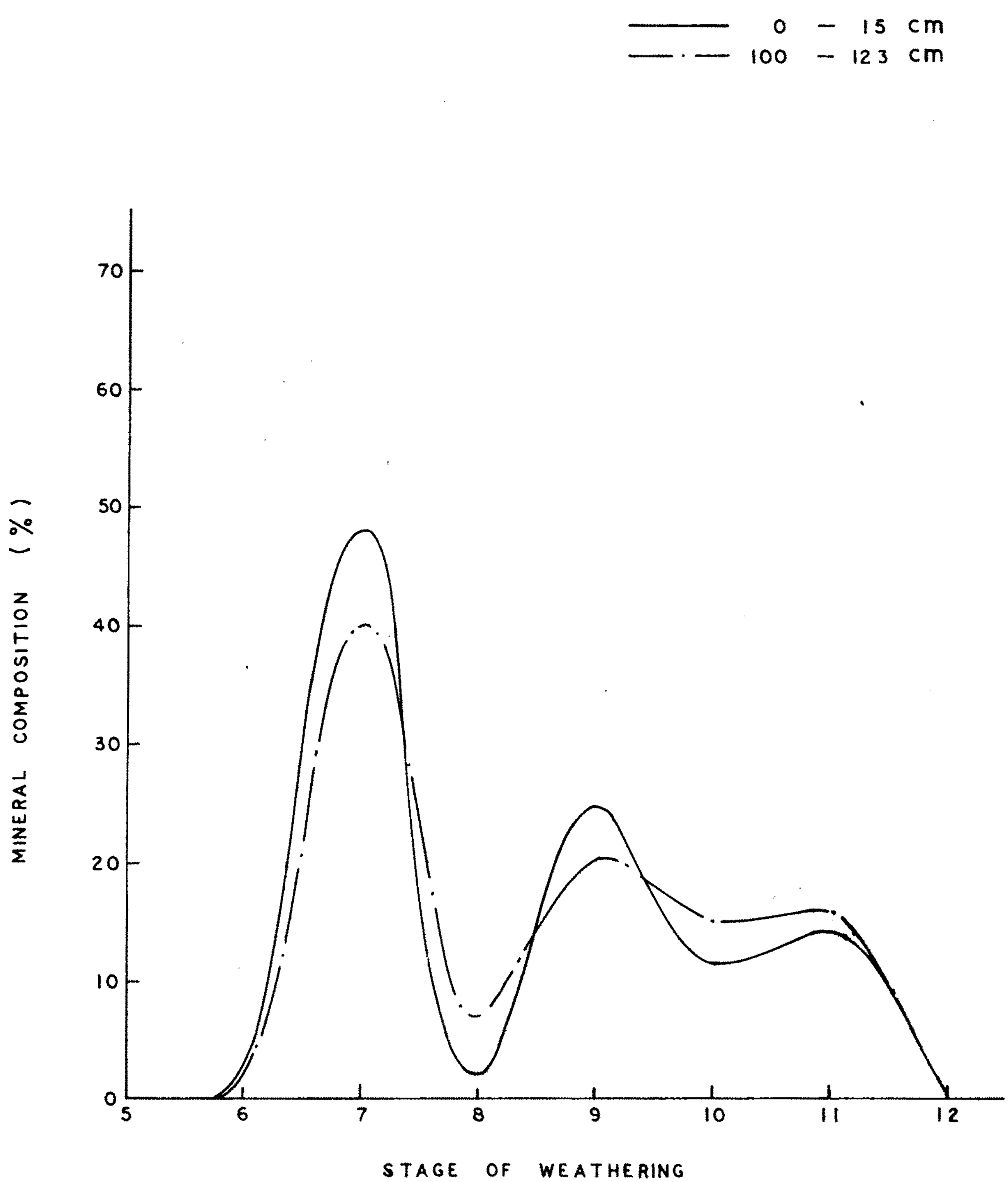


TABLE 21 : Lattice spacings in Å and Their Intensities (I) in Different Treatments of the Soil Clays from Five Soil Series

Soil series	Depth (cm)	Untreated d-values (Å)	I	Glycerolated d-values (Å)	I	Heated to 550°C d-values (Å)	I
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Leprijot soil clays	0-18	14.23	S	17.72	W	14.23	M
		12.01	VW	14.14	S	10.10	VS
		10.09	MS	12.00	VW	5.00	M
		7.15	MS	10.09	MS		
		5.00	M	7.13	MS		
		4.85	VW	5.00	M		
		4.73	VW	4.85	VW		
		4.27	VW	4.73	VW		
				4.27	VW		
	18-32	14.30	S	17.72	W	14.25	M
		12.07	VW	14.23	S	10.09	VS
		10.09	MS	12.04	VW	5.00	M
		7.15	MS	10.00	MS		
		5.00	M	7.13	MS		
		4.85	VW	5.00	MS		
		4.73	VW	4.85	VW		
		4.27	VW	4.73	VW		
				4.27	VW		
	32-76	14.21	S	17.70	W	14.21	M
		12.05	VW	14.14	S	10.09	VS
		10.09	MS	12.00	VW	4.99	M
		7.13	MS	10.05	MS		
		5.00	M	7.10	MS		
		4.73	VW	4.99	M		
		4.25	VW	4.73	VW		
				4.27	VW		

(Contd..)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	76-108	14.19	S	14.14	S	14.23	M
		12.07	VW	12.00	VW	10.09	VS
		10.09	MS	10.08	MS	4.99	M
		7.15	MS	7.13	MS		
		4.98	M	4.98	M		
		4.73	VW	4.73	VW		
		4.27	VW	4.25	VW		
	108-130	14.23	S	14.17	S	14.21	M
		10.09	MS	12.01	VW	10.09	VS
		7.13	MS	10.06	MS	5.01	M
		5.01	M	7.15	MS		
		4.25	VW	5.00	M		
				4.27	VW		
Ranga-pani soil clays	0-14	14.05	S	14.01	S	14.05	M
		12.01	VW	12.00	VW	10.09	VS
		10.10	MS	10.09	MS	5.00	M
		7.13	MS	7.12	MS		
		4.98	M	4.98	M		
		4.85	VW	4.85	VW		
		4.75	M	4.75	M		
		4.27	VW	4.27	VW		
	14-44	14.23	S	17.64	VW	14.15	M
		12.05	VW			10.09	VS
				14.14	S		
		10.09	MS	12.01	VW	4.98	M
		7.15	MS	10.09	MS		
		4.98	M	7.13	MS		
		4.85	VW	4.98	M		
		4.73	M	4.85	VW		
		4.27	VW	4.73	M		
				4.27	VW		

(Contd.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	44-78	14.12	S	14.10	S	14.12	M
		12.01	VW	11.99	VW	10.09	VS
		10.10	MS	10.07	MS	4.98	M
		7.15	MS	7.12	MS		
		4.98	M	4.98	M		
		4.85	VW	4.85	VW		
		4.73	M	4.73	M		
		4.27	W	4.27	W		
	78-104	14.23	S	14.21	S	14.23	M
		12.03	VW	12.00	VW	10.09	VS
		10.09	MS	10.09	MS	4.99	M
		7.13	MS	7.11	MS		
		4.99	M	4.98	M		
		4.27	VW	4.85	VW		
				4.73	M		
	104-130	14.25	S	14.23	S	14.25	M
		12.04	VW	12.00	VW	10.09	VS
		10.10	MS	10.09	MS	4.98	M
		7.13	MS	7.12	MS		
		4.99	M	4.98	M		
		4.73	W	4.73	VW		
		4.27	VW	4.27	VW		
	130-150	14.26	S	14.25	S	14.28	M
		12.01	VW	12.00	VW	10.13	VS
		10.14	MS	10.09	MS	4.98	M
		7.13	MS	7.13	MS		
		4.98	M	4.98	M		
		4.25	VW	4.25	VW		

(Contd.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Amkish-rajot soil clays	0-13.5	16.01	W	18.62	M	14.26	M
		14.26	S	14.23	S	10.09	VS
		10.09	MS	10.07	MS	4.99	M
		7.13	MS	7.10	MS		
		4.96	M	4.98	M		
		4.75	W	4.75	W		
		4.25	VW	4.25	VW		
	13.5-48	16.51	W	18.68	M	14.23	M
		14.23	S	14.21	S	10.10	VS
		10.11	MS	10.09	MS	4.98	M
		7.15	MS	7.13	MS		
		4.99	M	4.98	M		
		4.73	W	4.73	W		
		4.25	VW	4.27	VW		
	48-101	16.32	W	18.58	M	14.23	M
		14.26	S	14.21	S	10.09	VS
		10.09	MS	10.09	MS	4.98	M
		7.13	MS	7.10	MS		
		4.98	M	4.98	M		
		4.73	W	4.73	W		
		4.25	VW	4.25	VW		
	101-130	16.03	W	18.68	M	14.10	M
		14.12	S	14.07	S	10.10	VS
		10.13	MS	10.09	MS	4.99	M
		7.15	MS	7.13	MS		
		4.99	M	4.98	M		
		4.75	W	4.75	W		
		4.25	VW	4.27	VW		

(Contd.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Bandar-goj soil clays	0-11	14.21	S	14.17	S	14.23	M
		10.11	MS	10.09	MS	10.10	VS
		7.15	MS	7.13	MS	4.97	M
		4.98	M	4.98	M		
		4.77	W	4.77	W		
		4.27	VW	4.27	VW		
	11-31	14.25	S	14.21	S	14.23	M
		10.11	MS	10.09	MS	10.11	VS
		7.13	MS	7.13	MS	5.00	M
		5.00	M	4.99	M		
		4.77	W	4.77	W		
		4.27	VW	4.27	VW		
	31-89	14.25	S	14.21	S	14.23	M
		10.09	MS	10.09	MS	10.09	VS
		7.15	MS	7.15	MS	4.99	M
		4.98	M	4.98	M		
		4.77	W	4.77	W		
		4.27	VW	4.27	VW		
	89-120	14.23	S	14.17	S	14.23	M
		10.12	MS	10.09	MS	10.10	VS
		7.13	MS	7.10	MS	4.98	M
		4.99	M	4.98	M		
		4.77	W	4.77	W		
		4.27	VW	4.27	VW		
Bagdog-ra soil clays	0-15	14.28	S	14.23	S	14.25	M
		12.07	W	12.00	W	10.09	VS
		10.09	MS	10.09	MS	4.99	M
		7.13	MS	7.12	MS		
		4.98	M	4.99	M		
		4.77	W	4.77	W		
		4.27	VW	4.27	VW		

(contd.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	15-100	14.30	S	14.25	S	14.28	M
		12.07	W	12.00	W	10.10	VS
		10.10	MS	10.09	MS	5.00	M
		7.15	MS	7.13	MS		
		5.00	M	4.99	M		
		4.77	W	4.77	W		
		4.27	VW	4.27	VW		
	100-123	14.21	S	14.14	S	14.17	M
		12.12	W	12.07	W	10.10	VS
		10.13	MS	10.09	MS	4.99	M
		7.15	MS	7.14	MS		
		4.99	M	4.99	M		
		4.77	W	4.77	W		
		4.27	VW	4.27	VW		
	123-133	14.19	S	14.15	S	14.17	M
		12.05	W	12.00	W	10.09	VS
		10.09	MS	10.09	MS	4.99	M
		7.13	MS	7.11	MS		
		4.98	M	4.99	M		
		4.77	W	4.77	W		
		4.27	VW	4.27	VW		

Å = Angstrom Unit; I = Intensity;

VW = Very Weak; W = Weak; M = Medium; S = Strong; MS = Medium Strong and VS = Very strong.

TABLE 22: Mineralogical Composition (expressed as % of Clay)of the Crystalline Clays, Amorphous Materials and the Weathering Means of the soil Clays from the Five Soil Series

Soil Clays	Depth (cm)	Quartz (%)	Illite (%)	Kaolinite (%)	Chlorite (%)	Mixed layer (%)	Vermiculite (%)	Smectite (%)	Amorphous material (%)	Weathering Mean
Leprijot soil clay	0-18	2	32	16	16	14	2	3	15.28	8.74
	18-32	2	33	14	17	12	4	3	15.05	8.68
	32-76	3	35	14	13	15	3	2	15.27	8.62
	76-108	2	40	12	15	12	2	-	16.91	8.58
	108-130	3	40	7	14	15	2	-	18.94	7.82
Rangapani soil clay	0-14	3	40	15	10	13	3	-	15.52	8.55
	14-44	2	43	16	10	12	4	-	13.13	8.46
	44-78	2	48	11	9	10	5	-	12.50	8.12
	78-104	3	55	12	5	7	2	-	15.95	8.23
	104-130	3	58	9	5	7	1	-	16.72	8.17
	130-150	3	59	5	9	5	1	-	17.76	8.13
Amkishrajot soil clay	0-13.5	2	29	10	10	13	4	2	30.34	9.02
	13.5-48	3	32	9	9	11	4	3	28.56	8.90
	48-101	3	30	12	6	8	6	6	28.61	8.95
	101-130	3	36	7	7	10	5	5	27.32	8.75
Bandargoj soil clay	0-11	3	31	14	13	13	5	-	20.90	8.80
	11-31	2	33	13	12	13	5	-	21.85	8.80
	31-89	2	36	11	14	12	3	-	22.38	8.74
	89-120	3	39	8	12	11	2	-	25.11	8.69
Bagdogra soil clay	0-15	3	48	11	11	13	2	-	12.38	8.28
	15-100	3	41	15	11	11	6	-	12.79	8.44
	100-123	2	40	15	9	11	7	-	15.26	8.43
	123-133	3	48	8	11	8	2	-	19.67	8.41

9th, and 11th stage of weathering for all the horizons of this soil profile. Fig. 15.3 depicts the curve for two soil depths only viz., surface (0-15 cm) and third (100-123 cm), horizons.

4. STUDY OF GENESIS OF CLAY MINERALS OF THE CLASSIFIED SOILS

A study of soil genesis is the evolution of the soil body in the geochemical cyclic process operating in the crust of the belt of weathering. The first phase in this cyclic process represents the process of weathering, the disintergration and decomposition of rocks and minerals. And in the final analysis, soil genesis is linked with the reactions of the biosphere on the products of weathering. In the evolution of the cyclic process which includes the soil system, other factors besides the biosphere had been operating and had also contributed to the formation of the soil body. These factors enumerated by Dokuchaev are parent material, climate, topography, biosphere, and age of land (time factor). The interaction of these factors of soil formation may be expressed by a series of physical, chemical, and biological reactions. Collectively, these represent soil-forming processes which lead to the ultimate moulding of the soil body. In nature, this moulding of the soil by the transformation or weathering of primary materials (minerals) yield clay minerals which are all hydrous silicates or aluminosilicates although crystallization from solution has also been found to be significant in the formation of these aluminosilicates (Keller, 1954).

In the present study, an attempt has been made to delineate the important modes of the origin of the clay minerals of the five soil series identified. According to Mackenize (1965 b) and Millot (1970), three modes can be recognized; Detrital Inheritance from the parent material; Transformation or Alteration, and Neoformation or Synthesis. All these operate simultaneously. When physical weathering processea are involved, inheritance is of major importance. On the other hand, when weathering is chemical, transformation or alteration and synthesis or neoformation predominates.

In the light of the above observations the genesis of the clay minerals of the five soil series is discussed below.

4.1 Detrital Inheritance :

From the mineralogical study of the soil clays of the area it has been found that illite is the predominant mineral in all the five soil series established. This revealation shows the importance of inheritance from the past the soils solid, colloidal, and dissolved constituents. Though inheritance is of particular importance with sedimentary rocks and unconsolidated deposits (Southard and Miller, 1966), the soils formed on alluvium have predominance of illitic mineral partly inherited probably from micas which are predominant in the sand and silt fractions of these soils (Kanwar, 1959; Sehgal, 1972; Sehgal and De Coninck, 1973). The mineralogical composition of the sand and silt fractions of these soils has not been studied but the relative importance of the detrital inheritance factor in the development of clay-minerals of these soils is indicated on the basis of the mineralogy of soil clay fractions which is dominated with illitic mineral.

4.2 Transformation as influenced by topography and/or drainage , climate :

The transformation of clay minerals refers to those changes that modify a clay mineral without altering its two or three-layered structural types. Under natural environment various soil forming factors influence the transformation of silicate clay minerals. Therefore, in the following lines the influence of various soil forming factors (topography and/or drainage, climate) on the formation and/or transformation of the clay minerals of these five soil series is given.

The influence of relief on clay formation and/or transformation is due to such factors as drainage and transportation of dissolved elements by soil water. The area covered by all the five soil series is alluvial plain rolling and the drainage conditions are well to very poor with moderate to low permeability.

The mineralogical composition of the profiles show an overall increasing pattern of illitic minerals down the profile. Kaolinite distribution shows the reverse trend. Chlorite, interstratified, and vermiculite and smectite minerals show a more or less uniform pattern of distribution all along the profiles. The drainage conditions evidently points toward downward transportation of minerals(illite increases down the profile) whose percent distribution increased with depth as is also evident from the increase in percent base saturation values (28.94% to 86.59%) down the profile suggesting significant movement of cations due to leaching. Gawande and Biswas (1972) have found a relation between the differences in drainage conditions irrespective of parent material and mineralogical makeup or distribution in the horizons of four soil profiles of sedimentary formation.

All kinds of mineral groups occur in different climatic zones; but their distribution (percent) generally varies. In these soils the presence of fairly good amount of kaolinite in such sub-humid, sub-tropical climatic condition is in conformation with earlier findings of Bagchi, 1951; Prasad et al., 1969; and Ghosh et al., 1972 b.

4.3 Transformation as influenced by Parent Rocks :

The influence of parent rock is more conspicuous at the early stages of soil formation. Other factors become more important with the profile development. The predominance of illite and kaolinite in these soils developed from acidic rocks in the same climatic conditions is in conformity with the earlier findings of Parfenova and Yarilova (1965). Gupta (1968) working with the alluvia of western and central regions of India found illite and chlorite to be the dominant minerals. The parent material of the area has been derived from rock formations of a part of the Darjiling Himalayan formation which are rich in varieties of high grade schists, garnefiferous and biotite gneisses and slates. These rocks are rich in mica, chlorites, and quartz. Therefore, the occurrence of mica and chlorite in all the five soil series of the area is in good agreement with the mineralogy of the source material and indicates that their occurrence is by inheritance from the parent material. Small amount of quartz in the clay fractions of these soils have also been similarly inherited. Biotite mica easily observed with unaided eye appear to have weathered to mica - vermiculite interstratified mineral and also vermiculite. A portion of kaolinite in the clay fraction seems to have originated from the weathering of feldspar.

4.4 Neoformation or Synthesis of Clays :

Synthesis or degradation of clay minerals in the soil is determined by the weathering reactions, pH of the medium in which the reaction occurs, and the presence of chelating substances besides other factors like leaching, rainfall, and temperature.

The kind of clay mineral to form would depend on the ratio of SiO_2 to Al_2O_3 and Fe_2O_3, the pH of the medium, and the presence in solution of basic cations such as Ca, Mg, and K. The soils of the area covered by the five soil series is acidic in nature, the temperature and rainfall remaining more or less same for all the five soil series. The chemical composition of the soil clays of all the five soil series shows the proportion of colloidal SiO_2 to Al_2O_3 and Fe_2O_3 ranging from 2 to 4 with a pH varying from 4.5 to 6.2 and is low in K and moderate to high in Ca and Mg content, which gives rise to illite, kaolinite, and chlorite type of minerals . Due to the high Mg content all the five soil series contain a small amount of vermiculite, and only the Amkishrajot series contain smectite minerals in all the horizons; and the Leprijot series showing its presence in a few horizons. The formation or presence of significantly high amount of kaolinite in all the soils of the area is due to high rainfall and high leaching conditions. The ratio of kaolinite to vermiculite is also significantly higher for this reason. The formation, however, of illite appears to be determined not so much by the leaching conditions as by the parent material, only those high in K_2O content favour the formation of illite. Considerable quantity of chlorite found in all the horizons of the five soil series has its presence due to probably the brucite layer sandwiched between negatively charged mica-like layers as replacement for K in the mica structure. This also explains the reason for the low content of K_2O in the chemical composition of the clays which is considered essential for illitic mineral found in abundance in these soils. The amount of mixed layer minerals (interstratified mica-vermiculite) in the soils of the area has been due to the depletion of potassium from mica and fixation of aluminium and other cations between the plates. In the prevailing climatic conditions, degradation of biotite proceeds mainly by vermiculitization with ordered and non-ordered mixed layer mica-vermiculite formation and irregular chlorite-vermiculite formation as intermediate phase.

Furthermore, it is observed that the soil clays of all the five soil series contain a significant amount of Amorphous Ferrialuminosilicates (AFAS) in all the horizons. The weathering means calculated from the semi-quantitative clay mineralogical composition of Rangapani, Bandargoj, and Leprijot series decreases down the profile whereas in the other two series no definite trend has been found. This is indicative of the deposition of alluvial and co lluvial sediments over the surface soil through the ages and reveals the immature nature of the soil profiles. The present day sub-humid high rainfall conditions and also the porous nature of these soils indicate the leaching of bases from the soil environment including the soil clays which results in the acidity of the soil profiles. Prior to the development of this acidic condition, the alkaline reaction due to releasing of bases, takes part in changing the nature and chemical composition of the soil and clays environment. Due to development of alkaline condition, the silicon and aluminium are released from nearby minerals. The subsequent leaching of bases and dominance of Co_2 would lower the pH and thus result in the precipitation of silicon and aluminium and then formation of hydrous aluminosilicate occurs due to random cross linking with aging (Fripiat and Herbillion, 1971). Besides it is observed under this soil environment iron (Fe) is the first to be precipitated and/or form colloidal particles. The affinity of the silicic monomers for the surface of the Fe-colloid (Herbillion et al., 1969) would lead to chemi-sorption of silicon on the Fe-colloid. However, the aluminium which is in solution tends to be incorporated in the silica net work (Milliken et al., 1950) so that a tetrahedrally co-ordinated silica-aluminogel structure is obtained. The Fe-form dominate in this three dimensional mass. Now the lowering of pH due to the leaching of bases from the immediate environment leads to the formation of octahedrally co-ordinated Al-OH polymers in the outside solution. These positively charged polymers are bound electrostatically to the negatively charged Si-Al phase and partly neutralize the charge. Another consequence of the low pH is the tendency of the Al to change its co-ordination from four to six (Dekimpe et al., 1964). Such a coordination change would give rise to conditions suitable for crystallization of kaolinite. This crystallization is aided by the presence of octahedrally co-ordinate Al in the outermost layer. It might be proposed that these soil clays through the geologic ages form the AFAS material in association with the crystalline 'kaolinite + halloysite' in such pattern or sequence.

5. GENERAL DISCUSSION ON THE SOILS OF FIVE SOIL SERIES

The results of the soil classification, physical, chemical, and physico-chemical properties, soil clay mineralogy (chemical composition and X-ray diffraction analysis), amorphous ferri-aluminosilicates in the clay fractions, and genesis of the soils of the five soil series have been presented in the preceding pages. In the following section all the above results are being discussed soil series-wise and the findings correlated and tested with one property or the other of the respective soils.

5.1 Leprijot Series :

The soils of this series are coarse loamy in texture with mixed mineralogical composition, hyperthermic family of Typic Fluvaquents. The soils of the area are very poorly drained and covers an area of 6,420 thousand hectares or 16.54 % of the total area surveyed. The area is cultivated to paddy and show signs of inundation during the monsoonal part of the year when most of the precipitation is concentrated causing overflow of the Mahananda river.

As evidenced from the physical, chemical, and physico-chemical properties, the soils of all the horizons are acidic in nature with a downward decreasing trend juxtaposed with a corresponding increase in the distribution of exchangeable bases. The C.E.C. values are relatively high in the first two horizons. The organic matter content also follows the same trend. The C:N ratio values show maximum accumulation of undecomposed material in the first two horizons.

The chemical analysis data of the crystalline clay fraction particularly the molar ratios (SiO_2/Al_2O_3, SiO_2/R_2O_3, Al_2O_3/K_2O, Al_2O_3/MgO), reveal that the soils of all the horizons consist dominantly of illite mineral with sufficient amount of 2:1 non-expanding Mg-containing minerals. The K_2O % and MgO % and CEC also support the earlier observation that the relative abundance of illite increases down the profile. The presence of Mg-containing 2:1 lattice minerals of low CEC is also evidenced from these data.

The X-ray diffraction analysis confirms the findings of the chemical analysis where illite (distribution of K_2O%) has been found to be the predominant mineral in the clay fraction of all the horizons. Semi-quantitative estimation of the mineralogical composition shows the amount of illite to increase with depth. A considerable amount of kaolinite, chlorite and mixed layer minerals have also been isolated. The percentage distribution data of 'kaolinite + halloysite' found by Selective Dissolution analysis projects the mineral to be present in more amounts for all the horizons than the values obtained from the peak area measurement of the X-ray diffractograms. Vermiculite available in small amounts is found in the clay fraction of all the horizons whereas smectite is found only in that of the first three horizons (from the surface) of this profile.

The percentage distribution of amorphous ferri-alumino-silicates (AFAS) in the clay fraction is fairly high in all the horizons. It is also found to increase with the increase in depth. The relatively high amount of AFAS distribution is probably the reason, or contributes a major amount to the CEC of the soil clays which is otherwise considered low. The bulk density values which shows a decreasing trend down the profile may be accounted for the increasing amount of AFAS distribution downwards whose increasing availability contributes to corresponding lowering of bulk density. The significant amount of 'kaolinite + halloysite' and AFAS material found in all the horizons of the profile suggests their development or formation through the probable modes as described in the preceding section of genesis.

Thus the results obtained from the X-ray diffraction studies, AFAS studies, chemical analysis, and physico-chemical analysis, are in good agreement with each other and also the data from Total Chemical analysis substantiated the findings of X-ray analysis.

5.2 Rangapani Series :

Rangapani soils are coarse loamy over sandy, mixed, hyperthermic family of Typic Fluvaquents. The soils of the area are poorly drained with moderate permeability and remains stagnated with water during a considerable part of the year which gives rise to mottles throughout the soil profile. The area covered by this series amounts to 4.98 thousand hectares which is equivalent to 12.83% of the total area. The area is generally cultivated to paddy and jute.

The data on particle size distribution reveals that the soils are immatured and young. The physico-chemical data shows the profile to be acidic in nature and as the depth increases the acidity decrease to nearly neutral. The percentage base saturation is maximum in the sub-surface layers with corresponding CEC going down to a meagre less than 1 me/100 g of soil. The organic matter content goes on decreasing down the profile indicating maximum accumulation in the first two horizons. The nitrogen content is low in the first three horizons whereas the last three horizons show trace amounts of nitrogen to be present. The C:N ratio is maximum in the surface soil indicating accumulation of undecomposed matter.

The data on chemical composition viz., K_2O %, MgO%, CEC, and molar ratios of SiO_2/Al_2O_3, SiO_2/R_2O_3, Al_2O_3/K_2O, and Al_2O_3/MgO, shows that the crystalline soil clays of this series is dominated with illitic mineral. The CEC values should have been higher considering the high non-exchangeable MgO % content but indicates the presence of 2:1 type of non-expanding Mg-containing clay minerals or some of the intergrades of them in association.

The identification, chracterization, and quantification of the clay minerals present in this series by X-ray diffraction techniques confirms the findingsof mineralogical composition by chemical analysis and CEC. The diffractograms also show an increasing trend of distribution of the illitic mineral down the profile which finds support from the K_2O% of the clay. The profile also contains a fairly high amount of kaolinite, chlorite and mixed layer minerals. Vermiculite is also found throughout the soil depth with relative abundance in the upper horizons than the lower horizons. The most interesting feature is the fair amount of kaolinite present in the clay fractions of all the horizons showing an overall decreasing trend down the profile. From the total chemical analysis data the presence of 'kaolinite + halloysite' could not be suggested. 'Kaolinite + Halloysite' contents has been determined by selective dissolution analysis based on SiO_2%, Al_2O_3%, and Fe_2O_3% (Hashimoto and Jackson, 1960). It is observed that the amount of kaolinite found from the diffractograms yielded lower values for all the horizons than that of the amount found out by the above selective dissolution analysis.

So, it is evident that the results obtained from Chemical analysis of soil clays supplement partially the mineralogical findings by X-ray diffraction analysis.

Amorphous ferri-aluminosilicates (AFAS) content in the soil clays found out by Selective Dissolution Analysis of Hashimoto and Jackson (1960) has been found to be fairly high in these soils. Barring the first two horizons the amount of AFAS mineral in the soil clays is observed to increase down the profile depth. As the presence of AFAS minerals is considerably high and has a decreasing trend, so the bulk density values also show a corresponding decreasing trend down the profile, which is expected . Furthermore, the CEC of the AFAS-free clay is low in comparison to the CEC of total clays of all the horizons. It is therefore, obvious that the AFAS mineral contributes to the considerable part of the CEC in the soil clays.

The study of genesis of soil clays indicate the dominant role of parent material in the formation of illitic mineral and the degradation of biotite mica is the important factor in the synthesis of the mica-vermiculite intergrades. 'Kaolinite + Halloysite' and the AFAS-mineral have been chemically weathered following the inter-play of various factors which produced conditions suitable for the crystallization of kaolinite. The weathering intensity is high in the upper horizons whereas the last two horizons show signs of lesser weathering intensity.

5.3 Amkishrajot Series :

Amkishrajot soils are a member of the fine loamy, mixed, hyperthermic family of Aeric Haplaquepts. The area covered by this series is 7,640 hectares, i.e., 19.83% of the total area. The soils are poorly drained with moderate to low permeability. Among the five soil series established, this is the only one which shows signs of horizonation and have high productive potential. These soils are also exposed to periodic inundation during heavy monsoon months and are cultivated to paddy.

The soil profile shows an increase in the amounts of clay particle in the second and third horizons suggesting probable eluviation. The physico-chemical data reveals the profile to be acidic in nature. However, the acidity is found to decrease with increase in soil depth. The corresponding increase in the values of exchangeable bases suggests leaching of cations from the surface to sub-surface layers. From the physico-chemical data it is also evident that the organic matter content of the surface layer is considerably higher than that of the sub-surface layers. Total nitrogen content in all the horizons is low though it is fairly high in comparison to the soils of the other four series . C:N ratio is more or less uniform for the first two layers showing deposition of undecomposed materials.

As is evident from the analytical data on chemical composition and CEC of soil clays of this series, illite is fairly dominant in all the horizons. The fairly high amount of MgO % in all the horizons indicates the presence of Mg-containing 2:1 type of lattice minerals. The corresponding CEC values, though higher than the clays of four remaining soil series, is not so high as is indicated by the high amount MgO % content. This indicates the 2:1 type of mineral to be mostly of the non-expanding Mg-containing one along with a small amount of smectite or vermiculite minerals, which is evident from the X-ray diffraction studies of these soil clays.

Semi-quantitative estimation of the mineralogical composition from the X-ray diffraction analytical data confirms the earlier observations made from the total chemical analytical data. Illite is the dominant mineral found in relative abundance to others viz., kaolinite, chlorite, mixed-layer, smectite, and vermiculite. The X-ray data reveals that besides illite, it contains a fairly good amount of kaolinite, chlorite and mixed layer minerals, in all the horizons. A small quantity of smectite is also present in the crystalline component of the soil clays of all the four horizons. This expanding clay mineral is not found in the clays of all the horizons of the other three soil series (Rangapani, Bandargoj, and Bagdogra). The weathering mean values also points to the comparatively highly weathered nature of the soil profile. Furthermore, the amount of 'kaolinite + halloysite' estimated by SDA is found to be slightly higher for all the horizons than that found from the X-ray data.

This soil series being unique in all the characteristics from the remaining four shows the presence of high amounts of amorphous ferri-aluminosilicates (AFAS) in all the four horizons. The percentage distribution of this AFAS mineral shows a decreasing trend down the profile which is contrary to the observations of the other four profiles (Soil Series). Furthermore, it is to be noted that though these soil clays contain high amounts of AFAS mineral the corresponding CEC values of this component is not so high as compared to the AFAS-minerals of the remaining four soil series . It is therefore suggested that the AFAS-minerals of this soil series are made up of low CEC constituents.

From the study of the genesis of soil clays of this series it is observed that the high amount of illitic mineral found has its root to the detrital inheritance and parent rock factors. Biotite mica on degradation gives rise to the mica-vermiculite intergrades whereas kaolinite and the AFAS minerals have been chemically weathered following the inter-play of various factors suggested in the preceding section.

5.4 Bandargoj Series :

The soils of this series are coarse loamy, mixed, hyperthermic family of Mollic Udifluvents. Bandargoj soils are well drained with moderate permeability and covers an area of 4,180 hectares which is equivalent to 10.77% of the total area surveyed. The soils covered by this area suffers from inundation problem owing to its proximity to the Mechi and Mahananda River, during the monsoon times.

The particle-size distribution data shows the dominance of coarse over fine sand and coarse over fine silt, the amount of claybeing low. A significant feature of this soil series is the presence of coarse fragments all along the profile with the highest amount being found in the last horizon.

The profile is acidic in nature as is evident from the physico-chemical data. The data also reveals that the CEC of the soil decreases down the profile. The exchangeable cations are relatively abundant in the surface soils rather than in the soils of sub-surface layers. The percent base saturation also follows the same suit. The organic matter distribution is higher in the first two horizons. Nitrogen and phosphorus is available in small quantities. The C:N ratio is highest in the surface horizon indicating more availability of undecomposed matter.

From the data on chemical analysis it is obvious that the soils of the area are dominated with illite minerals. The molar ratios and the MgO% values suggest the presence of 2:1 type of Mg-containing minerals. This mineral, exclusively on the basis of total chemical analysis, has been found to be mostly non-expanding type of lattice mineral.

The data on X-ray diffraction of clay samples confirms the earlier assumption made on the basis of chemical analysis that these soils contain mostly 2:1 types of non-expanding Mg-containing mineral (Chlorite). Though illite is the dominant mineral in all the horizons, the presence of a fairly high amount of kaolinite and mixed layer minerals and with a small amount of expanding mineral (Vermiculite) is being confirmed from the X-ray diffraction data. Moreover, the percentage distribution of illite has been found to increase down the profile in the clay fraction whereas the other minerals present show more or less the reverse trend. The SDA data obtained for 'kaolinite + halloysite' content in the clays has been found to be more for all the horizons than the amount of kaolinite estimated from the peak area measurement of X-ray diffractograms of respective soil clay fraction isolated from different horizons of this profile.

The percentage distribution of amorphous-ferri-alumino-silicate (AFAS) minerals show an increasing trend down the profile depth. The corresponding bulk density values show a decreasing pattern with increasing depth suggesting the probable presence of high amounts of 'allophane' or AFAS - minerals which follows an increasing sequence of distribution with depth. Considering the presence of fairly high amount of AFAS mineral and low CEC values of amorphous free clay it is concluded that the relatively high CEC values of total clay could be due to the amorphous material present.

The study regarding the genesis of soil clays of this series points to the increasing influence of detrital inheritance and parent rock on the formation of illitic minerals which dominates the soil profile. Mica-vermiculite intergrades has been suggested to be the product of biotite mica degradation. Kaolinite and AFAS minerals might be produced due to chemical weathering with conditions conductive to such minerals formation.

5.5 Bagdogra Series :

6.41 % of the total area or 2.49 thousand hectares is under the soils belonging to the Bagdogra series. The soils of the area are very poorly drained with moderate permeability. This series is a member of the mixed,hyperthermic family of Typic Udipsamments. Owing to its proximity to the Mechi and Mahananda river the soils of the area are inundated periodically with the overflow of the rivers during high precipitation months.

This series is next to Rangapani in the characteristic content of sand fractions. However, the clay particle amount in the surface soils is more than what the Rangapani soils contain. This profile is also different from Rangapani in that the abundance of sand throughout the four horizons is evident whereas in the latter the abundance of sand is significant only below the third horizon.

The physico-chemical data shows the profile to be acidic in nature. Whereas the bulk density values show an overall increasing trend down the profile, the particle density values show the reverse. Percentage porosity as a consequence decreases slightly with the increase in depth. The organic matter content is relatively higher in the second horizon than that of the surface or remaining sub-surface horizons. Total nitrogen and available phosphorus is low. The C:N ratio is relatively high in the second horizon whereby accumulation and deposition of undecomposed material is at its maximum. The CEC value is highest in the first horizon and so is the exchangeable cations.

The K_2O%, MgO%, C.E.C., and molar ratios (SiO_2/Al_2O_3, SiO_2/R_2O_3, Al_2O_3/K_2O, and Al_2O_3/MgO) obtained from the total chemical analysis of the soil clays indicate the relative abundance of illite and 2:1 type of lattice minerals. However, considering the low CEC values and high MgO% content it is argued that the 2:1 type of mineral present mostly comprises of the non-expanding Mg-containing type.

The X-ray diffraction data confirms the above findings that the presence of fairly high amounts of chlorite is well evidenced and further indicates the presence of small amounts of vermiculite in the crystalline clays all along the profile depth. The X-ray data also reveals the predominating position of illite mineral in the soil profile and the presence of kaolinite and mixed layer minerals in fairly good amounts. The mixed layer minerals found has been argued to be of the mica-vermiculite type of intergrades. Comparing the data with the CEC of clays it is inferred that the vermiculite component of the clay is of low charge one. The kaolinite content obtained from semi-quantitative estimation (X-ray data) has been found to be slightly lower for all the horizons than that of the data obtained for 'Kaolinite + Halloysite' from SDA on the basis of SiO_2% , Al_2O_3%, and Fe_2O_3% estimation following the procedure of Hashimoto and Jackson (1960).

The analytical data on amorphous ferri-aluminosilicate (AFAS) minerals in the clay fractions of this soil shows the distribution of these minerals to be increasing with increasing depth. The increasing distribution of this mineral down the profile holds good while the corresponding decrease of bulk density values is expected in such soil conditions. Though the percent availability of AFAS mineral is comparatively lower than in the clays of the other four soil series, the CEC of the amorphous constituents of this series is comparatively higher suggesting the constitution of this mineral with components of different nature and amount than what the other four (soil series) AFAS-mineral constitutes of. Furthermore, considering the CEC values of total clay, amorphous free clays, and amorphous material (AFAS), it is opined that the latter component contributes a major share in the CEC of total clays.

The genesis of soil clays of this series has been found to follow more or less the same pattern as is described in the preceding section for the remaining four soil series.

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

On undertaking a reconnaissance survey of the area covering parts of Siliguri-Naksalbari-Bagdogra-Phansidewa-Kharibari blocks, five soil series viz., Leprijot Series, Rangapani Series, Amkishrajot Series, Bandargoj Series, and Bagdogra Series have been tentatively established on the basis of correlation and organisation of field data. Soil map has been prepared at the association level. Utility maps, viz., Land capability Map, Land Irrigability Map, Fertility Management Map, Land Use Map, and Suggested Land Use Map, have also been prepared to make the efforts meaningful and of practical importance.

Though the five soil series established exhibit more or less coarseness of texture, and exposed to similar climatic conditions, developed on weathered alluvium, four of them have been found to belong to the Entisols order and only one to the Inceptisols. Differences were observed also in drainage conditions, permeability and other profile characteristics which led to their separation into five distinct soil series. Due to impurities and overlapping of data at some points clear demarcation of soil series boundary could not be negotiated and hence the soil association grouping was preferred for soil maping. Other utility maps and results of the physical,chemical,physico-chemical,and mineralogical analyses performed in the laboratory followed trends which substantiated and validated the soil association grouping made earlier on the basis of correlation and organisation of field data. In fact, the data obtained in the laboratory from physical, chemical, physico-chemical, and mineralogical analyses of the soils of the five soil series were used as a check and test to confirm the earlier findings of the field where the basis for classification was only the morphological study or observations at hand.

Among the three soil associations, the Amkishrajot-Leprijot association has been found to possess the various characteristics of good soil which shows potentiality of producing more in terms of crop yield. Though the soils of this entire surveyed area show signs of immaturity, and at a few places only, signs of horizonation most of the area belonging to Amkishrajot-Leprijot soil association falls under the category of land capability sub-class IIw and land irrigability sub-class 1. These soils on a comparative basis, are lands with high productive potential provided soil fertility management practices are adopted wherever necessary.

The physical, chemical, and physico-chemical properties of the five soil series studied supports the foregoing proposition. From the percentage clay distribution to the availability of exchangeable cations and cation exchange capacity (CEC) the Amkishrajot - Leprijot soil association has a definite edge over the other two. Though the soils of the entire region is low in total nitrogen, phosphorus, and potassium content, the above mentioned association contains these essential nutrients to be available in more amounts in comparison to the other two soil associations. Moreover, the Amkishrajot soil profile shows definite signs of horizonation, as is evident from the presence of B horizons which the other four soil series are wanting in.

The soil clay mineralogical studies carried out by X-ray diffraction technique, total chemical analysis, and SDA methods unfolded the identity, nature and amount of the minerals present in the soil clays of the five soil series. Smectite, the 2:1 expanding type of lattice mineral, which is responsible for high CEC of the soils is present only in the first three horizons of Leprijot series and all the horizons of Amkishrajot series although in very small amounts. Vermiculite, the other expanding lattice mineral, however, is present in all the five soil clays in small amounts. Illite, the nonexpanding type of mineral, is present in large amounts in all the soil clays. Though it is the dominating mineral in all the five soil clays; in case of Leprijot and Amkishrajot series, they are relatively less abundant than the soil clays from the other three soil series. Another interesting feature of Amkishrajot-Leprijot soil association is the relative abundance of kaolinite and the high weathering mean values of the former in comparison to the other two soil associations.

Furthermore, the soil clays of all the five soil series contain a good amount of chlorite and mica-vermiculite regularly interstratified minerals differing only in their relative abundance. The occurrence of mica, chlorite, and mica-vermiculite regularly interstratified minerals with spacing (002) at 12 Å in the clay mineralogical studies of Darjiling Himalayan region has been reported by Sahu and Ghosh (1982). The presence of expanding and non-expanding 14 Å and 10 Å mineral sp. in association was also observed by Sahu et al.(1981) in the soils of this (Darjiling-Kalimpong) region. Hence, the mineralogical findings are in good agreement with the mineralogy so far reported.

The amorphous ferri-aluminosilicate (AFAS) minerals, till recently about which not much was known and emphasis laid, have been determined for all the five soil clay fractions. It has been observed and explained that this AFAS mineral has got ample role in governing the physical and physico-chemical properties of soil. The CEC and K-fixing capacity of soils are very much influenced by the amount and nature of AFAS mineral in soil clays. The amount and structural constituents of these amorphous materials separated from all the five soil clays, appear to differ from the model suggested by Krishnamurti et al.(1976). The soil clays of the five soil series viz., Leprijot, Rangapani, Amkishrajot, Bandargoj, and Bagdogra, contain 15.28% to 18.94%; 12.50% to 17.76%; 27.32% to 30.34%; 20.90% to 25.11%, and 12.38% to 19.67% of AFAS materials respectively.

The weathering means as calculated from the semiquantitative clay mineralogical composition of the Leprijot, Amkishrajot and Bandargoj soils is observed to decrease more or less down the profile, whereas the weathering intensity of Bagdogra soils increases from the surface to the immediate two sub-surface horizons and then again decreases in the last horizon . And, the Rangapani soils does not follow any regular trend of weathering mean values. This is indicative of the deposition of alluvial and colluvial sediments over the surface soil through the ages and reveals the immature and young nature of the soils of the area. An attempt to delineate the important features of genesis of clay mineral formation, points to the major role played by the parent material in inheriting most of the illitic mineral found in abundance in all the horizons of the five soil profiles. The genesis of vermiculite is suggested to have followed the sequence previously observed by Sahu et al.(1982) .

Biotite Mica →	Mica- Vermiculite →	Vermiculite
(Sand)	(Silt and clay)	(Clay)

It may be pointed out that the smectite in the soil clays corresponds to the 9th stage of weathering, whereas kaolinite represent the 10th stage (Jackson and Sherman, 1953). Therefore, association of small amounts of smectite with kaolinite clays is to be expected in the natural weathering product of Leprijot and Amkishrajot soils. Besides, the soil clays of all the horizons of the two soil profiles contain more amount of AFAS-minerals.

So, it is imperative at this stage, to conclude that the soils of the area, not classified till recently in the light of the Comprehensive System of Classification (7th Approximation), has been tentatively classified in this study. The above system. of classification followed in this investigation made it not only possible but necessary to consider all soil characteristics collectively, in terms of a complete integrated, natural body, rather than individually. The subsequent physical, chemical, physico-chemical, and mineralogical analyses performed in the laboratory of the soil samples collected, was obligatory to understand the characteristics (morphology-studied in the field while surveying) of the soils of the area as these characteristics are given weight during classification, according to knowledge gained through research (analytical tests) and experience in mineralogy, soil genesis, and the responses of soil to management or manipulation. Thus the study of physical, chemical, physico-chemical, and mineralogical properties and research in genesis in responses of soils, though one step removed from the classification, have vital roles.

BIBLIOGRAPHY

B I B L I O G R A P H Y

Abtahi, A. (1980) Soil genesis as affected by topography and time in highly calcareous parent materials under semi-arid conditions in Iran. Soil Sci.Soc.Am.Proc.44:329-336.

Adhikari, M. (1957) Physico-chemical properties of some West Bengal clays. J.Ind.Soc.Soil Sci.5 : 199-204.

____________ (1958) Physico-chemical properties of clay minerals in mixtures, J.Ind.Soc.Soil Sci. 6:147-152.

Alexiades, C.A. and Jackson, M.L. (1966) Quantitative clay mineralogical analysis of soils and sediments. Clays Clay Min, Proc.14th Nat.Conf.26: 35-51.

A.O.A.C. (1959) Methods of Analysis. Association of Official Agricultural Chemists. Washington, D.C.

Anjaneyulu, B.S.R., Shukla , S.S. and Roychaudhuri, S.P. (1965) Studies of some foothill soils of Himalayas. J.Ind.Soc. Soil Sci. 13: 115-122.

Bagchi, S.N. (1951)Minerals present in H-clays from Indian Soils-X-ray study. Bull.Ind. Soc. Soil Sci.6 : 19-42.

Basak, G.B. (1969) Personal Communication.

Beinroth, F.H. (1982) Some highly weathered Soils of Puerto Rico, 1. Morphology,formation and classification.Geoderma.27: 1-73.

Bhargava, G.P. and Abrol, I.P. (1984) Morphology and characteristics of some acid sulphate soils in Kerala state. J. Ind.Soc.Soil Sci. 32 : 137-145.

*Biswas, R.R. (1974) The effect of rainfall on morphological properties of soils developed in Ghod Catchment, Junnar Tahsil, Poona District (Maharashtra State).Sym.Ind.Soc. Soil.Sci. (April. 3-25, 1974)pp.18.

Black, C.A. (1965) Methods of Soil Analysis. Part 2. Am.Soc. of Agron. Inc., Pub., Madison, Wisconsin, USA. pp.1572.

Bray, R.H. and Kurtz, L.T. (1945) Determination of total, organic, and available forms of phosphorus in soils. Soil Sci.59; 39-45.

Brinkman, R., Jongmans, A.G., Miedema, R. and Maaskant, P.(1973) Clay decomposition in seasonally wet, acid soils: micromorphological, chemical and mineralogical evidence from individual argillans. Geoderma, 10 : 259-270.

Buol, S.W., Hole, F.D. and Mc Cracken, R.J. (1973) Soil Genesis and Classification. Oxford and IBH Pub.Co. New Delhi, India. pp.354.

Cabezas Viano, C., Fernendez Caldas, E., Tejedor Salguero, M.L. and Hernandez Moreno, J.M. (1979) Selective dissolution of Si, Al, Fe. I.Climatic Sequence:Andosols and Brown Soils,Anales de Edafologia. Y.Agroliologia.38 : 1573.

Campbell, J.B. (1977) Variation of selected properties across a soil boundary. Soil Sci.Soc. Am.Proc.41 :578-582.

Campbell, I.B. and Claridge, G.G.C. (1982) The influence of moisture on the development of soils of the cold deserts of Antarctica. Geoderma, 28 : 221-238.

Chakraborty, S.K., Sinha, H. and Mathur, B.S. (1984) Morphological and physico-chemical properties of some alluvial soils of Assam. J. Ind.Soc.Soil Sci.32: 128-136.

Chatterjee, B. (1951) Properties of Clayey soils of W.B., Chemical, Electrochemical, Viscosity, X-ray and petrographic studies J.Ind.Chem.Soc.India 28: 717.

Chatterjee, R.K. and Dalal, R.C. (1976) Mineralogy of clay fraction of some soil profile from Bihar and West Bengal. J.Ind. Soc.Soil Sci. 24 : 253-262.

Chesworth, W. (1973) The parent rock effect in the Genesis of soil Geoderma. 10 : 214-225.

Choudhury, J.S. and Dhir, R.P. (1983) Nature and distribution of amorphous alumino-silicates in Acid Soils of Western Rajasthan J.Ind.Soc.Soil Sci.3 : 94-98.

Cline, M.G. (1949) Basic principles of Soil Classification. Soil Sci. 67: 81-91.

Crocker, R.L. (1952) Soil Genesis and pedogenic factors. Quart. Rev. Biol.27: 239-168.

Das, D.K. and Das, S.C. (1970) Study of silt and clay mineralogy in relation to the genesis of clay minerals in some Black and Brown soils. J.Ind.Soc.Soil Sci. 18 : 473-478.

Dasog, G.S. and Hadimani, A.S. (1980) Genesis and chemical properties of some vertisols. J.Ind. Soc.Soil Sci. 28:49-56.

DeKimpe, C.R., Gastuche, M.C. and Brindley, G.W. (1964) Low temperature synthesis of Kaolin minerals. Amer.Mineral.49: 1-15.

DeKimpe, C.R. and Laverdiere, M.R. (1980) Amorphous material and aluminium interlayers in Qubec spodosols. Soil Sci.Soc.Am. Proc. 44 : 639-642.

Deshpande, S.B., Fehrenbacher, J.B. and Beavers, A.H. (1971) Mollisols of Tarai Region of Uttar Pradesh,Northern India, 1. Morphology and Mineralogy.Geoderma.6:179-193.

Deshpande, S.B., Fehrenbacher, J.B. and Ray, B.W. (1971) Mollisols of Tarai Region of U.P., Northern India, 2.Genesis and Classification.Geoderma. 6 : 195-201.

Dhamija, O.P., Murthy, R.S. and Raychaudhuri, S.P. (1956) Cinchona Soils of W.B.J.Ind.Soc.Soil Sci.4: 275-283.

Dhir, R.P.(1967) Pedological characteristics of some soils of the NW Himalayas. J.Ind.Soc.Soil Sci. 15 : 61-69.

Dhir, R.P. and Kolarkar, A.S. (1977) Observation on Genesis and evolution of soils of the arid zone. J.Ind.Soc.Soil Sci. 25 : 260-264.

* Digar, S. and Halder, A.K. (1974) Morphology, Genesis and Classification of some soils of Burdwan District, West Bengal. Sym.Ind.Soc.Soil Sci.(April,3-25, 1974)pp.13, New Delhi.

* Digar, S.,Thampi, C.J., Halder, A.K. and Goswami, Aruna (1974) Morphology,Genesis and Classification of some soils of Birbhum District, West Bnegal.Sym.Ind.Soc.Soil Sci.(April,3-25,1974).pp.12, New Delhi.

*Dokuchaev, V.V. (1883) Russian Chernozem. In collected writtings (Sochineniya), Vol.3 (Transl.from Russian by N.Kaner)Israel Prog.for Sci.Trans.,Jerusalem, 1967.

*_______________ (1886) Report to the provincial zenstro(local authority) of NiZhnii-Norgorod (Now Gorki)no.1.In Collectedwrittings (Sochineniya)Vol.4.Acad.Sci.USSR,Moscow,1950.

Dolui, A.K. and Roy, B.B. (1979) Clay mineralogy of some alluvial soils of W.B., India. Ind.Agric.22 : 57-66.

Dubey, D.D., Sharma, O.P. and Shila, P.K. (1984) Formation and Taxonomy of salt affected Aridisols. J.Ind.Soc.Soil Sci. 32: 146-149.

Duchaufour, P.H. and Souchier, B.(1978) Roles of iron and clay in Genesis of Acid soils under a humid,temperate-climate. Geoderma.20: 15-40.

Eswaran, H. (1972) Morpholcgy of allophane, Imogolite and Halloysite. Clay Min. 9: 281-285.

Farmer, V.C., Smith, B.F.L. and Tait, J.M. (1977) Alteration of allophane and imogolite by alkaline digestion. Soil Sci. 112: 263-294.

Fedorova, N.N. and Yarilova, E.A. (1972) Morphology and Genesis of prolonged seasonally frozen soils of Western Siberia. Geoderma. 7: 1-13.

Fey, M.V. and Leroux, J.(1975) Quantitative determination of allophane in soil clays. "In proceedings of the international clay conference".Mexico City, July, 16-23.

Fripiat, J.J. and Herbillion, A.J.(1971) in "Soils and Tropical Weathering". UNESCO, Paris, 15-24.

Gaikwad, S.T. and Govinda Rajan, S.V. (1971) Nature and distribution of silicon, aluminium and iron oxides in the lateritic soils from Durgdistrict, Madhya Pradesh. Ind.J.Agric.Sci. 41: 1079-1084.

*Gaikwad, S.T. and Rao, Y.S. (1974) Study of soils in relation to Geological (Structural)formations from cumbum areas in Prakasan Distt.Andhra Pradesh.Sym-on soil Genesis,Soil classification and Land Management (April 3-25,1974), J.Ind.Soc.Soil.Sci.pp.6, New Delhi.

Gawande, S.P. and Biswas, T.D. (1974) Genesis and distribution of catenary soils on sedimentary formation in Chattisgarh basin of Madhya Pradesh. J.Ind.Soc.Soil Sci.15: 111-118.

Gawande, S.P., Das, S.C. and Biswas, T.D. (1968) Studies in Genesis of catenary soils on Sedimentary formation in Chattisgarh Basin of Madhya Pradesh.J.Ind.Soc.Soil Sci.16 : 71-76.

Ghosh, B. (1965) The genesis of the desert plains in the central Luni basin of Western Rajasthan.J.Ind.Soc.Soil Sci.13: 123-126.

Ghosh, S.K. and Datta, N.P.(1974) X-ray investigation of clay minerals in the soils of West Bengal.Proc.Ind.Nat.Sci. Acad. B, 40: 138-150.

Ghosh, S.K., Ghosh, G. and Das, S.C. (1976 b) Smectite in some Gangetic alluvial soils of West Bengal. J,Ind.Soc.Soil. Sci. 24: 263-269.

* Ghosh, S.K.,Tomar, K.P. and Datta, N.P. (1972)

Proc.Ind.Nat.Sci.Acad.Sym.on clay minerals in Ind.Soils.Oct. 10-12, New Delhi.

Gjems, O. (1967)Studies on clay minerals and clay mineral formation in soil profiles in Scandinavia. Meddelelser fra Det Norske skogforskvesen, No.81. Bind 21,Vollebekk, Norway.

* Gobinda Rajan, S.V. and Krishna Moorthy, P. (1974) Characteristics of Red and Black Soils occurring in close physiographic association. Sym.Ind.Soc.Soil Sci.(April,3-25,1974).pp.8.

Gowaikar, A.S. (1973) Influence of moisture regime on the genesis of Laterite soils in South India.III.Classification. J. Ind. Soc. Soil Sci. 21:343-347.

Gowaikar, A.S. and Datta, N.P. (1971) Influence of moisture regime on the genesis of laterite soils in South India. I. Morphology and Chemistry of the soils. J.Ind.Soc.Soil Sci. 19 : 279-291.

Grim, R.E. (1953) Clay mineralogy. McGraw-Hill Book Co.New York. pp.596.

Grim, R.E. and Johns, W.D. (1954)Clay mineral sediments in the Gulf of Mexico.Clays and clay minerals.pp.81.(A swinford and N.Plumm er-Editors)Pub.327.Nat.Acad.Sci.Nat.Coun. Washington.

Gupta, R.N. (1968) Clay mineralogy of the Indian Gangetic Alluvium of Uttar Pradesh.J.Ind.Soc.Soil Sci.16:115-127.

Gupta, R.D., Ranst, E.Van. and Tripathi, B.R. (1984) Clay mineralogical composition of some soil orders from Himachal Pradesh. J.Ind.Soc.Soil Sci.32: 120-127.

Gupta, R.D. and Tripathi, B.R. (1983) Amorphous Aluminosilicates in some soil clays of North West Himalayas as affected by Biosequence and clims sequence.J.Ind.Soc.Soil Sci. 31: 99-109.

*Gupta, R.N.,Yadav, B.R. and Singh, B.D. (1974) Catenary relationship existing among the soils of Lower Vindhyan plateau in Uttar Pradesh. Sym.Ind.Soc.Soil Sci.(April,3-25,1974).

* Hadding, A. (1923) Eine rontgenographische Method Kristalline Und Kryptokristalline Substanzen Zu identifizieren.Ztschr. Krist. 58 : 108.

Harden, J.W. (1982) A quantitative index of soil development from field descriptions : Examples from a chronosequence in central California. Geoderma.28 : 1-28.

Hashimoto, I. and Jackson, M.L. (1960) Rapid dissolution of allophane and Kaolinite - Halloysite after dehydration.Clays Clay Min.7th Conf. Pergamon press, London. 10 : 2-13.

* Hendricks, S.B. and Fry, W.H. (1930) The results of X-ray and microscopical examinations of soil Colloids.Soil Sci.29:457.

Henmi, T. and Wada, K. (1974) Surface acidity of imogolite and allophane. Clay Min. 10: 231-245.

Herbillion, A.J. and Tran Vinh An, J. (1969) Heterogenesity in silicon-iron mixed Hydroxyloe. J.Soil Sci. 20 :223-235.

Jackson, M.L.(1967) Soil Chemical Analysis.Prentice Hall of India Pvt. Ltd., New Delhi, pp.498.

Jackson, M.L.(1978) Soil Chemical Analysis - Advanced course. Revised Edition. Deptt. of Soils.Univ. of Wisconsin, Madison 6,Wisconsin, pp.895.

Jackson, M.L. and Sherman, G. Donald (1953) Chemical weathering of Minerals in Soils. Adv.in Agron.5: 221-309.

*Jamagne, M. (1978) Soil forming process in a progressive evolutionary sequence on Loessial silty formations in a cold and humid temperate zone. Comptes Rendus Hebdomadaires des S'eances le 1'Acada mic des Sciences, D286:25-27.

Jenny, H. (1941) Factors of Soil formation.McGraw-Hill,Book Co., New York, pp.281.

Jones, R.C. and Uehara, G. (1973) Amorphous coatings on mineral surfaces. Soil Sci.Soc.Am.Proc. 37: 792-798.

*Kalbande, A.R., Rout, T.B. and Swaminathan, R. (1974) The effect of biocycling on soil development.Sym.Ind.Soc. Soil Sci.(April,3-25,1974)pp.18.

Karale, R.L., Bisdem, E.B.A. and Jongerius, A. (1974) Micromorphological studies an diagnostic sub-surface horizons of some of the alluvial soils in the Meerut district of Uttar Pradesh. J.Ind.Soc.Soil Sci.22 : 70-76.

Karale, R.L., Tamhane, R.V. and Das, S.C. (1969) Scil Genesis as Related to parent Material and Climate. I.Morphology, Physical,chemical and Physico-chemical properties.J.Ind.Soc. Soil.Sci. 17: 227-240.

Kanwar, J.S. (1959) Two dominant clay minerals in Punjab Soils. J.Ind.Soc.Soil Sci. 7: 249-254.

Kaswala, R.R. and Deshpande, S.B. (1983) Physico-chemical and mineralogical characteristics of some coastal and inland soil series of South Gujarat - II. Mineralogical characteristics. J.Ind.Soc.Soil Sci.31 : 572-579.

Keller, W.D., Westcott, J.F. and Bledsoe, A.O. (1954) The origin of Missouri fire clays. Clays Clay Min., Nat.Acad.Sci. - Nat.Res.Coun.Pub.327 : 7-46.

* Kelley, W.D., Dore, W.H. ahd Brown, S.M. (1931) The nature of the base exchange material of Bentonite,Soils and Zeolites as revealed by chemical investigations and X-ray analysis. Soil Sci. 31: 25.

*Khera, A.K., Log, J. and Sehgal, J.L. (1974) Genesis of Acid sulphate clays (cat clays).Sym.Ind. Soc.Soil Sci. (April,3-25, 1974). pp.10.

Koushik, R.N. and Shukla, U.C. (1977) A study on the development of salt affected soils in Typical area. J.Ind.Soc.Soil Sci. 25 : 276-283.

Krishna Moorthy, P. and Gobinda Rajan, S.V. (1977) Genesis and classification of Associated Red and Black soils under Rajolibunds Diversion Irrigation Scheme (Andhra Pradesh), J.Ind.Soc. Soil Sci.25: 239-246.

Krishna Murti, G.S.R. and Rao, T.V. (1981) Soils with variable charge. Proc.Intern.Symp.Newzealand, February,1981.

Krishna Murti, G.S.R., Sarma, V.A.K. and Rangaswamy, P.(1976) Amorphous ferri-aluminosilicates in some tropical ferruginous soils. Clay Min.11: 137-146.

*Kubiena, W.L. (1948) Entwicklungslehre des Bodens.Springer-Verlag. Wien.

Landey, R.J. and Kalbande, A.R. (1977) A New Approach to study the Vertisol Morphology.J.Ind.Soc.Soil Sci.25:221-232.

* Mac-Ewan, D.M.C. (1944) Identification of montmorillonite,Nature, London, 154: 557.

________________ (1948) Complexes of clays with organic compounds.I. Trans.Faraday Soc.44 : 349-367.

Mackenzie, R.C. (1965) Report of nomenclature sub-committee of CIPEA. Clay Min.Bull.6 : 123-127.

Mehra, O.P. and Jackson, M.L. (1960) Iron oxide removal from soils and clays by a dithionite - citrate system with sodium bicarbonate buffer. Clays Clay Min. 7th Conf., Pergamon. Press, London, 317-327.

Meixner, R.E. and Singer, M.J. (1981) Use of a field morphology rating system to evaluate soil formation and discontinuities. Soil Sci. 131: 114-123.

Mill, J.S. (1925) A system of logic, 8th ed.Longmans.Green,and Co., London.

Milliken, T.H., Mills, G.A. and Oblad, A.G.(1950) The chemical characteristics and structure of cracking catalysts. Disc. Faraday Soc.8 : 279-290.

Millot, G. (1970) Geology of clays. Chapman and Hall, London,pp. 492.

Murray, H.H. and Sayyab, A.S. (1955) Recent marine sediments.Clays Clay Min. PP.430.(W.O.Milligan-Editor)Pub.395.Nat.Acad. Sci.Nat.Res.Coun.Washington.

Parfenova, E.I. and Yarilova, E.A. (1965) Mineralogical investigation in soil Science. Israel Program for Scientific Trans., Jerusalem.

Perrott, K.W. (1977) Surface charge characteristics of amorphous aluminosilicates. Clays Clay Min. 25 : 417-421.

Piper, C.S. (1950) Soil and Plant Analysis. The Univ.of Adelaide, Adelaide Acad. Press, New York. pp.368.

Prasad, K.K., Karale, R.L. and Biswas, T.D. (1977) Studies on soil genesis from complex geological rocks in an area around Junagarh. J. Ind.Soc.Soil Sci. 25 : 207-220.

Prasad, R.N., Sinha, H. and Mandal, S.C. (1969) Clay Minerals in Bihar Soils. J.Ind.Soc.Soil Sci. 17 : 203-208.

Pundeer, G.S., Sidhu, P.S. and Hall, G.F. (1978) Mineralogy and Genesis of soils on two geomorphic surfaces of the Sutlej alluvium in central punjab. J.Ind.Soc.Soil Sci. 26: 151-159.

Pyman, M.A.F., Knuiman, M., Armitage, J.M. and Posner, A.M. (1979) Examination of the heterogeneity of amorphous Silico-aluminas and allophane using the electron microscope. J. Soil Sci. New Zealand. 30: 333-345.

*Raghu Mohan, N.G. and Murthy, D.A.N. (1974) Study of Soil Association in different geomorphologic units in the Union Territory of Goa. Sym.Ind.Soc.Soil Sci.(April,3-25,1974). pp.21.

Rao, T.V., Singh, Gwereharan and Krishnamurti, G.S.R. (1977) The nature of amorphous materials in alluvial soils. Zeitschrift Jwr. Pflanzener mahrung Wnd Badenkunde.140: 689-696.

Raychaudhuri, S.P., Agarwal, R.R., Datta Biswas, N.R., Gupta,S.P. and Thomas, P.K. (1963) Soils of India. Indian Council of Agricultural Research, New Delhi. pp.496.

*Rhine, F. (1924) Rontgenographische Untersuchungen an einigen feinzerteitten Mineralien. Kunstprodukten and dichten Gesteinen. Ztschr. Krist.60 : 55.

Rouston, R.C., Wildung, R.E. and Garland, T.R. (1977) Mineral weathering in an arid watershed containing soil developed from mixed basalticfelsic parent materials. Soil Sci. 124: 303-308.

Roy, B.B. and Das, S.C. (1979) Electrochemical properties of H-clays from typical Indian Soil.Trans.Fourth Int.Congr. Soil Sci. 3 : 81.

*Roy, B.B., Gupta, S.K. and Paul, D.K. (1974) Studies on some soil profiles of Tripura on a Catena with particular reference to fertility status. Sym.Ind.Soc.Soil Sci. (April,3-25, 1974). pp.7.

*Roy, B.B. and Paul, D.K. (1974) Genesis of some lateritic soils of West Bengal.Sym.Ind.Soc.Soil Sci.(April,3-25,1974)pp.12.

*Roy, B.B. and Rudra, P. (1974) Pedological characteristics of some lateritic soils of West Bengal. Sym. Ind.Soc.Soil Sci. (April,3-25) 1974) pp.12.

Roy, S. and Sahu, S.S. (1975) Chemical electrochemical Viscous properties and surface areas of clay fractions of some North Bengal (W.B.) Soil.M.Sc.thesis (1975).Univ.of Kalyani, Nadia, W.B.

Rudra, B.B. (1956) Forest Soils of W.B. (Red and Laterite)Part-I, Dists. Burdwan and Birbhum, J.Ind.Soc.Soil Sci.4:255-263.

Ruhe, R.V. and Walker, P.H. (1968) Hillslope model and soil formation 1. open systems.Trans.Int.Congr.Soil Sci. 9th., 4:551-560.

Rusanova, G.V. (1979) Soil genesis on binary parent materials. Soviet Soil Sci. 11 : 274-284.

Russel, M., Parfitt, R.L. and Claridge, G.G.C. (1981) Estimation of the amounts of allophane and other materials in the clay fraction of Egmont loam profile and other volcanic ash soils. New Zealand. Aust. J.Soil Res. 19 :185-195.

Sahu, G.C., Panda, N. and Nanda, S.S.K. (1983) Genesis and mineralogy of some red and laterite soils of Orissa. J.Ind. Soc. Soil Sci. 31: 254-262.

Sahu, S.S. and Das, S.C. (1972) Study of Electrochemical and Viscous properties and surface area of clay minerals and someof soil clays (W.B.) to characterise their clay mineralogy. Ind.J.Appl.Chem.35 : 40-44.

Sahu, S.S. and Das, S.C. (1974) Study of electro-chemical and physico-chemical properties of clay minerals and their mixtures and of some soil clays to characterize their mineralogy. Proc. Ind. Nat. Sci. Acad. 40: 235-248.

Sahu, S.S. and Ghosh, Sudhansu, K. (1982) Mineralogy of clay, silt and sand fractions of a pedon from Darjiling Himalayan Region. Proc.Ind.Nat. Sci.Acad.48:209-217.

Sahu, S.S., Roy, S. and Ghosh, S.K. (1977) Clay mineralogy of a Terai soil profile from Mohitnagar,Jalpaiguri District, West Bengal. Ind.Agric.21: 187-194.

Sahu, S.S., Roy, S. and Ghosh, S.K. (1981) Clay mineralogy of a Terai Soil profile Ind.Agric.25 : 231-239.

Sarkar, M. and Chatterjee, B. (1964) Clay minerals in Indian Soils. Proc.Symp. Fert.Ind.Soil Bull.Nat.Inst.Sci.India. 26: 184.

Saxena, S.C. and Singh, K.S. (1983) Clay mineralogy of semi-arid region soils of Rajasthan. J.Ind.Soc.Soil Sci.31: 25-93.

Schollenberger, C.J. and Simon, R.H. (1945) Determination of exchange capacity and exchangeable bases in soil-NH_4OAC method. Soil Sci.59 : 13-25.

Sehgal, J.L.(1972) Classification and distribution of the soils of Punjab. Proc.Ind.Nat.Sci.Acad. 40: 404-419.

Sehgal, Jawahar L. (1973) Studies of some soils in the NW Himalayas and the highlands of India. Geoderma. 9 :59-74.

Sehgal, J.L. and De Coninck, Fr. (1971) Identification of 14 Å and 7 Å clay minerals in Punjab soils. J.Ind.Soc.Soil Sci. 19 : 159-166.

Sehgal, J.L., Gambeer, R. and D'Hoore, J. (1976) Clay migration in the formation of argillic horizons in soils developed under varying moisture regimes. J.Ind.Soc.Soil Sci.24: 20-28.

Sharma, P.K., Sehgal, Jawahar, L., Sidhu, P.S. and Rosha, N.S. (1974) Genesis of the Salt affected soils in the Indo-gengetic plain of Punjab. Sym.Ind.Soc.Soil Sci. (April, 3-25, 1974).

Shoji, Sadao and Masui, Jun-ichi (1969) Amorphous clay minerals of recent volcanic ash soils in Hokkaido (II).Soil Sci. and Pl.Nutr. 15 :191-201.

Shukla, S.S., Roychaudhuri, S.P. and Anjaneyulu, B.S.R. (1965) Studies of some foot-hill soils of Himalayas. J.Ind.Soc. Soil Sci. 13 : 115-122.

*Sidhu, P.S., Hall, G.F. and Sehgal Jawahar, L. (1974) Genesis of soils at varying stages of development in the central Punjab. Sym. Ind.Soc.Soil Sci. (April, 3-25,1974).pp.8.

Sidhu, P.S., Pundeer, G.S. and Hall, G.F. (1978) Ferro-Manganeese concretions from the alluvial soils of central Punjab. J.Ind.Soc. Soil Sci. 26 : 268-273.

Simonson, R.W. (1952 a) Lessons from the first half-century of soil survey. I.Classification of soils, Soil Sci.74 : 249-257.

Slager, S. and Schuylenborgh, J.Van.(1970) Morphology and Geochemistry of three clay soils of a tropical coastal plain (Surinam). Agricultural Research Reports (Verslagen Van Landbouwkundige Onderzoekingen, Wageningen) 734: 33 (En) Agricultural University, Wageningen, Netherlands.

Smith, B.R. and Buol, S.W. (1968) Genesis and relative weathering intensity studies in three semiarid soils. Soil Sci.Soc. Am.Proc. 32 : 261-265.

Soil Survey Staff. (1951) Soil Survey Manual.Oxford and IBH Pub. Co. (Second Indian Reprint,1969),New Delhi.

__________ (1960) Soil Classification, A Comprehensive system 7th approximation. U.S.Dept.Agr.U.S.Govt.Printing Office, Washington.

Soil Survey Staff. (1964) Supplement to soil classification system 7th Approximation. U.S.Deptt.Agr.U.S.Govt. Printing Office, Washington.

________________ (1967) Supplement to soil classification system 7th Approximation. U.S.Deptt.Agr.U.S.Govt. Printing Office, Washington.

Souster, W.E., Arnand, R.J. ST. and Huang, P.M. (1977) Variation in physical properties and mineral composition of thin loess deposits in the swift current area of Saskatchewan. Soil Sci. Soc.Am.Proc. 41 : 594-600.

Southard, A.R. and Miller, R.W. (1966) Parent material-clay relations in some Northern Utah Soils. Soil Sci. Soc.Am.Proc. 30: 97-101.

Torrent, Jose and Nettleton, W.D. (1979) A simple textural index for assessing chemical weathering in soils. Soil Sci. Soc.Am.Proc.43 : 373-377.

Treadwell, F.P. and Hall, T.William (1948) Analytical chemistry Vol.II. Quantitative analysis. John Wiley and Sons,Inc., New York, pp.630.

Van Olphen, H. (1971) Amorphous clay materials. Science.171:91-92.

Veen, A.W.L., Slager, S. and Jongmans, A.G. (1971) A micromorphological study of four Pleistocene alluvial soils of Surinam (South America), Geoderma, 6: 81-100.

Wadia, D.N. (1981) Geology of India. Tata McGraw-Hill publishing Company Ltd. New Delhi. pp.508.

Walkley, A. and Black, I.A. (1934) An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37 : 29-38.

Wright, C.H. (1939) Soil Analysis. A Handbook of Physical and chemical Methods. Thomas Murby and Co.Flect Lane, London.

Yoshinaga, N. and Aomine, S.(1962) Allophane in some Andosols. Soil Sci. Plant Nutr. 8 : 6-13.

Zonn, S.V. (1971) Role of Al and Fe-Clay minerals in the diagnosis of recent crust and soil formation processes. Soviet Soil Sci. 36 : 718-725.

* Original not seen.