STUDIES ON FEW ASPECTS OF GENESIS AND MINERALOGY OF SOILS IN RELATION TO THE VARIED CLIMATIC ZONES OF MAHARASHTRA

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CANDIDATE'S DECLARATION

I hereby declare that thesis or part thereof has not been submitted by me to any other University or Institution for a degree or diploma.

PARBHANI

DATED: 25th Dec.,1981.

(S.A. GAFFAR)

CERTIFICATE

This is to certify that the dissertation entitled " STUDIES ON FEW ASPECTS OF GENESIS AND MINERALOGY OF SOILS IN RELATION TO THE VARIED CLIMATIC ZONES OF MAHARASHTRA" submitted for the degree of Doctor of Philosophy in the subject of Soil Science, is a bonafide research work carried out by Mr. S.A. Gaffar under my supervision and that no part of this dissertation has been submitted for any other degree.

(Dr. S.B. Varade)
Research Guide

PARBHANI

DATED: 23rd DEC.1981

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CONTENTS

1. INTRODUCTION

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Basically, soil is a medium for plant growth hence our understanding about the soil evolution, genesis, composition and constituents are of prime importance so as to decide its efficient use for boosting agricultural production.

Dokuchaev, the founder of modern pedology, was the first to recognize the fact that soil is an independent dynamic body that acquires properties in accordance with the forces which act upon it. He was the first to see the general picture of soil formation as consisting of the operation of a number of factors on a geological parent material. Jenny (1941) has contributed materially to the understanding of the effects of individual as well as of a combination of the different soil forming factors on the development of soils. According to him, any soil property is a function of the combined action of the five soil forming factors viz. climate, parent material, relief, organisms (including vegetation), and time.

All these factors possess equal status in the actual process of soil formation, still their relative importance can only be differentiated on the basis of their zone of operation. The most important amongst them are the climate and parent material. The parent material may be looked upon as the reactant material representing the initial stage in soil development which under the stress of the components of climate yields the resultant clay complex of the soil. Parent material being a function of time, changes with time in the

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process of weathering. Hence ultimately soil is more directly a function of climate. The clay being the resultant product of this reaction in time, will largely reflect the soil climate relationship in its mineralogical composition.

Studies on the genesis of Indian soils received attention in early forties. Wadia et al. (1934) and Vishwanath (1938) were few of the early workers in the field to give a broad generalised idea of the evolution of soils in this country. Later, the role of the genetic factors, parent material (Tamhane and Namjoshi,1959), climate (Tamhane and Karale, 1967) and of topography (Gawande et al., 1968) have been elucidated to a certain extent in the genesis of the soils. Due to extreme variation in meteorological parameters including uneven distribution of rainfall, factors of soil formation ~~are~~ widely differ~~ed~~ from region to region. Geology is the dominant factor at one situation in soil formation while climate at another situation (Tamhane, 1956). Quite a large number of studies have been made by Indian scientists to study the role of parent material in soil formation. The studies on the role of climate, on the other hand, have received comparatively less attention.

Basu and his co-workers (1938) were the first to adopt genetic approach to the study of soils through extensive soil surveys carried out by them in the Deccan Canal Tracts of Maharashtra state. Tamhane and Karale (1967), during the rapid reconnaissance survey of Nasik, Satara, Poona and

Kolhapur districts in Deccan area of Maharashtra State, observed that several distinct soils occurred on basalt rock. More common formations were black soils (grumusols), brown soils (Krasnozem), and lateritic soils (Latosols). They further emphasized the significant role of precipitation and its intensity from region to region. Few attempts were made on the fertility aspects and clay mineralogical make-up of black soils of Maharashtra (Maniyar et al., 1979; Malewar and Randhawa, 1978).

However, comprehensive studies on genesis, mineralogy of Maharashtra soils under varied agroclimatic conditions is still lacking. In order to bridge the gap in the ~~soils~~ of research on Maharashtra such projects are warrented to undertake a systematic and precise approach.

The basaltic rock is more or less uniform for most of the Maharashtra soils from which these soils are derived. However, soils formed under specific set of climate, topography get differed greatly though parent material remain same. Thus, a present research project was undertaken with the following objectives:

1) Qualitative and quantitative studies of clay minerals and their vertical variation in various soil profiles.
2) Sand mineralogy in relation to soil genesis.
3) Environmental chemistry and its significance in clay genesis.

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2. REVIEW OF LITERATURE

According to Jenny (1941), any soil property is a function of the combined action of the five soil forming factors viz. climate, organisms (including vegetation), relief, parent material and time.

Although, the importance of these five soil forming factors is now universally accepted, there is no complete agreement on their relative importance. Therefore, a pertinent review is presented under the following subheads:

1) Relationship of clay mineralogy of soils with parent material.
2) Relationship of clay mineralogy of soils with climate and time.
3) Relationship of clay mineralogy of soils with topography/drainage.
4) Mineralogy of sand fraction.
5) Distribution of clay minerals in Indian soils.

2.1 Relationship of clay mineralogy of soils with parent material:

The effect of the parent material has long been recognized in the formation of soil. The composition and texture of the parent rock are important in initial stages of weathering, but their importance decreases as the duration of weathering increases. Under conditions of drastic alteration due to humid environment, as in the development of podsolic and lateritic soils, the influence of parent rock is relatively short lived, whereas, in aridic zone it prevails almost indefinitely. Several types of soils are not expected to occur when climate alone is taken into consideration. Existence of such diverse soil types in close proximity could be attributed to the difference in parent material.

Inheritance is of particular importance with sedimentary rocks and unconsolidated deposits. In a study of soil profiles developed from sedimentary rocks (Southard and Miller,1966), there was a close association between parent material and kind of clay in the parent material and in the soil. The data lend strong support to the inheritance hypothesis and indicate a subordinate role of climate in the formation of soil clays. The soils of North India formed on alluvium have predominance of illitic mineral partly inherited probably from micas which were predominant in the sand and silt fractions of these soils (Mitra, 1959; Kanwar, 1959 and Sehgal, 1972).

The influence of soil parent material on morphological, physical, chemical and physico-chemical characteristics has been noted by different workers from different parts of the world.

Joachim (1935) while studying Ceylon soils, concluded that acidic and basic nature of the crystalline rocks of the island was responsible for the type of soil. Basic rocks generally gave rise to the soils having dark colour and fine texture than soils derived from acidic rocks.

Ramiah and Raghvendrachar (1936) observed that although the black and red soils occurring in Bellary district in close proximity were derived from granites and gneisses, the two types were associated with rocks containing minerals of different chemical composition. According to them, the black soils were formed from rocks containing sodalime feldspar whereas, rocks containing potashfeldspar gave rise to red soils.

Van der Marwe and Heystek (1952) reported the occurrence of laterites on dolomite; lateritic red earths on sandstone, shale, conglomorate, acid, basic and intermediate rocks; and ferrogenous lateritic soils on old red granites, sandstones, shales, quartizites, dolomites, acid and basic rocks.

Sanyasi Raju (1953) reported that the nature of parent rock is very important in the case of soils formed in situ. According to him the red soils of erstwhile Madras State were derived from haematite, quartzite, mica-schists, while the black soils were formed from hornblende and chlorite schists.

Tamhane and Sen (1954) showed that basalts, norites and metamorphosed Dharwarian rocks were the geological formations on which the black soils of South India have developed. According to them, non-basic rocks may give rise to red soils but a black soil was not likely to be derived from acidic rocks in the climatic conditions prevailing in India.

Laterites were found on a variety of parent rocks. They were common over basic igneous rocks as well as over acid rocks (Mohr and Van Baren, 1954).

MacEwan (1954) examined some single grains of Scottish soils derived from basic igneous parent material. When exposed to X-rays, a diagram similar to that of an "Oriented aggregate" of clay i.e. there was a definite indication of orientation with the montmorillonoid flakes parallel to the apparent cleavage. Each of the biotite grains is therefore, a polycrystalline aggregate of a montmorillonoidal material, showing a well marked preferential orientation. The most reasonable explanation of such a formation seemed to be that they were infact pseudomorphs after an original biotitic material.

Tamhane and Namjoshi (1959) observed that the black soils formed from different parent materials, having good amounts of calcium and magnesium, did not vary much under similar climatic conditions. The small change appearing only in the contents of silica, iron and alumina, both in soils and clay fractions are mainly due to the differences in the mineral make up of the parent rocks.

According to Van Eck and Engle (1964) montomorillonite occurred predominantly only in soils derived from calcareous materials, whereas, Kaolonite was an important constituent of sedimentary rocks.

Studies on both the acidic (granites) and basic rocks (basalts) in the same climatic conditions have shown the predominance of kaolinitic and illite in the former and of montmorillonite in the latter (Perfenova and Varilova,1965).

Jackson (1965) reported that the Quaternary clays have in part been inherited as minerals from rocks of the entire geologic column and in part formed pedogenically. Inherited micas have been depotassicated through leaching and thus have yielded a mixed mosaic of expansible layer silicates and mica remnants or cores. The valence charges of the layers have been lowered by weathering. Alumination (desilication) has transformed clays in actively leached soils, and has resulted in widely occurring (a) intergrade phyllosilicates, chloritic montmorillonite and vermiculite-and allophane (with mild alumination), (b) Kaolinite and halloysite (with an intermediate degree of aluminatiom-desilication), and (c) hydrous oxide clays such as gibbsite, geothite,and haematite (with intense desilication-laterization). In well drained soils, eluviation of silica and various basic cations (K,Na, Ca Mg and others) has taken place from the entire solumn in different degrees as a function of time during the Quaternary. Alluviation of colloidal minerals and Si, Mg and other ions into basins and analogous illuviation of them into B horizon or derivation of them from coarse basic rock or mineral grains, coupled with evaporative processes has produced pedogenic montmorillonite. A tactile replication mechanism for the formation of expansible layer silicates is proposed, starting with nucleation of the layers as (+) hydroxy sesquioxide units on (-) slicate surfaces followed by reaction of neutral $Si\ (OH)_4$ molecules with the nucleii to generate the phyllosilicate layers, effecting clay transformations in soil genesis during the Quaternary.

With decreasing alkali content and increasing hydration, Mackenzie (1965) reported the formation of dioctahedral vermiculite and smectite in the series containing muscovite, and that of trioctahedral smectite and vermiculite in the series containing phlogopite biotite.

Buol (1965) mentioned that the clay mineralogy in arid and semi-arid soils is probably controlled essentially by parent material.

The studies of Southard and Miller (1966) showed that Kaolinite predominates in soils formed from weathered calcareous conglomerates, whereas, montmorillonite predominates in soils derived from tuffs and tuffaceous sandstones; on limestone, the soils contained both the above minerals.

For any given rock under a set of climate, mineral formation depends on water circulation, which brings about modification of pH and ionic concentration and ultimately modifies the environment. The influence of the rock is decisive to the extent that it provides the elements for the formation of secondary minerals and amorphous components (Maignien, 1966).

Chrich (1967) observed that formation of different soil types of Yugoslavia is determined primarily by the content and composition of the insoluble residue in the limestones. Soil formation was observed to be rapid on dolomitic limestones, on which a friable weathering crust was formed.

Gupta (1968) demonstrated that alluvium of the Western and Central regions were predominantly composed of illite and chlorite and those of the Eastern regions were rich in montmorillonite. The differences may possibly be due to inheritance from the alluvium.

Karale _et al_. (1969) noted that the potential ability of the parent material, under low to medium rainfall, plays an important role in soil development. They further observed that such soils keep the imprint of the original parent rock in their characteristics.

According to Millot (1970), there are three possible origins for the clays: 1) they can be formed by inheritance from the parent rock (mechanical or detrital inheritance), 2) they can be the product of evolution through a more or less strong transformation of those inherited clays (mineral transformation or alteration), or 3) they can be formed by synthesis from products of hydrolysis (neosynthesis or neoformation).

McKeague and Brydon (1970) examined the mineralogical properties of ten reddish brown soils from Atlantic provinces in relation to parent materials and pedogenesis. Mica was apparently partly altered to montmorillonite and chlorite was weathered out of the clay of podzol Ae horizons, but chlorite remained and only slightly alteration of mica to vermiculite occurred in Lurisol (Alfisols) Ae horizons. The apparent weathering of clays in the Gleysolic (Aqualf and Aquept) Ae horizons varied in one, the clay mineralogy was like that of Podzol Ae, but in another little weathering was evident. Thus, in general but not in all instances, clay mineralogy was related to the classification of the soils based on morphological, physical and chemical data. Both the sand and clay mineralogy indicated some differences in parent materials, and some relationships of the soil materials with the underlying bed rock.

Satyanarayana et al. (1972) registered the influence of parent material on the clay mineralogical make up of soils developed on different sources of alluvium.

Satyanarayana et al. (1972) studied profiles from various alluvial soil regions under varying rainfall conditions and concluded that, in general, parent material has influenced the clay minerals.

Bhargava et al. (1973) attributed that alluvial soils of Thungabhadra catchment owe their origin to widely varying geological parent material.

Attar and Jackson (1973) reported that calcareous soils of Nile river alluvium of the U.A.R. and Republic of Sudan contained montmorillonite as a dominant clay mineral with moderate contents of mica, vermiculite, chlorite and kaolinite. Regularly and irregularly mixed layer phyllosilicates were abundant. A conspicuous amount of hydroxyl (Al, Fe) coatings occurred on the montmorillonite layer surfaces. Weathering of basic volcanic rocks underlying sundstone and granite appear to have dominated the mineralogical composition of the alluvium detrital minerals. Wind carried from deserts appear to have added mica, vermiculite, and quarts to the soils.

2.2 Relationship of clay mineralogy of soils with climate and time :

Out of the five factors of soil formation, climate is considered to be the most important in the development of soils. So much so, soil is considered the mirror of climate. Climate influences soil formation largely through rainfall and temperature. Precipitation governs the moisture regime of the soil and determines the character and extent of leaching to which a soil is subjected. It also affects the profile development through erosion. Temperature effects the rate of chemical reaction, organic matter decomposition,microbial activity and finally the efficiency of rainfall through evapotranspiration phenomenon.

The formation of different types of clay and development of many other properties in soils are the reflections of the variation in rainfall and temperature for a considerable period of time. Climate ultimately determines the types and rates of weathering and its redistribution processes. Climate also exhibits its influence by its control on organic matter.

Alluvial soils of Delhi, U.P., Bihar, West Bengal and Assam are in general characterised by the dominance of illite and chlorite in the clay fraction and kaolinite is increasingly manifested as the zone becomes more humid (Bagchi, 1951; Das, 1956; Gupta, 1968; Prasad _et al._, 1969; Ghosh and Datta,1972; Datta and Das, 1972).

Since weathering processes are relatively slow, time is a significant factor in the development of alteration products. In the initial stages of weathering of some rocks alkalies and alkaline earth may be present in the weathering zone, and as a consequence a certain kind of alteration product will develop. After a long time interval all the alkalies may have been removed by leaching and a different type of alteration product will form.

Bryan and Teakle (1949) reported that the soils were initially developed under the earlier wetter climate and as a result of pedogenic inertia, they have persisted inspite of long period of lower rainfall under which the associated black soils were formed.

Vander Voort (1950) opined that true laterite soils occurred only on old geologic formations and were probably formed under paleoclimatic conditions.

Under similar parent material and present day climate, Teakle (1952) found five groups of soils in close association, each soil group having its own characteristic features different from the other. He concluded that different soil groups had formed during different climate era, each soil type retaining its typical characteristics acquired during that era. It is suggested that factors other than the present climatic conditions, such as time factor in the form of past climatic era and the influence of geological erosion, may be important in the genesis of many soil patterns. Similar view was also expressed by Costin (1955).

Under temperate conditions excessive leaching led to podzolisation, while in the tropics, due to the influence of temperature, it led to laterisation (Mohr and Van Baren, 1954).

McCaleb (1954) while studying Ontario soils found increase in clay content and acidity with increase in rainfall and most acid profiles tended to contain kaolinite.

Simonett and Bauleke (1963) found that tropical black earths occurred in catenary association with low humic latosols in the low rainfall areas (75 cm-90 cm in a year) with the high rainfall areas (250 cm) having humic latosols.

Cooper (1960) observed that higher soil temperatures and cycles of freezing and thawing and of wetting and drying promoted greater chemical and biotic weathering and were thus, major factors accounting for greater clay content in the B horizon.

According to Sivarajasingham et al. (1962) the rainfall pattern and dry spells in the tropics cause intense lateritic weathering.

Gerasimov (1962) stressed the importance of dry season for immobilization of soil colloids and formation of differential concretionary horizons at varying depths in the soil profile.

Murthy et al. (1962) and Sehgal (1970) attributed the formation of North Indian alluvial plains to the influence of climate at the first place, followed by topography, while Shankaranarayana and Hirekerur (1972) registered the cause of formation of these soils mainly due to the influence of climate.

The mineral stability normally differs with the fineness of mineral. Jackson et al. (1952) and Jackson (1964) observed that weathering of true mica proceeded through illite, intermediates, vermiculite, and montmorillonite. A given K interlayer rapidly depleted of K along a preferential weathering place which led to various combinations of interstratified X-amorphous and X-crystalline zones of typical illite,vermiculite and montmorillonite.

Van der Merwe and Heystek,H. (1955) studied the clay minerals of South African soils developed from dolerite under different climatic conditions, and found that illite-montmorillonite composite occurs at low rainfall and high temperature as well as high rainfall and low temperature, whereas the Kaolinites predominate at high rainfall and high temperature.

Dudal and Bramao (1965) observed that in all cases the dark clay soils have higher summer temperatures seldom lower than 20 °C and reaching as high as 35 °C or more in Mali and Central India. The mean annual rainfall is between 50 cm and 100 cm, with markedly seasonal rainfall distribution.

Tamhane and Karale (1967) have collected four representative soil profiles from Sheral, Paud, Malvali and Trimbak in Bombay Deccan developed over basaltic parent material under varied rainfall and studied their morphological, physical, chemical and mineralogical properties with a view to investigate their genesis. The variable factor climate in conjunction with topography has predominantly affected the genesis of soils. Distinct variations in such properties viz. soil reaction, content of silica and sesquioxides, base saturation, CEC and clay mineralogy were related to rainfall.

Kovda (1967) cited a typical example of ancient hydromorphic soil forming process, which was accompanied by active accumulation of a variety of secondary sediments from ground waters of different chemistry, with an extensive association (formation) of black humus montmorillonitic soils.

Ruxton (1968) felt that rainfall was more important than temperature in determining the rate of weathering.

Ahmed *et al*. (1968) observed that much of the clay sized mica in the solum of West Indian soil was derived from physical weathering of sand and silt-size fractions. In non-calcareous parent material of these soils, the authors found that with only a small amount of feldspars as sources of bases, weathering of mica resulted in synthesis of Kaolinite in high rainfall and good drainage condition.

Juang and Uehara (1968) identified a soil mica in soils of the wet uplands in the Hawaiian Islands. It contained 7.2 per cent potash and predominantly a layered mica with vermiculite, montmorillonite and chlorite. The mica is concentrated in the surface horizons and its concentration increased with soils formed under increasing rainfall and elevation. Biological recycling of potash was proposed as a mechanism for its formation.

Krishna Murti and Narayana (1968) reported the presence of montmorillonite in the highest rainfall zone of Western Rajasthan deserts and attpulgite in all other soils. This may suggest that montmorillonite was an alteration product of attopulgite under weak weathering conditions caused by the so-called high rainfall.

Datta and Adhikari (1969) studied the effect of weathering on clay mineralization and indicated the predominant presence of illite and chlorite in arid zones; montmorillonite in semi-arid zones with suitable calcium magnesium environment; illite and vermiculite in humid regions under alkaline earth ionic environments; and Kaolinite with traces of illite in humid regions with intense leaching. The highly acid soils contained illite under favourable potassium equilibrium.

Loughman (1969) in his study of chemical weathering of silicate minerals noticed that plagioclase yields Al-smectite or Al-Mg-Fe rich smectites which weather to Kaolinite and halloysite while K-feldspars alter to Kaolinite and halloysite which in-turn forms bauxite minerals.

Karale *et al*. (1969) studied the influence of climate and parent material and also relative merits of the two factors on the processes governing soil development. Two distinct groups of soils varying in morphology, physico-chemical and chemical properties were found to have developed from basaltic parent rocks under low to medium and high rainfall. 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 contents of the soils were found to be more related to parent material.

The climatic factors appear to be decisive in characterising the soils inspite of their influence on weathering reaction. However, potential ability of the parent material, particularly under the mild reaction processes, as under low to medium rainfall, plays an important role in soil development.

Karale *et al*. (1969) observed that two different types of soil groups were formed from basalts, black soils under low to medium rainfall and red soil under high rainfall.

In tropical climate with seasonal contrast, Paquet (1969) postulated that the ions taking no part in the formation of Kaolinite in the highlands were removed and tapped in low lands where they gave rise to montmorillonite type of clay minerals.

Ismail (1970) reported that the biotite fractions separated from a desert soil and a soil developed under humid conditions indicated that the weathering of biotite resulted in formation of vermiculite and montmorillonite under arid conditions. Oxidation of octahedral iron under neutral and alkaline conditions decreased the surface charge to produce expanded lattices of montmorillonite. Under acid conditions the oxidation of ferrous iron was balanced mainly by a decrease in the octahedral layer charge through the loss of iron and magnesium. Accordingly, the total surface charge remained high and vermiculite was the main product of weathering under this condition. These findings support the work on the artificial weathering of biotites.

Mukherjee et al. (1971) have noted that under sub-humid zone coupled with pronounced wet and dry seasons resulted in formation of montmorillonite as the dominant mineral along with varying amounts of illite, Kaolinite and interstratified minerals.

Gowaikar (1972) correlated climatic data like K-index (rainfall to evaporation ratio) with the process of laterisation in South Indian soils and found that though the degree of laterisation was greater with increase in rainfall, excessive rainfall retarted laterisation.

Sehgal (1972) while working on soils of Punjab, Haryana, and part of Himachal Pradesh reported that the clay mineralogical composition in different climatic regions suggests the transformation of illite to montmorillonite and vermiculite as one moves from the areas representing aridic through the ustic, to the udic soil moisture regime, elucidating the influence of climate as an important factor in the transformation of these minerals.

Datta _et al_. (1972) determined mineralogical composition of clay, silt and fine sand fractions of some Indian soils occurring under different climatic zones and suggested that weathering of orthoclase and plagioclase felspars was an important factor in the formation of clay minerals. Partial hydrolytic decomposition of felspars may lead to the formation of mica in the fine sand and also in silt with resultant illite or expanding lattice minerals in soil-clays, whereas under intense weathering conditions complete hydrolytic decomposition brings about the formation of Kaolinite in silt and clay.

Brinkman _et al_. (1973) studied the effect of seasonal wetting and drying on weathering of soils in acid zones and observed that free iron was reduced and partly leached; smectite and illite were decomposed; atleast a part of liberated Al, Mg and K were removed by leaching; Si was liberated from smectite and illite was reprecipitated as micro-crystalline quartz.

Lamourous *et al.* (1973) emphasized that clay minerals, especially illite were very sensitive to climatic variations.

Gurcharan Singh and Krishna Murti (1972) signified the effect of parent material (basic, igneous), climate (semi-arid to semi-humid) and alkaline environment rich in bases upon the nature of clay (dominant in smectite) in the soils of Malwa Plateau, Madhya Pradesh.

Biswas (1974) studied the effect of rainfall on morphological properties of soils developed in Ghod Catchment, Junnar Tahsil of Poona district. In this connection he made a reconnaissance survey in three rainfall zones viz., 1) 2780-5820 mm, 2) 730-850 mm and 3) 250 mm and representative soil profiles from each of the zones were examined. It was observed that the soils of zone 1 were very deep brown in colour and devoid of lime in contrast to the soils of other rainfall zones. The forest vegetation was also found to change in succession from evergreen type to thorny scrub as the rainfall decreases. The cropping pattern adopted in the high rainfall zone mainly paddy followed by some other minor crops and sorghum, bajra and groundnut in rest of the area.

Wilson (1975) reported that the inherent fertility of soils was largely determined by chemical weathering of the primary rock forming minerals. He further observed that nature of the process depends on the type of prevailing climate and pedogenic conditions. This was true particularly with micas and ferromagnesian type of minerals, where oxidation, acidity and drainage status all determines the final products.

Hetier _et_ _al_. (1977) while studying the formation of clay minerals in andosols under temperate climate, observed the existence of two principal phases of clay genesis,strongly connected to the evolution of organic matter in andosols, as follows: i) an early prepedologic phase during which halloysites and smectites would form, ii) a late phase giving rise especially to some Kaolinite and gibbsite.

Hermann Harder (1977) reported that the synthesis of clay minerals was dependent on the SiO_2 and metal content and the pH content of the solution. Smectite has been formed by the weathering of basic or acidic igneous rocks and also in sedimentary and metamorphic rocks. From basic rocks with a high content of magnesium, smectite mineral formation was possible under alkaline or neutral pH conditions. From acidic magmatic rock with a low content of Mg, smectite mineral formation was only possible under alkaline pH conditions which were produced by the K or Na content of freshly weathered feldspar. Iron can favour the new formation of Al-rich three layer minerals only under reducing conditions. In lateritic weathering profiles, the reducing conditions were sometimes present. During the run of a year in a tropical climate the conditions in the potentially clay mineral forming environments may change drastically. During the wet seasons the silica contents were mostly very slow, and clay mineral formation is possibly below water table. It seems that three layer clay mineral formation in nature occurs in inorganic basic solutions, and Kaolinite formation in weakly acidic solutions aided by the presence of organic compounds.

Rangasamy _et al._ (1978) reported the relationship of geomorphic and climatic history and formation of the ferruginous soils, formed on the acidic Peninsular Gneiss of the Mysore Plateau. The profiles studied were on two different land systems. The soils of the older, fairly smooth landscape were composed of colluvium over truncated laterite profiles. These soils showed an accumulation of pedogenic haematite grains in the sand fraction and have considerable Kaolinite and amorphous ferri-aluminosilicate minerals in the clays. The soils of younger, rugged landscape have similar clay mineralogy but do not have haematite grains. The soils have been formed in an earlier, more humid climate than prevails today. The original laterite profiles were formed on a plane surface, and subsequent change in climate has led to change in the land forms and dissection.

Biswas _et al._ (1978) reported that the soils from high rainfall with strongly expressed dry season (Ratnagiri,Panhala) have preponderance of Kaolinite with small amounts of smectites. Soils from sub-humid to sub-arid with alternating wet and dry season (Bhindi, Saidapur, Parsodi, Kirkee, Rajputwadi) have dominance of smectites in their clay fractions.

2.3 Relationship of clay mineralogy with topography/drainage:

Topography determines whether or not there is active vertical movement of water through the weathering material. This is particularly significant in regions of relatively high rainfall in which low, flat areas may be saturated with water almost to the surface. Topography, by its control of the vertical movement of ground water, also influences the leaching processes. Thus, in low, flat areas with little movement of water through the soils, there would be relatively little leaching.

Topography also influences the rate of erosion at the surface, and hence the rate of removal of the products of weathering and the rate of which fresh parent material is brought close to the surface into the most active zone of alteration.

In India, investigations on soils with impeded conditions and/or salinity and alkalinity include those of Bagchi (1951), Kanwar (1961), Gupta (1961), Raychaudhuri et al. (1963), Rao (1963), Sehgal (1970), Pande and Pathak (1972), Gawande and Biswas (1972). Most of these authors observed the presence of montmorillonite, but did not study the origin.

Milne (1935) gave the name catena for variations in soils intimately connected with topography. He defined catena as consisting of a group of soils within a particular soil region, which developed from similar parent material differing in the characteristics of their profiles because of the varying topographic and drainage conditions.

The formation of red and black soils developed from similar parent material and under the same climatic conditions was attributed to the differential drainage conditions resulting from the difference in topography in various part of the country (Desai, 1942; Sen, 1939; Mukherjee and Agrawal, 1943; Narayana, 1959 and Biswas *et al*., 1966).

In the opinion of Allen (1952), the formation of a specific mineral was promoted by the condition of drainage and leaching, pH and chemical reactivity of the environment.

The influence of topography in the formation of diverse soil types was also clearly brought out by Menchikovasky (1932) in Palestine; Morrison (1935) in Sudan; Mohr and Van Baren (1954) in Indonesia; Nye (1954) in Africa; Goss and Allen (1968) in Texas. The differences in physico-chemical and mineralogical properties of these soils were assigned to the topography.

Jungerius and Levelt (1964) analysed the soils of three types as well drained, imperfectly drained, and poorly drained of Anambra-Do rivers for colour, pH, minerals and CEC. Kaolinite was dominant in all the soils and showed no evidence of disintegration, Montmorillonite, polygorskite, illite and to some extent quartz tend to disappear from better drained soils. Small amounts of gibbsite and a chlorite-like mineral were formed in some well drained soils.

Gawande and Biswas (1967) studied the genesis of Catenary soils on sedimentary formation in Chattisgarh basin of M.P. and reported that the soils and their clay fractions of the upland show sesquioxidic character and the soils become progressively siliceous down the slope. The eluviation of the mobile constituents was dominant in the soils of the upland and this process is slowed down the slope as the drainage becomes poorer. The low silica-sesquioxide and silica-alumina ratio and high free oxide of iron in the clay fractions exhibit highly weathered character of the upland soils. The molar ratio follow the similar course in the hydrological cycle across the two ends of drainage scale. Red earth soil showed evidence of laterization, whereas black soil, the calcification process. Thus, the marked effect of drainage was well reflected in chemical composition of the soils and their clay fractions.

Gawande <u>et al</u>. (1968) reported that gradual decrease in the preponderance of illite with concurrent increase in montmorillonite was the typical mineralogical property of the clays of the soils in toposequence. Illite with the 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 soils of the lower slope. Illite in the upland soil was mostly degraded.

Sehgal (1970) studied a soil catena in the warm and perhumid zones of Himachal Pradesh and observed that paddy soils in the valleys showed the presence of expanding minerals besides illite which was dominant. No such trend was noticed in the soils of the plateau and on slopes, which were rich in illite, chlorite, chloritized integrade and Kaolinite.

Four soil groups of sedimentary formation across the complete drainage scale have been studied (Gawande and Biswas, 1974). It has been shown that within the profiles, the pattern of distribution of clay minerals was more or less uniform. The differences in the mineralogical make-up (illite in well drained, degraded illite in uplands with excessive drainage and montmorillonite in low land positions having poor drainage) have been related to the differences in the drainage conditions irrespective of the parent material.

Govindarajan and Godse (1973) observed that the effect of climate may be profoundly modified by micro-relief of an area giving rise to various groups of soils developed on the same parent material.

Digar et al. (1974) while studying soils of Birbhum District of West Bengal identified three soil series in the three distinct toposequence from the forest upland to the lowest bottom land which also have distinct geomorphic sequence. Differences in the magnitude of the changes were brought out by their morphological, chemical and mineralogical studies.

Bhattacharjee et al. (1974) studied shallow, medium, deep and very deep black soils occurring in catenary sequence in sub-humid part of Maharashtra State and observed that the significant pedogenic heterogenity in these soils was due to the influence of differential expansion and contraction of surface and sub surface layers as a result of changes in soil climate induced by topographic variation despite the uniform overhead climate. The shallow and medium black soils occurring on the crest and gentle slope of the catena expressed weakly discernible horizon differentiation in their profiles while their deep and very deep associates on nearly level to level valleys exhibited dominance of cyclic processes in their profiles in different magnitudes impending the process of horizon differentiation in the profiles. In deep and very deep black soils, all the soil properties excepting the distribution of $CaCO_3$ were uniformly expressed along with depth while the profiles of shallow and medium black soils indicated that the trend of anistropism through depth.

Krishnamoorthy and Govinda Rajan (1974) studied the black and red soils developed in close proximity under similar conditions of climate under Rajolibunda Diversion Irrigation Scheme, Mahboobnagar District, Andhra Pradesh. The red soils occurred on the higher elements of topography was shallow, well drained, distinctly neutral, rich in potash, essentially Kaolinitic in clay mineral composition and had a par lower CEC and a lower SiO_2/R_2O_3 ratio of the clay fraction. Whereas, the black soil lying on the mid and lower elements of topography was deep, moderately drained, finer in texture, alkaline, calcareous, essentially montmorillonitic and was associated with a comparatively more basic make-up of mineral suite.

Roy and Pal (1974) studied three lateritic soil profiles situated in the upland, midland and in the valley in Bankura district of West Bengal. Their characteristics have been dominantly influenced by topographic situation. Illite was the dominant clay mineral in the soil. Some chlorite also appeared particularly in the low lying profile.

Roy and Rudra (1974) studied the pedological characteristics of three lateritic soils of Midnapore, West Bengal along a gentle slope. The soils were yellowish brown to olive brown in colour, sandy loam in uplands and loam in the bottom land, clay content and CEC increases with depth in all cases. The upland soils were more acidic (pH 4.45 to 5.25) than the bottom land (pH 6.1).

Gaikwad and Rao (1974) while studying the soils in relation to geological formations from Cumbum areas of Prakasam district of Andhra Pradesh observed that Cumbum area had sedimentary metamorphic rocks consisting mainly of phyllites and quartzite of Pre-Cambrian age and form upper part of Cuddapatis. The rise of Nallamallai in the West of Cumbum, caused the formation of localised synclines and anticlines. It was observed that 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 are deep, grey in colour, fine textured and had high ground water table. Moving away from the anticline, there was a gentle slope gradient and finally merge with level land while, in the case of synclines, slope gradient was abrupt and merge with level land. Other physical and chemical soil properties showed a pattern of catenary relationship indicating the dominant role of topography in the formation of these soils.

Roy _et al_. (1962) 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 have a distinct gradation with the toposequence. Clay content of the soils increased down the slope and so did the pH and cation exchange capacity. The fertility status increased from upland to low land paripassu with decrease in the intensity of drainage condition. The results thus, suggest the topography was the dominant factor in the development of the catenary sequence.

Gupta _et al_. (1973) have carried out a pedo-chemical study on the soils of lower Vidyan Plateau in Mirzapur District of Uttar Pradesh. Two catenas were selected for study. The first being developed on sand stone and the second on lime stone and shales. In each toposequence, soils were studied on uplands, terraces and low land positions and their detailed morphological, mechanical and chemical properties were determined to bring out the soil development and catenary relationships existing among the soils of the plateau. Soils

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assumed well defined catenary relationship and with decreasing drainage intensity down the slope exhibit 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. Silica content decreased while alumina, iron, calcium and magnesium increased in the toposequence order. Carbon nitrogen ratio of the soils occurring in the low lying areas was higher as compared to upland and terrace soils of both the toposequences. In general, soils of first catena were lighter in texture slightly acidic in reaction, richer in silica, poorer in sesquioxides, calcium and magnesium as compared to the soils of second catena developed on lime stone and shales.

Sehgal (1972) studied three soil profiles representing a toposequence developed under warm and per-humid climatic conditions in Himachal Pradesh. It was revealed that the soils on the uplands had attained a higher degree of weathering as indicated by red colour, deep textural 'B' horizon and low base saturation than those in the valleys where the soils had greyish colour and high base status. The soils on slopes had brown colour, shallow textural B horizon and relatively high base saturation.

Pundeer <u>et al</u>. (1974) studied soils developed on terrace I and the recent Flood- and meander plains of Sutlej in Central Punjab for their mineralogical characteristics and soil profile development. The soils at Kr-I (Udic HaplustalF) and NG-I sites (Udic Ustochrept) showed the presence of muscovite/illite, Kaolinite, vermiculite and montmorillonite

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in the decreasing order of abundance. The soils from the recent flood plain contained chlorite and calcite in addition. Muscovite/illite was the dominant mineral in all the studied soils. There was an increase of vermiculite and decrease of montmorillonite content from surface downwards in the soils of Sutlej terrace-I. Kaolinite did not show any definite trend. Sand/silt ratio as well as field observations indicated the presence of stratification in all the soils that were studied. However, it was not confirmed by the clay mineralogy. Decrease of montmorillonite and increase of vermiculite with depth indicated 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. A complete degradation of chlorite in the soils of the older geomorphic surface can not be ruled out.

Landey _et al_. (1974) also attributed the heterogenity of soils of Bor Command area to the effective changes in soil climate induced by differential geographic setting.

Tan _et al_. (1975) while working with andepts and oxisols of Indonesia and Costa Rica observed that in Indonesia and Corta Rica, Gibbsite formation was greater in mountains than in low land soils.

Pundeer _et al_. (1978) examined three soils developed on the Sutlej terrace and the Sutlej flood and meander plain in the Central Punjab for their mineralogy by X-ray diffraction technique. Quartz and muscovite were the dominant light minerals in the sand fractions. Biotite, tourmaline, garnet, Kyanite and sphene were the major heavy minerals. Illite, Kaolinite, Vermiculite, Smectite, metahalloysite, hydrobiotite and chlorite were the clay minerals present in the same order of abundance. The flood plain soils did not show any in situ mineral alterations. The terrace soils showed some systematic variations in the depth distribution of clay minerals. The influence of geomorphic surfaces and the Himalayan provenance in controlling the mineral composition of soils has been illustrated.

Murali *et al.* (1974) discussed the clay mineral distribution in two topose- quences of tropical soils of India. The clay fractions of the soils of two toposequences derived from gneissic rocks in Southern India consist chiefly of Kaolinite and amorphous ferrialuminositicetes. Considerable amounts of smectite were present in the clays of soils on the toeslopes.

2.4 Mineralogy of sand fractions:

Heavy mineral analysis of sand fractions of soil samples may be used to determine the maturity of soil profile development as well as the provenance of soils when parent rocks are not exposed.

Fermor (1925) observed that basaltic lavas of Bhusawal contained plagioclase feldspar (labradorite), enstatite,augite, iron ores (magnetite-ilmenite) and olivine.

Jeffries and White (1939) stated that mineral composition of very fine sand may be used as a means for soil classification because each soil profile appears to have some outstanding mineralogical characteristics. At present sand mineralogy has found place in many classification systems. In U.S. Soil Taxonomy (1975), mineralogy was considered at family and great soil group level.

Studies of heavy minerals have been used by soil scientists for knowing the origin of the parent material (Hardy and Raondriques, 1939; Swanson _et al_., 1952; Tedrow and Maclintock, 1953), for recognition of depositional differences in horizons of a profile (Carroll and Woof,1951; Carroll, 1953), as an index of weathering processes throughout the profile (Graham, 1953; Marel and Vander, 1949; Adam and Matelski, 1955) and as a guide in classification of soils (Cady, 1941; Jeffries and White, 1937, 1939, 1941).

The weathering sequence proposed by Pettijohn (1941) indicated that zircon is the most appropriate reference material for calculating mineral losses from chemical weathering.

Marshall (1940) outlined petrographic methods to confirm or establish the geological origin of soil based on assumption that certain resistant minerals remain constant during the soil development.

Matelski and Turk (1947) while examining fine sand fraction of some Michigan soils found that the B horizon was the result of various decomposition of a relatively high original content of opaque and ferromagnesian minerals.

In a sub-humid zone with pronounced wet and dry alternating. There was persistence of mica and feldspars in both silt and sand fractions (Datta and Adhikari, 1968; Krishnamurthy and Satyanarayana, 1969; Mukherjee et al.,1971).

Rankama and Sharma (1950) and Wild (1961) reported that weathering of heavy minerals was relatively slow by solutions, thereby these minerals may accumulate within the soil profile along with the iron oxide.

Ruhe (1956) used weathering ratios of both light and heavy minerals for indicating the intensity of weathering. Jaffries and co-workers (Marshall and Jaffries, 1946; Rolee and Jaffries, 1952) have outlined mineralogical methods in correlating the soil types with parent material and for study of maturity of soils.

Tamhane and Sen (1954) reported that 75 to 98 per cent of the heavy fraction of basaltic soils was accounted by augite and iron ores. They also confirmed the presence of small amount ($<$ 5 per cent) of acid minerals like tourmaline, zircon and garnet.

McAleese (1958) studied the basaltic soils of northern Ireland and reported the presence of pyroxenes, opaque minerals (magnetite), quartz, greenish yellow particles (pseudo aggregates) and traces of zeolites in the sand fractions.

Tamhane and Namjoshi (1959) reported the following minerals from basaltic soils of Ahmednagar-pyroxene,magnetite, ilmenite, zeolite, limonite, apatite and garnet.

Soils under strongly weathered and on relatively inert parent material showed little mineralogical differentiation (Cady, 1941).

Sahay _et al_. (1960) studied the soils developed on alluvium and observed that predominant colours in soils was a reflection of the mineralogy of the sand fractions. According to them white, reddish brown and yellow colours were associated with the presence of quartz, calcedony, feldspars, muscovite, biotite, hornblende and magnetite.

Simonett and Bauleke (1963) studied the soils on basalt in northern Queensland and reported the dominance of quartz and haematite with moderate amounts of magnetite and occasional rutile.

Sinha and Mandal (1963) and Thakur _et al_. (1969) observed that the alluvial soils of Bihar contained easily weatherable minerals in greater amounts than the sedentary soils.

Roonwal _et al_. (1967) observed that a deficiency of ferromagnesian minerals in alluvial soils of Hissar was due to its source from acidic rocks like gneisses and schists, while a higher percentage of silt and clay was probably the result of feldspar alteration.

Singer (1967) studied the mineralogy of non-clay fractions of basaltic soils in the Galilee, Israel and reported that silt and light mineral groups of fine sand fractions were composed entirely of quartz and plagioclase. Olivine pyroxene and opaques dominate the heavy mineral groups.

Tamhane and Karale (1967) stated that the sand fractions from basaltic soils of Bombay mainly consisted of augite, diopside and epidote with fair amounts of magnetite and traces of ilmenite, olivine and basaltic glass.

Carbett (1968) studied the mineralogy of sand fractions of basalt soils from New South Wales. He divided the minerals into a) those derived from basaltic rocks-feldspar, pyroxene, basaltic glass, olivine, brown hornblende, zeolite, calcite, feldspathoids, apatite, black opaque minerals, altered opaque minerals and titan biotite and (b) those minerals which were non-basaltic (with the exception of quartz) and increase with the age of the soil- quartz, zircon, rutile, tourmaline, epidote, monazite and garnet.

Gouri et al. (1970) studied the mineralogical composition of the coarse fractions of soils from different places of West Bengal. They observed that the high percentage of a group of heavy minerals (other than opaques) in certain localities such as Purulia was an indication of the fact that the soils of these localities are immature, near to rocky lands and colluvial in nature.

Das and Das (1970) reported that a striking relationship exists between the mineralogical composition of the clay fractions and that of the silt and fine sand fractions of some black and brown soils. The 2:1 expanding lattice minerals in clays developed under slow weathering process by hydrolysis of feldspars in alkaline environment or as a result of diagenetic change from chlorite and mica in the silt and sand fractions. Mechanism of the formation of illite was likely to be as orthoclase mica hydrous mica in the silt to illite in clay; Kaolinite resulted from complete hydrolysis of feldspars. The 14 Å chlorite like mineral was likely to be formed due to transformation of minerals in the parent materials consisting of chlorite schists to expanding lattice minerals and its subsequent interlaying with aluminium.

Singh and Gangwar (1971) studied the rock fragments and fine sands of Mirzapur soils. They have reported that these soils were residual in character. The soils of upper Vindhyan system seemed to have developed on sedimentary rocks consisting of various types of sandstones, lime stones, siliceous shales etc. and one profile from most fertile region indicated its parentage to limestone and dolomitic limestone. But soils of lower Vindhyan system indicate their parentage to widely varied types of metamorphic, sedimentary, and igneous rocks. The mineralogical composition of the fine sands indicated that quartz represents the major fraction of the fine sands in most of the soils.

Mukherjee _et al_. (1971) reported dominance of quartz, mica and feldspars in silt fraction of Lakhimpur soils in Brahmaputra valley.

Satyanarayana *et al.* (1972) examined fine sand fraction from M.P., Rajasthan, Punjab, Delhi and Gujarat soils and observed that the light fractions of these sands were dominant in quartz and feldspars. Excepting one profile each in Rajasthan, Gujarat and Delhi, the resistant mineral zircon was in traces and the mica minerals were predominant. In these three profiles high amounts of hornblende and chlorite were observed.

Sultan Singh *et al.* (1972) studied six representative profiles of Hissar and observed that the mineralogy of the sand fraction in all profiles showed quartz, feldspars and muscovite as light minerals and amphiboles, biotite, chlorite, epidote, tourmaline, zircon, garnet, apatite, iron ores, sphene; Kyanite and staurolite as the heavy mineral assemblage (1.2 per cent of the total). Soil clays were dominantly composed of illite and chlorite minerals. However, clays and minerals seemed to be transported, rather than formed in situ. The source of minerals seemed to be mostly from granitic or granite gneissic terrain (Rajasthan) and sedimentary provenance (Siwaliks or Indo-Gangetic alluvium).

Gurcharan Singh and Krishna Murti (1972) studied the mineralogy of different fractions of a few basaltic soils of Malwa Plateau, M.P. and noted the presence of quartz,feldspars and augite in sand fractions, which indicated the contribution of basic minerals in soils under study.

Pundeer *et al.* (1974) investigated the sand fractions of 20 samples from five soil profiles (representing

Entisols and Inceptisols) located in the flood plain of Hoshiarpur district of Punjab. The profile did not show any major differences in the mineral types present. The presence of rounded garnet grains and quartz grains with growth structures, as well as the heavy mineral suite substantiate the assumption that the parent material of these soils have been derived from the reworked Siwalik formations.

Investigations on light and heavy minerals of medium black soils of Kota (Rajasthan) were undertaken to ascertain their provenance by Sharma and Kant (1977). They observed that the soils contained similar suites of light and heavy minerals as contained in local Vindhyan sedimentary rocks along with many other minerals of different rocks of igneous and metamorphic origin.

Maniyar _et al_. (1979) reported that the light minerals contributed 92.04 to 99.20 per cent of the primary minerals. Amongst all the light minerals identified from Parbhani soils, quartz was noticed in abundance, followed by feldspar, mica and calcite. Amongst all the heavy minerals identified, the iron ere constituted bulk followed by pyroxene, apatite, hornblende and chlorite. He concluded that the soils were formed from Deccan trap rock.

2.5 Distribution of various clay minerals in Indian soils:

Clay is the most active part of the mineral soil mass and is the seat of most chemical and physico-chemical reactions. Soil properties like swelling, plasticity, moisture retention and release, ion exchange etc. are dependent to a large extent on the nature and quantity of clay minerals. Clay mineral data have also been used in the genetic classification of soils. The contribution of our soil scientists to the knowledge of clay mineralogy of Indian soils is fairly sizable.

Bagchi (1951) reported predominance of Kaolinite with small amount of montmorillonite and quartz in Jorhat soils.

Das (1956) observed the dominance of illite and Kaolinite in Delhi soils.

Kanwar (1959) observed that dominant clay minerals of Punjab alluvium soils were chlorite and illite.

Kanwar (1961) observed the dominant clay mineral illite with chlorite in four saline alkali and one saline soils of Punjab. Further, he reported that there was not much difference in the clay mineral composition of saline alkali and normal soils of the same tract, which was taken to be an evidence of the fact that as a result of salinization and alkalization, there did not occur much alteration in the clay mineralogy of the soil.

Occurrence of illite in alluvial soils has been reported by Murty _et al_. (1962).

Sinha and Mandal (1963) have observed that Kaolinite and hydrous mica constitute the major components of the clay fraction of Chhotanagpur soils.

An extensive range of interstratified chlorites has been discovered by Bhattacharya and Mitra (1963, 1964) in the sediment of Mid-Sewalik at Dholkhand.

The presence of 14 Å mineral interlayered with Fe and Al hydroxides (Chlorite like) in Chhotangpur soils have been reported by Ghosh and Das (1963).

Rao (1963) identified clay minerals present in 12 Indian soils by X-ray diffraction technique. Illite has been found to be an important constituent of all soil clays studied except two. Chlorite was also present in one sample from Jwalamukhi.

Das and Das (1966) studied the mineralogical make up of soil clays from black, brown and red soils of Mysore State by X-ray diffraction method and supplemented by chemical analysis. They have noted that the black and brown soils 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 constitutes the dominant fraction in red soil clays with less quantities of Kaolinite and expanding lattice minerals. A 2:1 lattice 14 Å chlorite mineral constitutes the characteristic feature in all soil clays.

Gupta (1968) reported that the alluvia of the Western and Central regions were predominantly composed of illite and chlorite minerals while those of Eastern region were richer in montmorillonite. Small amounts of vermiculite and significant amounts of quartz and feldspars have also been recorded in the coarse clay fraction specially in the Western and Central regions. The mineralogical variations of the alluvium in different regions were due to differences in soil forming materials arising out of different flood plains from where the alluvium was derived.

Prasad _et al._ (1969) reported that the chemical, X-ray, and D.T.A. of soil clays of Bihar indicated the dominance of Kaolinite with fair amounts of illite and small amounts of chlorite like minerals in sedentary soils of Bihar. The presence of montmorillonite was also indicated in the clays of Chaibasa, Putida and Giridih soils. Illite and Kaolinite constitute the main bulk of clay fractions of alluvial soils, possibly with some amounts of chlorite. In addition, Patna soil may also contained small amounts of montmorillonite.

Chatterjee and Gupta (1970) studied the clay mineralogical make up of the surface and sub-surface soils collected from nine different localities of Western Uttar Pradesh by X-ray diffraction and differential thermal analysis methods and supplemented by chemical analysis and surface area determination. The results clearly broughtout that the dominant clay mineral in these soils was illite with some chlorite. Traces of Kaolinite in some soils was also observed.

Sehgal and Coninck (1971) in detail survey comprising of 50 clay samples representing 30 profiles of Punjab indicated that all soils which hither to 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. It has been realised that for the precise appraisal of 7 Å^{o} and 14 Å^{o} peaks, the use of warm HCl and sodium citrate treatments was imperative in Punjab soils.

Mukherjee *et al.* (1971) reported Kaolinite (dominant) and degraded illite in clay fractions of Lakhimpur soils. Both of these soils have developed on Brahmaputra alluvium.

Sahu *et al.* (1972) studied the clay mineralogy of red, lateritic and black soils of Orissa and reported that the red soil constitute of Kaolinite followed by illite. The laterite soils contained both Kaolinite and illite-type clay minerals while black soils contained mainly montmorillonite with some amount of illite-type clay minerals.

Ghosh and Datta (1972) investigated clay minerals in the soils of West Bengal by X-ray diffraction. They observed that the brown hill soil of Kalimpong was dominated by illite together with chlorite, Kaolinite and quartz. The soils of Naxalbari and Alipurduar also contained illite as the dominant mineral, but they had as high as 25-40 per cent chloritic mineral. The red sandy soils of Gogra and Sriniketan were dominantly Kaolinitic with appreciable amount of illite. Clay from Sriniketan also contained some smectite. The red loamy soil from Gazal was characterised 60 per cent illite, some mixed layer and chloritic minerals and very small amount of Kaolinite. The lateritic soil of Midnapore was dominantly Kaolinitic, but it also contained small amount of illite, mixed layer minerals, chlorite, smectite and quartz. The alluvial soils from Kalyani and Dhatrigram were dominantly smectitic. Illite was next in abundance in both the clays. The alluvial soil of Dinhata was, however, illite-dominant with appreciable amount of chlorite, mixed layer mineral and Kaolinite. The deltaic alluvial soil from canning was characterised by dominance of illite, fairly high amount of smectite, some chlorite, mixed layer mineral and small amount of Kaolinite.

Yadav and Gupta (1972) analysed semi-arid soils of Western U.P. for clay mineralogical content. In Mathura, North of Bharatpur and Jaipur soils, they observed 25-35 per cent montmorillonite, 19-34 per cent illite, 19-26 per cent chlorite, 9-16 per cent Kaolinite, 9-11 per cent quartz and felspar and traces of allophane and colloidal silica in their clay fraction. Whereas, soils of Southern part of Bharatpur and Agra in tran-Yamuna area and Etawah, Aligarh and Meerut in the doab,contained 35-45 per cent montmorillonite, 26-31 per cent illite, 19-28 per cent chlorite minerals with 3-11 per cent quartz and felspar, 4-6 per cent allophane.

Ghosh et al. (1972) examined clay mineralogy of alluvial, red and lateritic soil profiles of West Bengal and observed that the alluvial soil profile from Mandauri revealed the dominance of smectite in association with illite, Kaolinite, little chlorite and small amount of mixed layer minerals. The content of smectite increased with the depth, whereas, illite and Kaolinite content decreased in the same direction. The red soil from Midnapore was dominantly Kaolinitic all through the profile. Kaolinite content was higher in the subsoil than in the surface soil. Illite, smectite, chlorite and mixed layer minerals were also present in the clay. Both the lateritic soil profiles, representing Bhulanpur and Manderboni series were similar in mineralogical make-up. Dominant mineral was Kaolinite, followed by illite and mixed layer minerals. Chloritic minerals and smectite were also present in small amounts. Bhulanpur series showed an increase in the Kaolinite content down the profile.

Lotse et al. (1972) have analysed for two red and the two black soils of India for their chemical and mineralogical composition. The red soils were formed from granites and gneisses under conditions of good drainage. The black soils were formed from micaceous schists, gneisses and basalts under conditions of poor drainage. Kaolinite was found to be the predominant clay mineral in the red soils, illite, quartz, felspar and in a few cases montmorillonite, vermiculite and chlorite also being present in small amounts. The silt and clay fraction of the black soils were montmorillonitic in character. Small amounts of Kaolinite, illite, chlorite, quartz and felspar were also present.

Jagan Nath and Das (1972) examined the mineralogical composition of soil clays of desert soils of Hanumangarh (Rajasthan) and reported that the mineralogical make-up of soil clays of all the four profiles studied was more or less similar. The soil clays mainly consist of chlorite, hydrous mica with small amount of Kaolinite and irregularly interstratified mineral of illite-chlorite and chlorite-illite type.

Gurcharan Singh and Krishna Murti (1972) studied the mineralogy of different fractions of a few basaltic soils of Malwa Plateau, M.P. and reported the presence of quartz,feldspars and augite in sand fractions confirming the basaltic parent material with smectite dominant both in the silt and clay fractions. The similarity in mineral composition in all these profiles revealed the same trend in the transformation and weathering sequence of minerals. The frequency distribution curves showed that the profiles were not well developed and the soils were young. It appeared that the parent material (basic, igneous), climate (semi-arid to semi-humid) and alkaline environment rich in bases have an outstanding effect upon the nature of the clay (dominant in smectite) in the soils investigated.

Sarkar and Raj (1973) examined black, alluvial, red and latosol soils from West Bengal and South India for clay mineral identification. The values obtained for silica/sesquioxides, cation exchange capacity, and the pattern of potentiometric titration curves indicated that the black soil was dominated by montmorillonite clay minerals, alluvial and red soils had variable admixture of montmorillonite, illite and Kaolinite. While Kaolinite tended to dominate in alluvial soil, there was comparatively high proportion of illite in red soil clays; Kaolinite dominated in clays of latosols having possible admixture with expanding lattice clay minerals in minor proportions.

Murali *et al.* (1974) reported the mineralogy of two red soil (Alfisol) profiles of Mysore State. Petrographic examination of the light fraction of the sands of the soil horizons and the parent materials showed the presence of quartz,feldspars, small amounts of biotite, and traces of muscovite. The heavy fraction consisted entirely of biotite, with very small amounts of magnetite. In addition the coarse sand fractions of the soil horizons alone contained considerable haematite in the heavy mineral separate. The detected clay minerals were considerable amount of Kaolinite, smectite and amorphous material with traces of quartz.

Govinda Rajan and Krishnamoorthy (1974) analysed red and black soils occurring in close physiographic association. For this purpose pairs of red and black soils located in close proximity under similar climate and topographical conditions were chosen from two areas in Andhra Pradesh. One pair of soil profiles was located in Krishna district, while three pairs were chosen in Guntur district falling under the Nagarjunsagar command area. The data on chemical composition of the clay fraction indicate that while montmorillonite is the preponderent mineral in black soil clay, it was high in the clays of adjoining red soils also, with illite and Kaolinite making only a minor proportion. The studies reveal 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.

Khangarot and Mehra (1974) while characterising alluvial soils of Udaipur Valley noticed that these soils have developed in alluvium derived from phyllites, biotite schists, limestones and quartzites. Alluvium depth was highly variable and was controlled by local bed rock. Texturally the soils were loam to clay loam and are generally calcareous throughout the profile, A layer of lime concretions occurred within a meter or so. Cation exchange capacity of total soil and clay contents vary from 14.9 to 25.5 me/100 g and 14.8 to 40.2 per cent, respectively. Silica sesquioxide ratios and X-ray diffraction data showed predominance of montmorillonitic clay minerals.

Gawande and Biswas (1974) concluded that pedochemical studies of black soils formed from basaltic material and occurring on a single slope in Amraoti district of Maharashtra, exhibit marked differences in their morphological, chemical and other related properties. CEC of the soils and clays were high. Montmorillonite was the dominant clay mineral of these types.

Chatterjee and Rathore (1974) studied the quantitative clay mineralogical make-up of four typical soil profiles of the black soils developed from the basalts in Madhya Pradesh by the combination of X-ray diffraction technique,differential thermal and thermogravimetric analysis, supplemented by chemical analysis, surface area determination and electron micrographs. The results showed that the soils were essentially dominant in montmorillonites with the presence of small amounts of Kaolinite and traces of illite. Electron micro-graphs corroborated the mineralogical make-up as estimated by other methods and revealed further that the Kaolinite present in these soils were in a very poorly crystalline state.

Gurcharan Singh and Krishna Murti (1975) while deriving chemical formulae for soil smectites, have observed the only mineral, smectite, in fine clay ($< 0.8 \mu$) fraction of basaltic soils of M.P., as evidence from X-ray diffraction analysis, cation exchange capacity and elemental analysis data.

Ghosh *et al*. (1976) confirmed the presence of smectite as a dominant mineral in Gangetic alluvial soils of West Bengal. Vermiculite was also detected in a sample. Except for two samples, chlorite was recorded as one of the constituent mineral in the clays.

Chatterjee and Dalal (1976) working on Bihar and West Bengal soils observed that different horizons of the same profile did not show any noticeable variation in their mineralogical composition. Soil clays from all the profiles contained illite as a prominent mineral but with varying amounts of Kaolinite, chlorite and quartz. Soils from Purulia and Midnapur of West Bengal also contained considerable amounts of iron oxides, probably goethite and/or haematite.

Chatterjee and Rathore (1976) while working on M.P. soils have noticed that all the soil clays were essentially dominant in smectite (60 to 78 per cent) and small quantities of illite (5 to 12 per cent). Further, they noted that all the soil profiles studied have almost similar clay mineral assemblage. Indore soil clays differed from the other three profiles in that the illite content decreased with depth.

Sharma and Kant (1977) investigated clay mineralogy of three profiles of black soils representing major textural differences in Kota district of Rajasthan by chemical, X-ray diffraction, and differential thermal analysis. Montmorillonite was the dominant mineral in clays of two profiles, while quartz predominates in the third profile. Other minerals identified were Kaolinite, illite, chlorite, calcite, feldspars and haematite. Clay mineralogy reflects the impact of parent material.

Malewar and Randhawa (1978) studied the shallow black, forest shallow, medium black and deep black soils of Marathwada. They observed that the montmorillonite was invariably the dominant clay mineral with the presence of moderate amount of Kaolinite and traces of illite in almost all soils.

Maniyar (1979) while working on Parbhani soils identified chlorite, montmorillonite, illite and Kaolinite by X-ray diffraction technique. He, further, concluded that there was no remarkable variation in the clay mineral assemblage of normal and salt affected soils.

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3. MATERIAL AND METHODS

3.1 Material:

Five representative soil profiles were exposed at Nankheda (Parbhani). Degaon (Solapur), Dharmabad (Nanded), Khopoli (Kolaba) and Dapoli (Ratnagiri) from the different agroclimatic zones of the state. The location from where profile samples were drawn are given in Map (Fig.1). The morphological features of five profiles are presented in Appendix I to V .

3.2 General description of the area:

3.2.1 Location:

Maharashtra, the third largest state in India, with a total geographical area of 307.7 lakh hectares, covering 26 districts, forms about one-tenth of the total area of the country (Department of Agriculture, M.S., 1976) and occupies a major portion of the Peninsular India. It is located between $16^{\circ}.04'$ - $22^{\circ}.01'$ N latitudes and 72° -06' -80°-10' E longitudes. The state is bounded by Gujarat and part of the Union Territory of Goa. Dadra and Nagar Haveli in the north west, Madhya Pradesh in the north and east, Andhra Pradesh in the south east and Karnataka and Union Territory of Goa in the south and the Arabian Sea forming the western border of the state. The land utilization pattern reveals about 60 per cent under cultivation including about 12 per cent under irrigation, 18 per cent under forest and remaining 22 per cent under miscellaneous land use.

3.2.2 Physiography, relief and drainage:

The chief element in the lithological complex of the region is basaltic plateau which has been configurated by diastrophic movement in the past and lateron by sub-aerial processes resulting in several microforms in the present terrain. The general elevation ranges from 300 to 1200 m above MSL. The western margin of the plateau, the relict of original surface subjected to erosional cycle is known as the Sahyadri range. The west of Sahyadri marks the highest elevation with peaks attaining the heights of 1650, 1567 and 1424 m above MSL near Kalsubai, Salher and Harischandragarh respectively. Sahyadri is a narrow crest zone of the divide with a width of 15 to 25 km.

The western part of Sahyadri drops abruptly giving rise to steep escarpments followed by low hillocks and subdued ridges with intervening valleys merging into the Arabian sea giving rise to a strip of rocky and rugged coast line in the west. Eastward, from Sahyadri crest zone, the landscape is characterised by inter-digitating elongated interfluvial ridges running eastward enclosing deep valley bottoms in between. The plateau surfaces running south east are flanked by number of mesas and buttes overlooking deep valleys with precipitous rectilineal escarpments. Further, the eastern part is characterised by flat block like interfluves gradually narrowing down and finally disappearing giving rise to broad alluvial plains covered with black soils.

However, in such a terrain occasional distant buttes interrupt the monotony of the vast stretch of the flood-plains. As such, this terrain of broad valley lies in between Ajanta and Mahadeva plateaus with eroded pediment followed by depositional piedmont merging to flood plains of the Godavari, Bhima and Krishna rivers. Tapti basin is an asymmetrical valley bounded by Satpuras and Ajanta ranges in the north and south respectively. The valley lies in the extreme northern part of the State. It has a gentle southern slope abruptly rising in the north in Satpura hills. The rocky and rugged topography of Satpura hill ranges with elevation ranging from 300 to 1200m above MSL limits the northern border of Maharashtra State.

The eastern part of the State is again marked by mesas, buttes and isolated plateau furrowed by the rivers viz. Wardha, Wainganga and Kanhan. This region marks the transition between the trappean and pre-cambrian landmass. The extreme eastern part of the State is covered by deep alluvium interrupted by isolated residual hillocks projecting over the valley floor. The dissected rolling topography covering the eastern part of Bhandara and Chandrapur districts is formed of subdued hillocks and ridges with intervening valleys.

The entire State is drained by three major river systems viz. Godavari, Krishna and Tapti. However, a small portion in north western corner is drained by the Narmada and north eastern corner by the Mahanadi river systems. More than half of the State is covered by Godavari basin, one fifth by the Tapti and remaining by the Krishna. With exception of the Narmada and Tapti rivers draining into the Arabian sea, rest of the rivers join the Bay of Bengal (Sing, 1971). In the Sahyadrian region the drainage network is fairly close having sub-parallel sub-dendritic type. On the tabular mesas, the drainage pattern is mostly radial whereas, along the escarpment it is mostly fine textured sub-parallel type. However, in the eastern alluvial plain or flood plain fine textured dendritic pattern is clearly visible.

3.2.3 Geology:

A major part of the State consists of plateau basalts (Deccan trap) of more or less uniform composition. The alluvial deposits in the flood plain are not older than the early pleistocene. The extensive basaltic sheet is of varied thickness which gradually decreases and ultimately disappears towards east, north-east, whereas, maximum thickness of more than 2000 m is observed in western margin of the Sahyadri crest zone. Laterisation of this rock is noticed in Ratnagiri district and western part of Kolhapur, Satara and Poona districts. In the eastern part of the State Wardha-Wainganga basin comes under rocks of older formations comprising granites, gneisses, etc., flanked by metamorphosed precambrian sedimentaries, Dharwarian schists with sporadic exposures of rocks of Gondwana system Cuddappahs and Vindhyans.

From the geochemical point of view, augite basalt, granites and gneisses contribute to the parent material.

In addition, sand stone, limestone and ferruginous quartzite encountered under Gondwana formations form important parent materials in the far eastern region of the State.

3.2.4 Climate:

The entire state broadly falls under tropical monsoonic climate having three distinct seasons viz., rainy season from June to October, winter from November to February and summer from March to May. The rainfall varies from50 to 500 cm, with the State average of about 100 cm distributed over 60 to 70 days. The rainy season is confined mostly to south west monsoon from June to October receiving about 80 per cent of the total annual precipitation. Normally, there occurs heavy rainfall immediately following the onset of monsoon with an interlude of dry spell and again it is followed by a second maximum in the month of September. In Vidarbha region the rains are largely confined to a six week period which includes about10 days in June and the whole of July. July in fact is the rainiest month in the whole of Maharashtra. However, in Vidarbha, September rains are dependable. In Poona, heavy rains occur approximately from June 25th to August, 8th, whereas in the semi-arid zone, the heaviest rainfall occurs in late September. Further east, in and around Solapur, maximum rainfall occurs in late September and early October resulting from the retreating south west monsoon. The eastern part of Vidarbha gets heavier rains and is more prolonged than in the western part and also it is distributed evenly more or less during the entire monsoon season. A few showers from retreating north east monsoon associated with cyclonic storms are also received in these parts during winter season in the months of January and February.

The isohyet map of the State shows wide variations in rainfall from humid to rain-shadow semi-arid climate. The area between 250 to 400 cm isohyets lying in the western part of the State indicating the high rainfall zone constitutes the wind-ward western flank of the Sahyadri range. This zone being close to the Arabian sea is under the influence of meritime climate experiencing more humidity with low range of diurnal as well as annual temperature fluctuation with mean summer temperature of 24 °C and the mean winter temperature of 20 °C. The eastern flank of Sahyadri range forming the leeward side shows rapid decrease in the precipitation from 70 to 50 cm in the central part of Maharashtra, accounting for 40 to 50 per cent coverage of the annual potential evapotranspiration. It is,therefore, a drought prone area exposed to the risk of practising normal crop husbandry. The mean summer and mean winter temperatures of this part are 29° and 22 °C, respectively.

The moderate rainfall zone with the isohyets ranging from 100 to 150 cm lies in the central and eastern parts of the State showing wide diurnal fluctuations of temperature and humidity. It experiences mild winter temperature around

20 °C rising to 32 °C during dry summer period causing sub-humid climate. Besides, the most extensive area is found between isohyets of 100-75 cm in north central part experiencing high temperature associated with low humidity, thus making it sub-humid to semi-arid.

In view of the above, the coastal areas and the south central parts of the State qualify for isohyperthermic soil temperature regime whereas, the rest of the State remains hyperthermic.

3.2.5 Natural vegetation:

About one fifth of the total area is covered by forests. Despite high rainfall and suitable edaphic conditions, many parts of the state do not support forest due to unfavourable soil conditions, rugged terrain, etc. However, the far eastern part of the State supports good forest cover due to good supply of moisture and it accounts for more than 60 per cent of the total forest area of the State.

According to ecological conditions the forest types of the State may be classified as follows:

i) Tropical wet evergreen forests in heavy rainfall areas (400 cm) on the western margin of the Sahyadri crest zone.

ii) Tropical wet evergreen grading to tropical semi-evergreen eastward from Sahyadri crest zone to Maval.

iii) Further eastward grading to Tropical moist deciduous which covers areas receiving 125 cm including eastern slopes of Sahyadri, Chandrapur, etc.

iv) Tropical moist deciduous grading to tropical dry deciduous forests with generally teak-bearing forests that are found in Ajanta-Aurangabad area.

v) Tropical dry deciduous forest grading to biotic forests of tropical thorny and dry Sevanah forest in drier central and south central parts.

The state of Maharashtra has been divided into six agroclimatic zones.

Zone I- includes coastal districts of Ratnagiri, Kolaba and Thana and extreme Western parts of Nasik, Poona, Sangli and Kolhapur. It is heavy rainfall zone having 205-355 cm of rain per annum.

Zone II - is transitional, having 190.5 cm of rain in the western parts and 101 cm in the Eastern parts. It comprises western parts of Kolhapur, Sangli, Satara, Poona, Ahmednagar and Nasik districts. It receives maximum rain in July.

Zone III - is arid or semi-arid zone, which covers greater part of Maharashtra and scarcity tracts of Dhulia, Nasik, Ahmednagar, Poona, Sangli and Satara districts and western talukas of Solapur. It receives 50-65 cm of rain or even less.

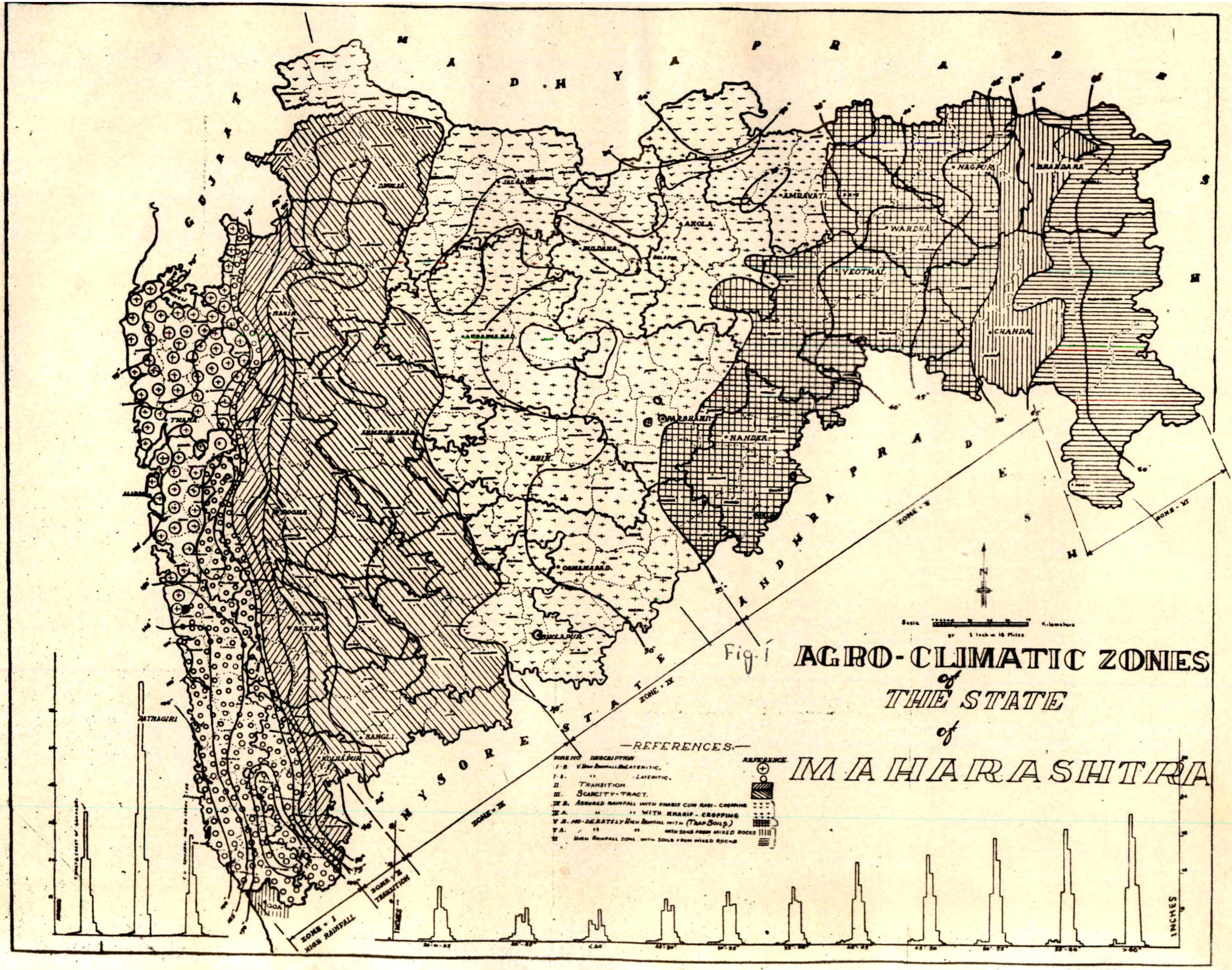

Fig. 1

AGRO-CLIMATIC ZONES of THE STATE of MAHARASHTRA

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Zone IV - has moderate rainfall. It receives 63 cm in its western part and 88 cm in the eastern part.

Zone V- is of moderately high rainfall of 88-140 cm. It covers the whole of Nanded, Parbhani and Osmanabad district and parts of Amravati, Yeotmal, Akola. The whole of Wardha and Nagpur districts and the western parts of Bhandara and Chandrapur districts.

Zone VI - has high rainfall of 140-150 cm and still more towards its eastern region.

3.3 Methods:

3.3.1 Soil analysis:

The profile sites have been examined according to the standard methods described in the Soil Survey Manual (1966). The soil samples thus, collected were thoroughly air dried and ground in a wooden pestle and mortar and passed through 2 mm sieve for physico-chemical analysis. The soil samples were characterised by their colour. pH, mechanical composition, organic matter, calcium carbonate, cation exchange capacity and free iron oxide.

3.3.2 Colour:

The colour of the soils was characterised by Munsell soil colour chart.

3.3.3 pH:

This was measured in soil water (1:2.5) suspension using glass electrode pH meter.

3.3.4 Electrical conductivity:

Electrical conductivity of the saturation extract (1:2.5 soil water suspension) was measured with Solubridge conductivity meter.

3.3.5 Organic carbon:

It was estimated by Walkley and Black's rapid titration method as described by Piper (1950).

3.3.6 Calcium carbonate:

Calcium carbonate was determined by dissolving it in 1 N NaOH, the excess of which is back titrated using standard H_2SO_4 (Piper, 1950).

3.3.7 Mechanical analysis:

It was carried out according to the method outlined by Jackson (1956). The soil was freed of carbonates, organic matter and free iron oxides with N NaOAC (pH 5.0), H_2O_2 (30 per cent), and citrate bicarbonate dithionite treatment and colloidal alumina and silica by boiling with 2 per cent Na_2CO_3. The soil residue was then dispersed in Na_2CO_3(pH 9.5) solution (Jackson, 1969). The sand fraction (50μ) was separated by wet sieving. Fine sand (0.10-0.25 mm) and very fine sand (0.05-0.10 mm) were separated by dry sieving. Silt (0.10-0.002 mm) and clay ($<$ 0.002 mm) were determined by International Pipette Method (Kilmer and Alexander, 1949).

3.3.8 Free iron oxides:

A suitable quantity of the soil was freed of carbonates and organic matter, using sodium acetate (pH 5.0) digestion and 30 per cent H_2O_2 treatment, respectively. The soil was heated at 80 °C with sodium citrate biocarbonate buffer. The free iron oxides were extracted with sodium dithionite (Mehra and Jackson, 1960). The iron content in the extract was determined colorimetrically with O-phenanthroline (Krishna Murti *et al*., 1970).

3.3.9 Cation exchange capacity:

Total cation exchange capacity was determined by leaching a weighed quantity of soil with neutral 1 N ammonium acetate solution and estimating the adsorbed ammonium by distillation with magnesium oxide powder (Piper, 1950).

3.3.10 Exchangeable calcium and magnesium:

A suitable quantity of ammonium acetate leachate was taken in a porcelain dish to which was added 5 ml of 10 per cent potassium hydroxide followed by 0.3 g of Murexide (ammonium purpurate). The amount of calcium was determined by titration with 0.1 N versenate solution to a purple end point. The calcium plus magnesium content was determined from a suitable aliquot of ammonium acetate leachate buffered with pH 10.0 NH_4Cl- NH_4OH, by versenate titration using Erichrome black-T indicator. Magnesium is determined by difference (Jackson, 1958).

3.3.11 Exchangeable sodium and potassium:

A fresh quantity of soil was taken and leached with neutral 1 N ammonium acetate. Sodium and potassium contents were determined with flame-photometer (Schollen-berger and Simon, 1945).

3.4 Total chemical analysis:

3.4.1 Sodium carbonate fusion analysis:

A known quantity of sample was taken in a platinum crucible, to which approximately 7-8 times of sodium carbonate was added, the contents were mixed thoroughly and completely fused. The fused material was dehydrated with perchloric acid and 6 N-HCl. Silica was separated by filtration and the filtrate was made up to a known volume for further elemental analysis (Jackson, 1958).

3.4.2 i) Silica: The residue on the filter paper was ignited and weighed as SiO_2 (Jackson, 1958).

ii) S-esquioxides: About 1 g of NH_4Cl was dissolved in a suitable aliquot of the filtrate and few drops of bromocresol purple indicator were added. The solution was warmed and S-esquioxide precipitated by adding ammonia. The solution was then filtered while still hot. The precipitate of sequioxide was dissolved in 6 N-HCl and re-precipitated with ammonia and filtered while still hot after washing with 0.5 per cent ammonium nitrate solution till free of chloride. The precipitate was placed in a weighed platinum crucible, oven dried at 105 °C and then charred carefully and finally ignited to a constant weight (Jackson, 1958).

3.4.3 Calcium and magnesium oxide:

The filtrate from above was evaporated and decolourised with 2 ml of bromine water and filtered. The filterate was then evaporated to dryness after adding 10 ml of HNO_3. The residue obtained was dissolved with 2 ml of 6 N-HCl and diluted to known volume. A suitable aliquot was taken in a porcelain dish and rest of the procedure followed was as discussed earlier in exchangeable calcium and magnesium (Jackson, 1958).

3.4.4 Potassium:

Total K_2O was determined from fusion extract by flame-photometer.

3.4.5 Aluminium:

Al_2O_3 was determined by substraction of total Fe_2O_3+ TiO_2 from sequioxides in case of soils, but in case of clays only total Fe_2O_3 was substracted.

3.4.6 Iron:

It was determined by using O-phenonthroline (Krishna Murti *et al.*, 1970). A suitable quantity of aliquot was pipetted into a 50 ml volumetric flask. Ten ml of NaOAC-AcOH buffer of pH 3.5 and 1 ml of 4 per cent thioglycollic acid were added.

The contents were mixed and 2 ml of 0.4 per cent O-phenanthroline was added and the volume was made up to the mark. The percentage transmission was measured at 515 μ . A standard curve in the range of 0.3 ppm of Fe and the concentrations of iron in the test solutions were read out directly from the standard curve.

3.4.7 Colorimetric methods of analysis:

Spectrophotometer, " Spectronic 20" was used.

3.4.8 Titanium:

This was determined by using Tiron (Mohrir *et al.*,1971). Five ml of 4 per cent Tiron was taken in a 50 ml volumetric flask to which was added 20 ml N-sodium acetate buffer of pH 5 followed by suitable quantity of aliquot (oxidized previously with a drop of H_2O_2). Then 1 ml of 40 per cent thioglycollic acid was added and the volume was made up to the mark. Percentage transmission was measured at 380 μ . A standard curve was prepared for 0 to 2 ppm of Ti and the concentration of Ti in the test solutions were read out directly from the standard curve.

3.4.9 Manganese:

It was determined by developing permanganate colour in a suitable aliquot of fusion extract as periodate method. The percentage transmission was measured at 530 μ. A standard curve was prepared and the concentrations of manganese were directly read out from the curve (Jackson, 1958).

3.5 Mineralogical analysis:

The soil samples were dispersed after pre-treatment and fractioned into various particle size ranges. The minerals in the clay fraction were identified by X-ray diffraction analysis. Quantitative mineralogical analysis of clays was carried out by the procedure of Alexiades and Jackson (1956). The sand fractions were analysed with petrological microscope.

3.5.1 Clay fraction:

The fractioned clay obtained from mechanical analysis was stored in NaCl medium. The concentration of clay suspension was determined by weighing a suitable volume of the clay suspension after potassium or ammonium saturation (Alexiades and Jackson, 1966).

3.5.2 X-ray diffraction analysis:

Soil clay fractions freed of amorphos materials (Hashimoto and Jackson, 1960) were used for X-ray diffraction analysis. For identifying clay minerals by X-ray diffraction, the specimens were prepared as described by Jackson (1969).

3.5.3 i) Magnesium saturated-glycerol solvated samples:

A suitable portion of well mixed clay suspension was taken in a 15 ml centrifuge tube. Saturation with magnesium was achieved by washings of the clay with N-$MgCl_2$. The excess salt was removed by successive washings with methanol. One washing with 10 per cent solution of glycerol in methanol was given to accomplish the solvation. The specimen was prepared with moist sample. Magnesium saturated and glycerol solvated clay samples were smeared on the slides and dried at normal room temperature.

ii) Potassium saturated- heated samples:

A suitable portion of the well mixed clay suspension was taken in the centrifuge tube, saturated with potassium by repeated washing with N KCl. The excess salt was removed by methanol washings. The K-clay thus, prepared was dried and powdered in an agate-mortar. The potassium saturated samples were smeared on glass slides in duplicate and dried at room temperature. One slide was exposed to heat in muffle furnace at 550 $^{\circ}$C temperature for four hours and then placed in a vaccum desiccator till it is placed in X-ray diffractometer.

3.5.4 X-ray diffraction:

Clay slides were exposed to the X-ray diffractometer and diffractograms were obtained using a Phillips-PW-1051 with Cu-X α radiation and 20 mA-30 Kv at the scanning speed of 2° per minute from 2° to $20^{\circ} 2\theta$

3.5.5 Interpretation:

The criteria for species differentiation concern only the most commonly found layer - silicates in soils (Warshaw and Roy, 1961).

X-ray diffraction spacings obtained from (001) planes of layer-silicate species:

Diffraction spacing (Å)	Mineral (or minerals) indicated
	Mg-saturated air dried
14-15	Montmorillonite,vermiculite,chlorite
9.9-10.1	Mica (illite), Halloysite
7.2-7.5	Metahalloysite
7.15	Kaolinite,chlorite (2nd-order maximum)
	Mg-saturated glycerol-solvated
17.7-18.0	Montmorillonite
14-15	Vermiculite,chlorite
10.8	Holloysite
9.9-10.1	Mica (illite)
7.2-7.5	Metahalloysite
7.15	Kaolinite, chlorite (2nd order maximum)
	K-saturated air dried
14-15	Chlorite, vermiculite (with interlayer aluminium)
12.4-12.8	Montmorillonite
9.9-10.1	Mica (illite),halloysite, vermiculite (contracted)
7.2-7.5	Metahalloysite
7.15	Kaolinite,chlorite (2nd - order maximum)
	K-saturated, heated (550 °C)
14	Chlorite
9.9-10.1	Mica, vermiculite (contracted), montmorillonite (contracted)
7.15	Chlorite (2nd order maximum)

3.5.6 Cation saturation of clay:

Suitable quantity of clay suspension is taken in a centrifuge tube and successively washed with neutral chloride salt solution of the required ion i.e. $CaCl_2$ for Ca-clay, KCl for K-clay, NH_4Cl for NH_4-clay. The excess salt is then removed by successive washings with water, methanol, methanol-acetone mixture and acetone till the washings are free of chloride. The clay thus, prepared gives mono-ionic clay.

3.5.7 Cation exchange capacity of clay fractions:

A suitable quantity of sample (amorphous free clay) is first saturated with Ca and the Ca in the sample is extracted with N - $MgCl_2$ of PH 7. Calcium content in the $MgCl_2$ solution is determined and the CEC (Ca/Mg) is calculated.

3.5.8 Selective dissolution analysis: (Hashimoto and Jackson, 1960):

The Na-clay (amorphous free) of about 1.0 g was NH_4-saturated as described earlier and weighed after heating at 110 °C.

3.5.9 Kaolinite plus halloysite:

A suitable quantity of amorphous free NH_4-clay was heated in a muffle furnace for four hours at 550 °C. The clay suspension [illegible] led [illegible] NaOH for exactly 2.5 minutes. It wa [illegible] e extract was analysed for Si [illegible] the residue as discussed

The Kaolinite plus halloysite content is calculated using the following equations.

a) If SiO_2/Al_2O_3 molar ratio 2.0,

$$\% \text{ KaOl.} + \text{Hly} = \frac{\% \text{ SiO}_2}{46.5.} \times 100$$

b) If SiO_2/Al_2O_3 molar ratio 3.0,

$$\% \text{ Kaol.} + \text{Hly} = \frac{\% \text{ Al}_2\text{O}_3}{39.5} \times 100$$

c) If SiO_2/Al_2O_3 molar ratio is between 2 and 3,

$$\% \text{ Kaol.} + \text{Hly.} = \frac{\frac{\% \text{ SiO}_2}{46.5} + \frac{\% \text{ Al}_2\text{O}_3}{39.5}}{2} \times 100$$

(Rangasamy *et al.* 1975; Murali *et al.*, 1978; Alexiader and Jackson, 1966).

3.5.10 Mica by HF-dissolution analysis:

A suitable quantity of NH_4 saturated amorphous free clay was dissolved with $HF-HClO_4$, extracted in dilute, HCl and diluted to suitable volume, K in the extract was determined by atomic absorption method (Jackson, 1958). The non-feldspar K was used to estimate mica as :

$$\% \text{ Mica} = \% \text{ K}_2\text{O (non-feldspar)} \times 10$$

3.5.11 Smectite and vermiculite:

Smectite and vermiculite were calculated (Alexiades and Jackson, 1966) from CEC (Ca/Mg) and CEC (K/NH_4) of amorphous free clay (Rangasamy *et al.*, 1975) as:

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$$\% \text{ Vermiculite} = \frac{\text{CEC (Ca/Mg)} - \text{CEC (K/NH}_4\text{)}}{1.54}$$

$$\% \text{ Smectite} = \frac{\text{CEC (K/NH}_4\text{)} - 5}{1.05}$$

3.5.12 Quartz, feldspar:

A suitable quantity of amorphous free NH_4- clay was subjected to sodium pyrosulphate SDA (Jackson, 1958). The residue was then fused with Na_2CO_3 and extracted in dilute HCl. Silica and Al were determined colorimetrically using Jackson (1958) and Krishnamurthy **et al.** (1974) methods, respectively. Since the quantity of K in the extract was small in most of the samples and could not be determined with the same precision as Al, the Al content was used to estimate the amount of feldspar in the samples. Quartz was determined as the difference between the residue weight and feldspar content.

3.6 Mineralogy of fine sand fractions:

The fine sand (0.10-0.25 mm) fractions obtained from the samples dispered for clay separation (Jackson, 1956) were further separated into heavy and light mineral fractions using bromoform (Sp.gr. 2.82) in a separating funnel. The samples were mounted on glass slides with canada balsam and the minerals were identified by examination under a petrological microscope.

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4. RESULTS AND DISCUSSION

4.1 Morphological features:

A detailed description of the morphological features is given in Appendix I to V.

4.1.1 Colour:

4.1.1.1 Profile I (Nankheda profile):

The colour of the soil in AP horizon is in hue of 10 YR with values of the solum ranging from 3 to 3.5 and chroma 2 to 3 both for dry and moist soils. The colour of the pedons varies from dark greyish brown at the top to greyish brown at the bottom of the solum, except A_{13} horizon whose colour is observed to be dark brown. Weathered parent material (IC) horizon contains strips of greenish bluish material, lime concretions and blue coloured rock pieces. IIC is the less weathered material and contains green coloured rock. IIIC horizon, which is above the water table, contains reddish colour rock (inside colour of the rock is black) and dark green coloured irregular spots with white patches on the comparatively less hard rock.

4.1.1.2 Profile II (Solapur profile):

These soils are also developed on basalt. They are light brown (7.5 YR 6/4) to dark brown (10 YR 3.5/2) in colour. The colour of the AO horizon is light brown (7.5 YR 6/4) and it changes to very dark grey brown (10 YR 3.5/2) in the A_{11} layer. The colour of the weathered parent material is very pale brown (10 YR 7/4). IIC horizon has greenish spots with white strips of lime. White coloured lime concretions in patches with iron strains are observed in III layer. The lowest horizon has grey coloured slightly weathered basalt.

4.1.1.3 Profile III (Dharmabad profile):

The colour of the soil in surface horizon is in hue of 5 YR with a value of 4 and chroma 6. It is yellowish red. The colour of the soil in B horizon is dark red and is in hue of 5 YR with the values ranging from 3 to 3.5 and chroma 3 to 4. First layer of the weathered parent material has greyish red colour with black spots. Subsequent layers of the weathered parent material have green and red coloured spots. The soils are formed on gniess rock which has dark green colour with shining white spots mixed with pinkish tinge.

4.1.1.4 Profile IV (Khopoli profile):

These soils are developed on basalt. The colour of the surface horizon is yellowish red (5 YR 4/6 moist) and that of A_{12} horizon is reddish brown (5 YR 4/3). Lowest horizon of solum has red colour (2.5 YR 4/6). Weathered parent material has three layers having grey colour. Below all is black basalt.

4.1.1.5 Profile V (Dapoli profile):

The colour of these soils ranged from yellowish red to dark reddish brown. The colour of the A and B horizons is in hue of 5 YR with a value of 4 to 3 and a chroma of 6 to 3 respectively. Weathered parent material is having dark red colour (2.5 YR 3/6).

The profiles of Nankheda and Solapur occur on gentle slope, whereas Dharmabad and Khopoli profiles on moderately steep to steep slope. The topography in case of Dapoli series is undulating to rolling.

4.1.2 Texture:

Description of the texture is given in Appendix I to V. There are wide variations in texture not only amongst the different profiles situated in different agro-climatic zones but also within the horizons of the same profile. The texture of the deep black soils of Nankheda profile varies from clayey at the top to clay loam down the depth at the bottom. Medium black soils of Solapur profile have clay loam to sandy loam texture. Soils of the zone of transition i.e. Dharmabad profile are sandy loam to sandy clay loam in texture. Khopoli and Dapoli soil profiles, which are located in high rainfall areas, have sandy loam texture in the surface horizons and clay loam texture in the sub-surface horizons.

4.1.3 Structure:

The detailed description of the structure is given in Appendix I-V. Since the soil profiles under study occur on a variety of climate with marked variation in rainfall, distinct variation has been observed in the structure of these soils both amongst and within the profiles. The deep black soils of Nankheda profile have strong sub-angular block at the surface to medium angular block structure at the sub-surface horizon. There is not much difference in the structure of soils of Solapur profile as their conditions of soil development did not vary much as compared to Nankheda conditions. However, the soil structure differ in Dharmabad profile which is medium granular at the top, weak fine crumb in the middle and medium sub-angular blocky at the bottom of the solum. Khopoli soils, which receive higher rainfall, have weak single grained structure in A_{11}; weak sub-angular blocky in A_{12}; and weak fine single structure in A_{13} horizon. Dapoli soils, which also receive higher precipitation, have medium single grained structure of A layer and medium coarse crumb structure of B horizon. Thus, it has been observed that climatic variations have markedly changed the structure of different soil profiles under investigation.

4.2 Particle size distribution:

The data is reported in Table 1.

4.2.1 Clay:

After seeing the results of mechanical analysis in Table 1, it can be concluded that clay content is higher in soil profiles receiving less rainfall (Nankheda and Solapur) as compared to profiles under high rainfall (Dapoli and Khopoli). Within the profiles of these two groups the change

Table 1: Mechanical composition and chemical properties of soils:

Location	Depth in cms	% clay	% silt	% Fine sand	% Coarse sand	% Free $CaCO_3$	% Org. Car.	pH	EC in mmhos/ cm at 25°C	CEC m.e./ 100 g of soil	W.S.+Exchangeable bases in m.e./100 g of soil			
											Ca	Mg	K	Na
Profile I	0-40	62.50	12.50	8.65	2.40	12.0	0.56	7.40	0.391	68.00	48.75	14.5	0.80	3.30
(Nankheda)	40-100	60.00	15.25	9.20	3.30	10.5	0.36	7.40	0.405	62.90	39.25	16.0	1.80	2.50
	100-170	40.00	27.50	11.90	10.25	12.5	0.28	7.35	0.440	48.60	31.00	12.5	0.55	3.34
	170-270	22.50	32.50	16.80	16.95	18.5	0.06	7.50	0.441	31.00	21.50	5.5	0.45	1.68
Profile II	0-15	51.00	14.00	8.50	4.50	19.250	0.52	7.35	0.314	57.00	39.25	12.5	0.85	2.20
(Solapur)	15-30	39.00	18.00	9.50	18.70	12.00	0.26	7.30	0.342	42.16	28.00	8.6	0.75	1.75
	30-50	32.50	17.50	13.10	18.60	16.75	0.14	7.40	0.360	37.55	19.75	9.9	0.80	3.80
	50-105	27.50	21.50	17.00	23.90	8.00	0.08	7.35	0.414	28.48	16.00	6.6	0.60	2.45
Profile III	0-15	33.75	17.50	29.30	16.20	0.5	0.86	6.80	0.258	42.50	18.50	2.97	14.55	0.90
(Dharmabad)	15-30	35.75	14.75	24.90	20.90	2.0	0.56	6.10	0.211	33.50	15.50	1.30	14.85	0.80
	30-90	37.50	12.50	22.55	22.00	3.5	0.12	6.35	0.270	24.60	5.25	4.64	13.20	0.85
	90-225	16.25	19.00	20.75	36.80	4.5	0.08	6.90	0.284	20.60	8.50	1.57	6.40	0.35
Profile IV	0-15	22.50	36.25	26.50	10.30	2.50	0.86	6.00	0.150	20.45	9.50	1.97	0.30	0.80
(Khopoli)	15-30	27.25	32.50	22.60	11.60	3.25	0.58	6.00	0.214	21.50	10.25	2.80	2.80	0.90
	30-100	31.00	30.75	22.50	11.70	1.85	0.26	6.10	0.342	23.62	14.85	3.00	3.55	0.55
	100-250	12.50	34.25	18.20	25.50	6.50	0.06	6.50	0.382	18.15	6.50	1.15	0.35	0.60
Profile V	0-37.5	29.90	38.00	18.85	8.90	0.00	0.92	5.80	0.137	21.50	8.50	2.64	0.50	nil
(Dapoli)	37.5-97.5	40.00	29.75	16.15	10.00	0.00	0.52	5.85	0.171	29.26	15.12	3.60	0.70	nil
	97.5+	30.00	19.00	9.90	37.90	0.00	0.14	6.20	0.242	23.45	11.75	2.15	0.40	nil

in content bears inverse relationship i.e. in high rainfall area profiles the clay content increases with depth, whereas, in low rainfall area profiles, it decreased with depth. Similar observations have been reported by Jenny (1941).

Accumulation of clay content in the sub-surface horizons has been observed in Dapoli, Khopoli and Dharmabad profiles. This may be due to eluviation of the fine material from the surface to sub-surface as these two profiles are located in high rainfall areas. In profiles receiving less rainfall, the clay content has decreased with depth. This may be due to insufficient downward moisture movement within the soil.

4.2.2 Silt:

The data in Table 1 indicate a very high content of silt in soil profiles (Dapoli and Khopoli) receiving high amount of precipitation as compared to Nankheda and Solapur profiles which falls under low rainfall area. An interesting observation noted is that the content of silt decreases with depth within the solum in profiles receiving higher amount of rainfall, whereas, just reverse is observed in Nankheda and Solapur profiles which receive low amount of rainfall. Silt seems to be accumulated in weathered parent material layer of Dharmabad and Khopoli profiles.

4.2.3 Sand:

The coarse and fine sand fractions of soils occur in lesser quantities under higher precipitation as compared to precipitation. Fine and coarse sand fractions at Nankheda and Solapur indicates an increasing trend with the depth. Same trend is also observed in rest of the profiles, but only in case of coarse sands whereas, just reverse is noted in these profiles as far as the fine sand fractions are concerned.

The decrease in clay content and increase of sand fractions indicates decreased weathering activity. Barshad (1964) has pointed out that relative amount of clay and non-clay fractions in each horizon of a soil profile gives an approximates evolution of soil development.

4.2.4 Free calcium carbonate:

The data regarding the free $CaCO_3$ content in Table 1 clearly brings out that medium and deep black soil profiles under low rainfall region (Solapur and Nankheda) contain appreciable amount of free $CaCO_3$ in almost all layers as compared to Dharmabad and Khopoli profiles, which have very little amount of this compound in the solum. However, some accumulation of free $CaCO_3$ is observed in the weathered parent material layer of these two profiles. Dapoli profile is free from calcium carbonate.

The differences in $CaCO_3$ content of the profiles are possibly due to the differences in the amount of annual precipitation under which these soils have developed. In Dharmabad and Khopoli soil profiles the amount of $CaCO_3$ is less and it is totally absent in Dapoli profile. This might again be attributed to the high amount of annual precipitation which induces heavy leaching. Under heavy rainfall it is likely that $CaCO_3$ is leached away.

Bear (1964) has reported that the black earths are high in $CaCO_3$. Waters rich in bicarbonates and other temporarily soluble ions accumulate over the hard layer of the parent material and when active evaporation proceeds, bicarbonates get precipitated as carbonates. The amount of this deposit will depend upon time status of original parent material and the depth at which it occurs will depend upon the effective rainfall. Basalts which are rich in bases play dominant role in the formation of these different soil series and thus, accounts for high carbonates in the soil profiles. Calcium carbonate up to 20 per cent was reported by Tamhane (1950), Kunze and Templin (1956) and Hosking (1935) in soils developed from basalts in India, Africa and Australia respectively.

4.3 Chemical constituents:

The data are reported in Table 1.

4.3.1 Organic carbon:

The organic carbon occurs in larger quantity in soils of high rainfall zone and while it is low in soil receiving less precipitation. The higher amount of organic carbon in the humid region is due to more vegetation. Such relationships for Indian conditions have been reported by Jenny and Raychaudhuri (1960) and Pathey and Kibe (1971).

It is observed from the Table 1 that organic carbon content decreases with depth in all the profiles. The amount of organic carbon was low in sub-surface layers of almost all the soil profiles. Similar results have been reported by Basu and Sirur (1938), Desai (1942), Raychaudhuri et al.(1943), Roy and Das (1952), Roy and Borde (1962), Tamhane and Karale (1967) and Gurcharansingh and Krishnamurti (1972).

4.3.2 Soil reaction (pH):

The pH values decrease with increase in intensity of rainfall (Godse, 1957; Jenny and Raychaudhuri, 1960; Pathe and Kibe, 1971 and Bidappa and Rao, 1973). In regions of high rainfall to which Khopoli and Dapoli belongs, acid reaction has been noted, because these are subjected to heavy leaching which removed bases to a larger extent, with the result they indicate acid reaction.

In the areas of low rainfall to which Solapur and Parbhani profiles belong, on the other hand, the precipitation is not high enough to cause leaching of bases and consequently the reaction of these profiles is alkaline. Similar results have been reported by Gurcharansingh and Krishnamurti (1972).

The nature of variation in pH values of the soils developed on basalt, indicates the extent of leaching, the soils have undergone. When the profile has undergone a mild leaching, the free carbonates are retained throughout the profile. This gives an alkaline reaction to the profile. The high pH values of Nankheda and Solapur profiles are attributable to presence of high amount of free $CaCO_3$ in these profiles.

4.3.3 Electrical conductivity:

The electrical conductivity values in all the cases fall below 1.0 mmhos/cm indicating non-saline nature of soil. There is a tendency of EC values to increase with the depth. The low conductivity values in soils from high rainfall areas are attributed to the leaching of soluble salts in these profiles. Similar results have been reported by Godse (1957) and Chakroborti (1974).

4.3.4 Cation exchange capacity:

The capacity of a soil to hold cations and to exchange species of these cations in reversible chemical reactions is an important property for plant nutrition as well as for soil genesis studies (Buol et al., 1973). It is valuable in evaluating the capacity of the soil to retain cations, its degree of weathering and general chemical reactivity.

Cation exchange capacity of soils in all the profiles (except Khopoli and Dapoli) is higher than the total clay content. This indicates that besides clay, silt and fine sand fractions of the soil are also contributing towards the total CEC of the soil. This is in accordance with the work of Hosking (1948), Brown (1951), McAleese and McConghy (1957), McAleese (1958), McAleese and Mitchell (1958), Satyanarayana *et al.* (1969,1970) and Gurcharansingh and Krishnamurty (1972).

In Dapoli and Khopoli profiles as well as in sub-surface horizons of Dharmabad profiles, cation exchange capacity is lower than the clay content, indicating the presence of other minerals of low exchange capacity like Mica and Kaolinite (Gurcharansingh and Krishnamurti, 1972).

It is also evident that the CEC of the soils in Dapoli and Khopoli profile increases awith depth of the solum. This may be attributed to the increase in clay with decreasing depth of these profiles. Findings of Millar *et al.* (1943) and Lavti *et al.* (1969) support these results.

4.3.5 Water soluble plus exchangeable bases:

Calcium and magnesium are the dominant cations in the black soils of Nankheda and Solapur which receives low amount of rainfall. Sodium and K are low in soils of almost all profiles except Dharmabad which shows high amount of potassium. Presence of K in the weathering environment greatly influences the processes of genesis of clay minerals. Potassium when present usually brings about formation of illite. This effect is observed in the clay mineralogy of these soils. The black soils appear to be base saturated indicating the absence of leaching. The parent rock appears to be rich in bases contributing towards exchangeable Ca and Mg. There is a predominance of Ca in exchange complex. The exchangeable Ca has in general a tendency to decrease with depth in profiles of Nankheda, Solapur and Dharmabad. Exchangeable Mg constitutes the second dominant cation in two black profiles. It is suggested that high values for Ca and Mg and associated high cation exchange capacity may be due to the presence of partially weathered rock minerals (McAleese and McConghy, 1958). Similar results have also been reported by Gurcharan Singh and Krishna Murti (1972).

Total replacable bases are lower in soils located in higher rainfall zone (Dapoli and Khopoli). The contents of exchangeable Ca and Mg are lowest in these soils. Further, accumulation of bases in sub-surface horizons have been observed in these two profiles. This may be ascribed to leaching as they are subject to high precipitation. Similar results have also been reported by Godse (1957), Karale (1958), Shingte (1963), Khutate (1970) and Pathey and Kibe (1971).

4.4 Fusion analysis of soils:

The sodium carbonate fusion analysis of the soil denotes the dynamic state of soils, stage of profile development and provides information regarding the alteration that might have occurred. It further throws light on the degree of weathering and mobility of silica, sesquioxide and other constituents.

The results of the fusion analysis of soils are presented in Table 2.

4.4.1 Silica:

The silica content of deep black soils of Nankheda varies between 50.75 and 60.35 per cent and that of Solapur between 51.7 and 56.26 per cent. These two profiles receive less rainfall as compared to rest of the profiles under investigation. The low values of silica in the third and fourth layer of Nankheda and surface layer of Solapur may be due to accumulation of magnesium and free calcium carbonate in the respective layers. Silica content of Dharmabad, Khopoli and Dapoli profiles varies between 44.0 and 55.0 per cent, 40.2 and 49.6 per cent,and 39.59 and 52.45 per cent respectively. In Dharmabad and Khopoli profiles, silica content increases with lesser magnitude as compared to Dapoli profile. In Dapoli profile considerable accumulation of silica has been observed in the lower horizons.

The silica content of the profiles (Dapoli and Khopoli) from the high rainfall zone, in general, is low and shows a higher trend of increasing with depth than that of the profiles of Solapur and Nankheda receiving low rainfall. In the low rainfall areas, on the other hand, the content of silica is higher and more or less constant throughout the profile with slight variation. It seems that silica in high rainfall areas has been leached down to lower horizons, whereas, the translocation of silica under low rainfall region is practically negligible. It may be inferred that silica content seems to be related to rainfall and increases with decrease in rainfall.

Small variations in the silica content down the profile suggest that mobilization of silica has not taken place through the horizons of profiles from Solapur and Nankheda. Weathering of silicates and alumino-silicates results in the dissolution of silica. But, since weathering processes are slow in semi-arid regions and silica is soluble at a pH range of 6 to 7 (Mohr and Van Baren, 1954), solubility of silica in profiles from low rainfall areas is not expected as the pH of these profiles is above seven. Presence of dissolved $CaCO_3$ also reduces the solubility of silica (Goldschmidt, 1958). The high content of silica in Solapur and Nankheda profiles is due to the presence of appreciable quantities of quartz and 2:1 type of clay minerals in addition to the parent material, basalt, they have. All the samples studied in these two profiles have silica as the most abundant constituent and this is also a criterion suggested to indicate low intensity of weathering (Bear, 1962).

4.4.2 Sesquioxides:

The results are presented in Table 2. It is seen from the table that the sequioxide content varies from 26.52 to 28.20 per cent in Nakheda; 26.50 to 29.43 per cent in Solapur; 28.50 to 34.64 per cent in Dharmabad; 41.57 to 47.28 in Khopoli;

and 45.13 to 48.42 per cent in Dapoli profiles. It is more in Dapoli and Khopoli profiles as compared to rest of the profiles. It may be due to the reason that loss of silica under heavy rainfall regions causes the sesquioxide content of the soil to increase. It is seen that sesquioxide content is dependent on rainfall, being maximum under high rainfall conditions and decreases with decrease in rainfall (Godse, 1957 and Karale, 1958).

4.4.3 Iron oxides:

The data presented in Table 2 indicates higher amount of iron content in profiles receiving high rainfall (Dapoli and Khopoli) as compared to the profiles under low precipitation (Nankheda and Solapur).

Total Fe_2O_3 in soil is due to the presence of minerals like biotite, pyroxene, amphiboles and hydrated oxides similar to limonite, which constitute the make-up of parent material. Under high rainfall when weathering conditions are optimum, rapid breakdown of weatherable minerals occurs with the accumulation of more resistent minerals like magnetite, haemetite and limonite which may account for higher iron content as suggested by Hough _et al._ (1941). Iron decreases with depth to a certain extent and then remains more or less uniform in the lower hirozons. Slight decrease with depth in Fe_2O_3 content is observed in Nankheda and Solapur profiles. The tendency of Fe_2O_3 to decrease to a

Table 2: Fusion analysis of soils (oven dry basis):

Location	Depth in cm	% SiO_2	% R_2O_3	% Fe_2O_3	% Al_2O_3	% CaO	% MgO	% K_2O	% MnO	% TiO_2
Nankheda	0-40	60.35	26.52	15.05	28.74	12.68	6.80	0.78	0.12	0.64
	40-100	58.20	26.52	14.80	19.98	11.05	6.25	0.98	0.10	0.64
	100-170	52.80	27.89	14.25	18.25	14.57	5.22	0.24	0.08	0.83
	170-270	50.75	28.20	13.85	16.80	12.59	8.05	0.68	0.08	0.88
Solapur	0-15	51.70	29.43	12.74	19.43	8.67	5.21	0.92	0.18	0.64
	15-30	52.95	28.55	11.80	17.24	5.42	5.60	0.95	0.06	0.83
	30-50	55.80	27.70	11.45	17.80	4.38	6.64	0.91	0.06	0.78
	50-105	56.26	26.50	12.34	18.25	9.86	6.80	0.26	0.09	0.88
Dharma-bad	0-15	44.00	34.64	18.50	16.80	2.28	1.22	3.85	0.16	0.72
	15-30	46.71	33.35	16.42	16.25	3.45	3.35	3.24	0.11	0.93
	30-90	47.34	30.50	19.25	17.75	7.94	4.78	2.63	0.11	0.91
	90-225	50.00	28.50	19.25	18.42	9.95	5.10	2.82	0.10	0.95
Khopoli	0-15	40.20	47.28	22.25	17.42	0.89	0.24	1.79	0.28	0.88
	15-30	43.93	44.31	19.20	15.75	1.50	0.35	1.24	0.24	0.89
	30-100	45.68	51.25	26.85	14.05	2.78	0.38	1.32	0.28	0.91
	100-250	49.60	41.57	27.20	14.00	4.67	0.46	0.94	0.26	0.93
Dapoli	0-37.5	39.59	48.42	21.69	18.25	0.85	0.98	0.24	0.24	0.81
	37.5-97.5	42.20	46.81	19.78	16.65	0.96	1.25	0.11	0.26	0.94
	97.5 +	52.45	41.13	29.74	22.20	1.50	1.44	0.06	0.26	0.88

limited extent with depth was also observed by Joshi (1950), Roy and Borde (1962) and Tamhane and Karale (1967) in black soils of Madhya Pradesh, Andhra Pradesh and basaltic soils of Bombay Deccan respectively. Slight decrease of Fe_2O_3 with depth in Nankheda and Solapur profiles is due to the absence of leaching, clayey texture of soils and an alkaline reaction. According to Goldschmidt (1958), oxidizing and alkaline conditions promote precipitation of iron and mobility of iron down the profile is greatly reduced.

4.4.4 Aluminium oxides:

The data presented in Table 2 denotes an interesting feature regarding the relationship between aluminium and iron in the soil profiles receiving less rainfall (Nankheda and Solapur) and profiles receiving high rainfall (Dapoli and Khopoli). In case of profiles receiving low rainfall aluminium exceeds iron, whereas in the profiles receiving high rainfall aluminium content is less as compared to that of iron. These results are quite in accordance with the results obtained by Joshi (1950), Roy and Borde (1962) and Tamhane and Karale(1967).

4.4.5 Calcium oxide:

The results in Table 2 indicates that the calcium oxide content is high in profiles receiving less rainfall (Solapur and Nankheda) as compared to profiles in high rainfall areas (Dapoli and Khopoli). It means CaO content decreases with increasing precipitation. Most of the calcium is present in non-clay portion of soils, thereby suggesting that calcium in soils is obtained from minerals like plagioclase feldspar, augite, hornblende and calcite. The percentage of calcium in montmorillonite group of minerals is 0-3 (Bear, 1964) and hence calcium has been mostly derived from the primary minerals. In regions receiving low rainfall $CaCO_3$ commonly accumulates in soils. According to Polynav (1937), calcium is more mobile than iron, aluminium and silica.

4.4.6 Magnesium oxide:

Magnesium, similar to calcium, bears an inverse relationship with rainfall as seen from the data presented in Table 2. The content of MgO in profiles receiving low rainfall (Nankheda and Solapur) varies from 5.21 to 8.05 per cent, whereas, it varies between 0.24 and 1.44 per cent in profiles under high rainfall (Dapoli and Khopoli). Basalts are rich in calcium and magnesium and as such under normal conditions, the soils developed on the rock are high in these constituents.

4.4.7 Potassium oxide:

The data are presented in Table 2. The content of K_2O is low in Nankheda and Solapur profiles as compared to Dapoli and Khopoli profiles. It is maximum in Dharmabad profiles.

The low content of K_2O in Nankheda and Solapur profiles may be explained by the low amount of potash bearing primary and secondary minerals like orthoclase, feldspar and mica in sand and clay fractions of soil respectively. The K_2O content in profiles receiving high rainfall does not decrease with depth as potassium is resistent to leaching. Similar results have been obtained by Karale (1962) and Shingte (1963). Resistance of potassium to leaching might be attributed to the fact that it might be forming a constituent of clay crystal lattice in the profiles under high rainfall areas.

4.4.8 Manganese oxide:

Results in Table 2 indicates decrease of manganese with depth. It is low in Solapur and Nankheda profiles as compared to Dapoli and Khopoli profiles. This may be due to the presence of $CaCO_3$ in these two profiles. The high clay and presence of $CaCO_3$ check the mobility of Mn. Further, in alkaline conditions the availability of Mn is low. This is related to the state of oxidation and aging of insoluble compounds in such soils (Goldschmidt, 1958).

4.4.9 Titanium oxide:

The data are presented in Table 2. The TiO_2 content is considerable in almost all soils under investigation. Its presence might be attributed to its occurrence in the parent rock i.e. basalt which contains this element in considerable quantity (Karale, 1958). The variations within profiles are not well marked and it increases with depth. Titanium bearing minerals are notably resistant to weathering. They have a tendency to accumulate when other easily weatherable constituents weather away (Bear, 1964). Titanium is found in soils in sand and silt fractions in the form of rutile/anatase (TiO_2) and ilmenite ($FeTiO_3$). It is also found in small quantities in many iron bearing minerals such as augite, hornblenda and biotite. Since the tetravelent titanium ions have raddi close to that of ferric iron, titanium may be associated with the clays of smectite and mica groups as very tiny needles of rutile (Goldschmidt, 1958).

4.5 Chemical composition of the clay fractions:

The data are reported in Table 3.

Analysis of hydrogen clay reveals the composition of the inner structure constituting the clay fraction. According to Gieseking (1949), clay fraction promotes the weathering of resistant minerals by sorbing the soluble products of weathering reaction. Therefore, knowledge of the composition of clay fraction as stated by Barshad (1946), Jackson (1958) and others, elucidates the degree and direction of soil development.

4.5.1 Silica:

It can be seen from Table 3 that silica content of the clays from profiles developed under high rainfall (Khopoli and Dapoli) is much less as compared with the silica from clays in the profiles developed under low rainfall (Solapur, Nankheda). This is expected as under heavy rainfall conditions

Table 3: Chemical composition, cation exchange capacity and molar ratios of clay fraction of soils:

Location	Depth in cms	% SiO_2	% R_2O_3	% Al_2O_3	% Fe_2O_3	% CaO	% MgO	% K_2O	CEC m.e. per 100 g of clay	Molar ratios		
										SiO_2/Al_2O_3	Al_2O_3/MgO	SiO_2/R_2O_3
Nankheda	0-40	56.63	36.44	20.78	15.66	0.58	2.69	1.20	73.2	4.59	3.00	3.12
	40-100	56.56	36.04	21.35	14.69	0.65	2.45	1.35	71.7	4.42	3.39	3.12
	100-170	56.76	36.85	20.95	15.90	0.62	2.12	1.17	65.4	4.59	3.82	3.10
	170-270	54.62	37.99	22.73	15.18	0.74	2.04	1.42	60.2	4.08	4.34	2.83
Solapur	0-15	57.84	36.18	21.56	14.62	0.57	3.42	1.82	89.2	4.42	2.46	3.12
	15-30	56.72	34.90	21.49	13.41	0.58	3.01	1.46	82.5	4.42	2.88	3.19
	30-50	56.26	36.95	22.18	14.77	0.62	2.44	1.65	80.6	4.25	3.54	3.01
	50-105	54.24	34.62	20.19	14.43	0.66	2.41	1.42	78.7	4.42	3.24	3.12
Dharmabad	0-15	50.87	40.84	25.09	15.76	0.18	1.12	2.82	78.0	3.43	8.73	2.45
	15-30	50.60	40.59	24.61	15.98	0.16	1.32	2.65	80.2	3.48	7.25	2.46
	30-90	51.24	42.69	26.42	16.27	0.52	1.76	2.74	81.4	3.23	5.85	2.35
	90-225	51.36	39.61	23.40	16.21	0.67	1.98	2.36	78.0	3.57	4.60	2.57
Khopoli	0-15	44.84	46.66	28.52	18.14	0.08	0.85	1.98	20.2	2.67	13.06	1.90
	15-30	44.63	47.53	31.48	16.05	0.09	0.69	2.55	24.8	2.38	17.78	1.81
	30-100	46.42	47.80	29.30	18.50	0.17	1.03	1.28	21.7	2.55	11.07	1.91
	100-250	46.27	50.40	30.50	19.90	0.49	0.74	1.69	27.0	2.55	16.07	1.83
Dapoli	0-37.5	43.62	49.04	28.61	24.43	0.07	0.98	2.44	23.4	2.58	11.39	1.67
	37.5-97.5	46.56	48.64	28.26	20.38	0.12	1.75	1.34	29.5	2.72	6.28	1.91
	97.5 +	49.87	41.26	37.54	24.02	0.22	1.98	1.88	32.0	2.21	7.37	1.45

the soil is depleted of calcium which forms a protective cover to the colloidal clay. Under such conditions the clay crystal lattice starts breaking down. Desilicification takes place and the silica so released is leached away. Whereas, under low rainfall conditions the base status of the soils is high and they are saturated with calcium, with the result that the conditions inhibit the desilification of clay minerals. The percentage of silica obtained in low rainfall and high rainfall receiving soil clays is in accordance with Roy and Borde (1962) obtained for black soils of M.P. and A.P., Van der Merwe (1957) for sub-tropical black clays, Godse (1957) for both red and black soils of Bombay state; and Karale (1962) obtained for both types of soils.

The presence of high silica in weathering complex (Nankheda and Solapur) is due to incomplete leaching in semi-arid regions and alkaline conditions, which prevent the removal of silicic acid formed by hydrolysis. High percentage of silica indicates the dominance of 2:1 type silicate minerals in this fraction (Grim, 1968).

4.5.2 Sesquioxides:

The data in Table 3 on sesquioxide content indicates an accumulation of the same under high rainfall conditions. The amount of sesquioxides present in clay gradually decreases with the decrease in the amount of rainfall. Similar observations are recorded by Gurcharan Singh and Krishna Murti (1974).

Dapoli and Khopoli soil clays deficit an increase in the subsurface horizon thereby indicating some translocation in the subsurface horizons. Shingte (1963) and Gowda (1959) also noted similar observations.

4.5.3 Aluminium:

The aluminium content of the soil clay also shows the same trend as observed in sesquioxide i.e. gradually decreases with the decrease in rainfall. That is why about 32 per cent of aluminium is noted in Dapoli and Khopoli profiles as against about 22 per cent in Nankheda and Solapur soil clays.

Here again the aluminium content of Khopoli and Dapoli clays shows an increasing tendency with depth suggesting some translocation of the same in lower horizons. Similar results were obtained by Godse (1957), Karale (1962) and Shingte (1963).

4.5.4 Iron oxide:

The iron content of the clay in all the profiles is in the range of 14 to 25 per cent. Lawton (1955) (quoted by Bear, 1955) has re-reported 0-30 per cent as range of iron content of montmorillonite clays. The iron content of clays from black soils of Solapur and Nankheda ranges between 14 and 17 per cent, whereas those receiving high precipitation show 18 to 24 per cent iron in their clays. Considerable amount of iron in black clays may be explained on the basis that soil clays carry large amounts of amorphous iron minerals like limonite, geothite etc. on their surfaces.

Further, it can be noted that iron content shows a tendency to decrease with depth in dry regions, whereas, generally it increases with depth in soil clays receiving higher precipitation. The values of iron in Nankheda and Solapur profiles indicate that iron has not been reduced to promote solution in these profiles, due to the presence of alkaline and oxidising conditions in the weathering environment.

4.5.5 Calcium oxide:

The data reported in Table 3 indicate that calcium occurs in a higher range in black soil than that of red and lateritic soils of Khopoli and Dapoli. The average content of calcium in these two black soils is 0.60 per cent. Roy and Borde (1962) reported calcium to the extent of 0.33 to 1.44 per cent in black soils of Madhya Pradesh and Andhra Pradesh. More calcium content in black soils may be due to accumulation of free $CaCO_3$ and presence of smectite type of clay minerals in these two profiles. Grim (1968) stated that calcareous conditions, in which smectite clays have been formed, may also be one of the contributing factors for the presence of more calcium in the clay fraction.

4.5.6 Magnesium oxide:

The quantity of MgO reported in Table 3 is considerably large particularly in soil clays from Nanakheda, Solapur and Dharmabad. Its content tends to decrease with increase in rainfall. Similar trend was also noticed by Pathey and Kibe (1971) and Godse (1957).

Roy and Borde (1962) noted 2.06 to 3.29 per cent MgO in black soils. The higher percentage may be due to more MgO being substituted in octahedral layer in place of aluminium. Grim (1968) has reported a higher percentage of magnesium in smectites (0-25 per cent) and holds the view that magnesium in the chemical environment leads to the formation of montmorillonite and calcium probably to the formation of montmorillonite with added tendency to block the formation of Kaolinite. Krishna Murti and Satyanarayana (1969, 1970) have reported that the magnesium in the chemical environment helped the formation of smectites in basaltic soils.

4.5.7 Potassium oxide:

Potash content of the soil clays seems to be unaffected by variation in rainfall. However, the soil clays derived from gneiss (Dharmabad) contain higher K_2O than those from basalt. This may be due to unidentified orthoclase feldspar or secondary mica. The average K_2O content of the Dharmabad soil clays is about 2.5 and that of black soils Nankheda and Solapur is 1.5 approximately. Slightly higher K_2O occurs in Dapoli and Khopoli profiles than K_2O content in black soils.

4.5.8 Cation exchange capacity:

The data presented in Table 3 indicate that the cation exchange capacity of clay was lowest in Dapoli and Khopoli soil profiles which receive higher amount of rainfall.

The value is relatively much higher in soils of basaltic origin. The CEC of clays from black soils was quite high indicating the predominance of smectite minerals. Comparatively lower values in Dharmabad indicates the presence of mica. Much lower values of CEC in Dapoli and Khopoli profiles indicate the presence of Kaolinitic type of clay minerals. Godse (1957) and Pathey and Kibe (1971) have also obtained lower values of cation exchange capacity of clays receiving high amount of rainfall and much higher values for soils of basaltic origin receiving less rainfall. Similar results have also been reported by Narayana (1959), Karale (1962) and Khutate (1970).

4.5.9 Molar ratios:

The silica is leached under high rainfall conditions, whereas, it remains unaffected under low rainfall conditions. So also, sesquioxides accumulate under high precipitation. This results in lowering the silica/sesquioxide ratio under high rainfall conditions. This can be noted from Table 3.

The chemical composition of the clays from different layers of Nankheda and Solapur profiles is almost uniform, thereby pointing almost identical mineralogical composition of the clays throughout these two profiles. SiO_2/R_2O_3 ratios of Nankheda and Solapur of 2:1 type of lattice minerals in them indicate the presence of montmorillonite or illite. The low Al_2O_3/MgO ratios of clays from different layers of these two profiles indicates that the 2:1 type is being montmorillonite. High cation exchange capacities of clays from these two profiles also indicate its montmorillonitic nature.

This leads to the conclusion that clays from low to moderate rainfall areas are predominantly montmorillonitic in nature when enough Ca and Mg is present in the soil environment and are illitic when potash dominates the soil environment. This is in agreement of the statement of Grim (1953) that when basic rocks containing alkaline earth cations weather under conditions of insufficient leaching due to impeded drainage or high evaporation over rainfall or due to scanty rainfall, there is an accumulation of the liberated alkaline earth cations in the weathering zone. This ionic environment leads to the formation of montmorillonite as the dominant clay mineral in soils under similar conditions of weathering if the alkali cations like Na and K dominate the ionic environment, illite is the dominant clay mineral formed, and when both alkali and alkaline earth cations charge the ionic environment, both montmorillonite and illite are the minerals in the composition of the soil clays. The removal of these ions away from the weathering zone under conditions of good drainage and high rainfall, leads to the breakdown of the above minerals i.e. montmorillonite and illite with the formation of Kaolinite under an acidic environment, and further leaching under high rainfall condition resulting in the formation of hydrous oxides of iron and aluminium.

Predominance of montmorallonite under alkaline earth cations and illite under alkali cations in the soil clays from low to moderate rainfall is noted by several workers (Raychaudhuri <u>et al</u>., 1943; Roy and Das, 1950; Das, Rao and Tamhane, 1952; Tamura, 1952; Das, 1956; Sherman and Uchara, 1956; Van der Merwe, 1957; Tamhane and Namjoshi, 1959 and Das and Tamhane, 1960).

Predominance of kaolinite minerals in soil clays from high rainfall areas likewise have been reported by Hallsworth, 1951; Hallsworth <u>et al</u>., 1952; Laplante, 1954; Van der Merwe and Heystek, 1955; Nicolls and Tucker, 1956 and Das and Tamhane, 1960.

Analysis of Dapoli and Khopoli profile soil clay presents altogether a different picture than the rest investigated. SiO_2/R_2O_3 and SiO_2/Al_2O_3 ratios are strikingly lower than those discussed earlier. Another notable feature is low content of MgO and low CEC. Therefore, these clays appear to reveal their predominantly kaolinite nature. This is further supported by high Al_2O_3/MgO ratio, a characteristic feature of kaolinitic minerals.

Soil clays from Dapoli and Khopoli profiles are low in silica and magnesium contents and are rich in sesquioxides. They give narrower SiO_2/R_2O_3 and SiO_2/Al_2O_3; and high Al_2O_3/MgO ratios. It can, therefore, be concluded that Al_2O_3/MgO ratio of soil clays bear a direct relationship with rainfall, whereas, SiO_2/R_2O_3 and SiO_2/Al_2O_3 ratios of soil clays bear an inverse relationship with rainfall. These observations are in accordance with those of Martin and Doyne (1930), Craig and Halais (1934), Prescott and Hasking (1936), Taneda (1951), Prescott and Pendleton (1952), Cline (1955) and Karale (1962).

4.6 Clay mineralogy of soil profiles:

Identification and quantification of soil clay minerals is of great importance for understanding the weathering process and formation of soils and their chemical and physico-chemical behaviour requires a thorough knowledge of the composition of soil clays. Clay mineralogy of profile samples helps in understanding the genesis of soils. It is, therefore, that an attempt has been made to understand the clay mineralogy of the soil profiles from different agroclimatic zones of Maharashtra. The X-ray diffractograms obtained are presented in Figs. 1 to 21 and the lattice spacings with their relative intensities in different treatments are presented in Table 4&5.

The clay mineralogy of the soil profiles under investigation by X-ray diffraction technique (diffractograms in Figs. 1 to 21) indicates that the soil profiles from medium to high rainfall zone (Dharmabad, Khopoli, Dapoli) have different clay assemblage than those from low rainfall areas (Nankheda and Solapur). Nankheda and Solapur soil profiles have also different mineralogy when compared amongst themselves, but this is not the case with clay mineralogy of Dharmabad, Dapoli and Khopoli soil profiles. They have almost similar clay assemblage.

Table 4: Quantitative mineralogical analysis and the weathering mean of soil clays:

Sr. No.	Location	Depth in cms	% Smectite	% Mica	% Kaolinite + Halloysite	% Chlorite	% Vermiculite	% Quartz	% Feldspar	% Weathering mean
1.	Parbhani	0–40	–	10	13	62	10	5	–	5.58
2.	Solapur	30–50	70	10	15	–	–	5	–	8.80
3.	Dharmabad	0–15	–	28	38	–	10	10	15	7.91
4.	Khopoli	0–15	–	19	56	–	5	10	10	8.43
5.	Dapoli	0–37.5	–	18	62	–	5	10	5	8.71

Table 5: Lattice spacings in Å and their intensities in different treatments: (from horizons of different profiles)

Location	Depth in cms	Mg-saturated		Glycerol solvated		K-saturated & heated to 550 °C	
		d-spacings	I	d-spacings	I	d-spacings	I
1	2	3	4	5	6	7	8
Nankheda soil clays	0-40	14.01	B & VVS	16.0	VS	13.8	B & VVS
		9.9	B	9.9	W	9.9	M
		7.07	MS	7.02	M	4.9	M
		4.9	M	4.9	W	3.32	M
		3.5	MS	3.5	M		
		3.32	M	3.32	S		
	40-100	14.1	B & VVS	16.9	VVS	13.9	VS
		7.0	M	7.0	M	4.6	W
		4.7	M	5.6	W	3.34	S
		3.5	M	3.5	M		
		3.34	S	3.34	VS		
	100-170	13.6	B & VS	13.6	B & VS	10.0	B & W
		6.96	MS	6.96	MS	4.2	MS
		4.2	W	4.2	W	3.74	
		3.5	MS	3.5	W		
		3.34	S	3.34	S		
	170-270	13.79	B & VVS	17.3	VVS	13.18	B & VS
		7.0	M	7.0	MS	4.6	W
		4.7	W	5.7	W	3.34	S
		3.5	MS	3.5	W		
		3.34	S	3.34	VS		

Continued

Table 5 (continued)

1	2	3	4	5	6	7	8
Solapur soil clays	0-15	14.2 4.2 3.34	M B MS	17.3 4.2 3.34	B&S MS MS	10.0 4.2 3.34	W MS MS
	15-30	14.9 3.2	B&S MS	17.2 3.2	B&VVS MS	9.6 3.2	MS MS
	30-50	14.4 7.0 4.7 3.34	B&VVS W W S	17.6 8.8 7.0 5.8 3.34	VVS MS W W S	9.9 4.9	VS M
	50-105	14.8 3.34	VVS M	15.8 3.34	B&VVS M	9.6 4.8 3.24	VVS MS VS
	105-180	14.7 4.2 3.34	B&VVS W S	17.3 4.2 3.34	B&VVS W S	9.9 4.2 3.24	VVS W S

Continued

Table 5 (continued)

1	2	3	4	5	6	7	8
		9.82	MS	9.82	S	9.82	VS
		7.02	MS	7.07	MS	5.0	W
Dharmabad	0–15	5.0	W	5.00	W	4.2	W
soil		4.2	W	4.16	W	3.33	VS
		3.50	MS	3.50	S		
clays		3.32	VS	3.33	VS		
		10.15	S	9.82	S	9.82	S
	15–30	7.13	M	7.13	S	5.0	W
		5.0	W	5.0	W	3.32	S
		3.5	S	3.5	S		
		3.32	S	3.32	S		
		10.04	S	10.04	MS	9.82	S
		7.18	S	7.2	S	3.28	MS
	30–90	3.5	S	3.5	S		
		3.32	MS	3.3	M		
		10.04	M	10.04	M	9.7	W
		7.13	S	7.13	S	3.32	M
		3.5	S	3.5	S		
		3.32	M	3.32	M		

Continued

Table 5 (continued)

1	2	3	4	5	6	7	8
	0–15	7.1	MS	7.1	MS	–	–
		4.2	W	4.2	W	4.2	W
		3.58	MS	3.58	MS	–	–
	15–30	7.2	S	7.2	S	4.2	W
		4.2	W	4.2	W		
		3.6	MS	3.6	MS		
Khopoli soil clay	30–100	10.0	M	10.0	M	9.8	M
		7.2	M	7.2	M	4.2	W
		4.2	W	4.2	W		
		3.5	M	3.5	M		
	100–250	8.8	W	8.8	W	8.6	M
		7.0	M	7.0	M	4.3	W
		4.4	M	4.4	M	4.08	M
		4.08	M	4.08	M		
		3.5	M	3.5	M		
	250–450	10.0	VS	10.0	VS	10.0	S
		7.1	S	7.1	S	5.0	W
		5.0	W	5.0	W	4.2	M
		4.2	M	4.2	M	3.3	M
		3.5	MS	3.5	MS		
		3.3	M	3.3	M		

Continued

Table 5 (continued)

1	2	3	4	5	6	7	8
Dapoli soil clays	0–37.5	9.82	W	9.82	W	9.82	W
		7.02	S	7.02	S	4.8	W
		4.89	W	4.89	W	4.2	W
		4.2	W	4.2	W	3.3	S
		3.5	S	3.5	S	3.2	W
		3.3	S	3.3	S		
		3.2	W	3.2	W		
	37.5–97.5	9.7	W	9.7	W	9.2	W
		7.13	S	7.13	S	4.6	W
		4.95	W	4.95	W	4.17	W
		4.17	M	4.17	M	3.32	W
		3.5	S	3.5	S		
		3.32	M	3.32	M		
	97.5+	7.1	S	7.1	S	3.34	M
		3.5	S	3.5	S		
		3.34	M	3.34	M		

B = Broad
S = Strong
V = Very
M = Medium
W = Weak

Dominance of 'swelling chlorite' has been observed in Nankheda soil profile up to 100 cm depth. The other minerals present in small quantities along with chlorite are kaolinite and quartz. Surface layer contains some mica also. In the third layer (100-170 cm) from the surface, vermiculite has been detected as the dominant clay mineral along with small quantities of kaolinite and quartz 'Swelling chlorite' as a dominant clay mineral along with some kaolinite and quartz has also been observed in weathered parent material layer (170-270 cm).

In another black soil clay i.e. Solapur profile, presence of smectite has been observed throughout the profile as a dominant clay mineral. Along with smectite the only mineral present is quartz in almost all the profile except 3rd layer (30-50 cm) which also contains little kaolinite.

The diffractograms of Dharmabad soil clays denotes the presence of mica, kaolinite and quartz throughout the profile. Mica dominates in the top two layers, whereas, kaolinite is found to be the dominant clay mineral in the lower two horizons. Khopoli soil profile which has been developed under very high rainfall contains only kaolinite and quartz minerals up to 30 cm depth, thereafter mica has also been observed in the lower depths along with kaolinite and quartz. Mica dominates in the bottom layer.

Dominance of kaolinite clay mineral has been detected in all the horizons of soil profile at Dapoli. The profile also contains some amount of mica and quartz along with kaolinite, but no mica exists in the bottom layer.

The characteristics of diffractograms of various minerals found in various profiles are as under.

4.6.1 Nankheda profile (Fig. 1 to 4):

4.6.1.1 Swelling chlorite:

Presence of strong 14.01, 14.1 and 13.79 Å magnesium saturated peaks which swells to 16.0, 16.9 and 17.3 Å on glycerol solvation and collapse to 13.8, 13.9 and 13.78 Å on heating to 550 °C respectively (Fig. 1 to 4) leads to infer that chlorite occurrence is possible. Also presence of 4.7 Å magnesium saturated, 5.6 Å glycerated and 4.6 Å heated 3rd order peaks in Fig.2 and 4.7 Å 5,7 Å and 4.6 Å peaks Fig.4 helped to confirm the presence of swelling chlorite.

4.6.1.2 Mica:

Persistence of first order 9.9 Å and second order 4.9 Å peaks in all the treatments (Fig.1) renders a support to the occurrence of mica.

4.6.1.3 Kaolinite:

Presence of 7.07, 7.0, 6.96 and 7.0 Å magnesium saturated first order reflections which won't swell on glyceration (7.02, 7.0, 6.96 and 7.0 Å respectively) but gets destroyed after heating to 550 °C. Further, presence of 3.5 Å second order reflections in magnesium saturated and glycerol solvated treatments which get destroyed on heating in all the horizons of profile (Figs. 1 to 4).

4.6.1.4 Vermiculite:

Presence of 13.6 Å magnesium saturated peak which remains as it is on glyceration but collapses to 10.0 Å on heating to 550 °C (Fig.3) leads to infer that vermiculite is present.

4.6.1.5 Quartz:

Persistence of 3.32 and 3.34 Å first order (Figs. 1 to 4) and 4.2 Å peaks (Fig. 3) in all the treatments and all the horizons of profile points to the presence of quartz.

4.6.2 Solapur profile (Figs. 5 to 9):

4.6.2.1 Smectite:

Presence of strong first order 14.2, 14.9, 14.4, 14.8, 14.7 Å and third order 4.7 Å Magnesium saturated; first order 17.3, 17.2, 17.6, 15.8, 17.3 Å and second order 8.8 Å and third order 5.8 Å glycerol solvated; and first order 10.0, 9.6, 9.9, 9.6, 9.9 Å and second order 4.9, 4.8 Å heated reflections in five horizons of Solapur profile, leads to the conclusion that smectite occurs.

4.6.2.2 Quartz:

3.34 and 3.32 Å first order and 4.2 Å second order peaks in all treatments of all horizons of Solapur profile points to the presence of quartz.

4.6.2.3 Kaolinite:

Small reflection of 7.0 Å in third layer (Fig.3) which get destroyed after heating up to 550 °C temperature denotes the presence of kaolinite.

4.6.3 Dharmabad profile (Fig.10 to 13):

4.6.3.1 Mica:

Magnesium saturated first order peaks at 9.82, 10.15, 10.04, 10.04 Å which neither swell on glycertation nor collapse much on heating (9.82, 9.82, 10.04, 10.04 Å and 9.82, 9.82, 9.82, 9.7 Å respectively). Further, 5.0 Å magnesium saturated second order peaks which neither swell nor collapse on heating in Figs. 10 and 13.

4.6.3.2 Kaolinite:

Presence of 7.02, 7.13, 7.18, 7.13 Å magnesium saturated and 7.07, 7.13, 7.2, 7.13 Å glycerated first order peak which get destroyed on heating to 550 °C leads to the conclusion of kaolinite occurrence. Further, second order 3.5 Å magnesium saturated and glycerol solvated reflections which get destroyed on heating to 550 °C in all the horizons leads a support to this view.

4.6.3.3 Quartz:

Persistence of first order reflections at 3.32 Å in all the treatments and all the horizons and persistence of second order 4.2 Å reflections in all the treatments of surface horizon (Fig.10) points to the presence of quartz.

4.6.4 Khopoli profile (Figs.14 to 18):

4.6.4.1 Kaolinite:

First order magnesium saturated reflections at 7.1, 7.2, 7.0, 7.1 Å and second order reflections at 3.58, 3.6, 3.5 Å which did not expand on glyceral solvation but got destroyed on heating.

4.6.4.2 Mica:

Presence of first order magnesium saturated reflections at 10.0, 8.8, 10.0 Å (Figs. 16 to 18) which neither swell on glyceration nor collapse much (9.8, 8.6, 10.0 Å) on heating to 550 °C. Further, presence of second order magnesium saturated reflection at 4.4, 5.0 Å (Figs. 17 and 18) which also neither expand nor collapse on heating (4.3 and 5.0 Å) supports the occurrence of mica.

4.6.4.3 Quartz:

Persistence of first order reflections at 3.3 Å in lower most horizon and 4.2 and 4.08 Å reflections in all the treatments and throughout in all the profile points the presence of quartz.

4.6.5 Dapoli profile (Figs. 19 to 21):

4.6.5.1 Mica:

Presence of unchanged basal reflections at 9.82, 9.7 Å with any treatment in top two layers and second order peaks at 4.89, 4.95 Å. Further, presence of third order reflection at 3.2 Å which neither expand on glyceration nor collapse on heating (Fig.19) supports the view that mica occurs in the profile.

4.6.5.2 Kaolinite:

Presence of first order peaks at 7.02, 7.13, 7.1 Å and second order peaks at 3.5 Å in all horizons which show no change with glyceration but vitiate on heating up to 550 °C temperature indicates the occurrence of kaolinite.

4.6.5.3 Quartz:

Persistence of first order peaks at 3.3, 3.32, 3.34 Å and second order peaks at 4.2, 4.17 Å in all the treatments.

Dominance of smectites in clays derived from black soils has also been reported by Chatterjee and Rathore (1976) in M.P., Sharma and Kant (1977) in Rajasthan, Malewar and Randhawa (1978) and Maniyar (1979) in Marathwada. Medium and deep black soils from Madhya Pradesh, Rajasthan, Andhra Pradesh, Mysore and Maharashtra which have been investigated by several workers, contain montmorillonite as the major mineral (Nagelschmidt *et al*., 1940; Desai, 1942; Raychaudhuri *et al*., 1943; Tamhane, 1950; Roy and Das, 1952; 1953;Tamhane and Namjoshi, 1959. Illite and small amount of kaolinite have also been recorded in many of the areas (Das, 1956; Rao, 1963; Datta and Adhikari, 1968a,b.).

Theisen *et al*. (1959), Sehgal and Conick (1971), Chatterjee and Gupta (1970), Prasad *et al*. (1969), Rao (1963) and Kanwar (1959) working on various soils have reported

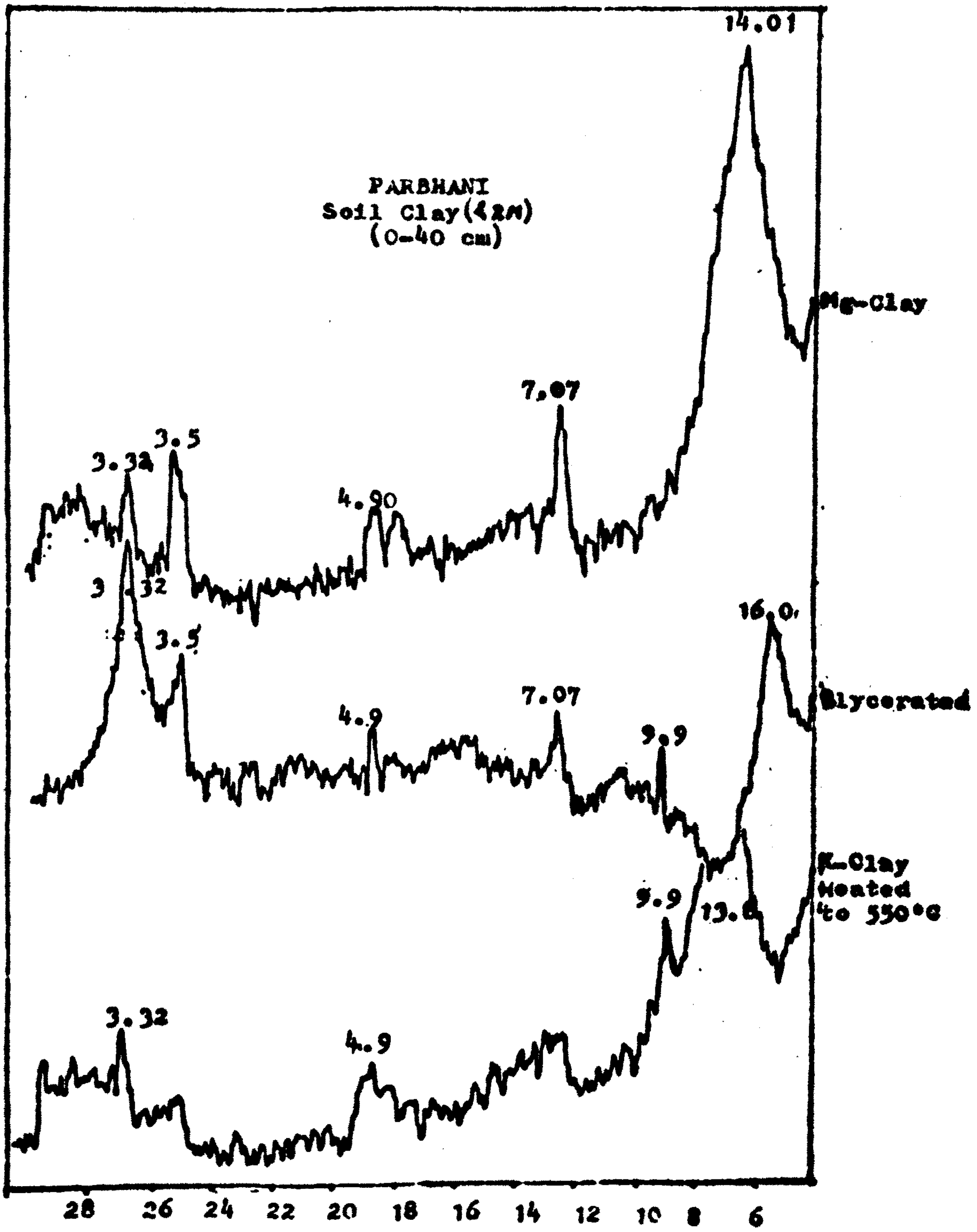


FIG. 1.X-RAY DIFFRACTOGRAMS OF PARBHANI SOIL CLAY SEPARATED FROM 0-40 CM.LAYER.

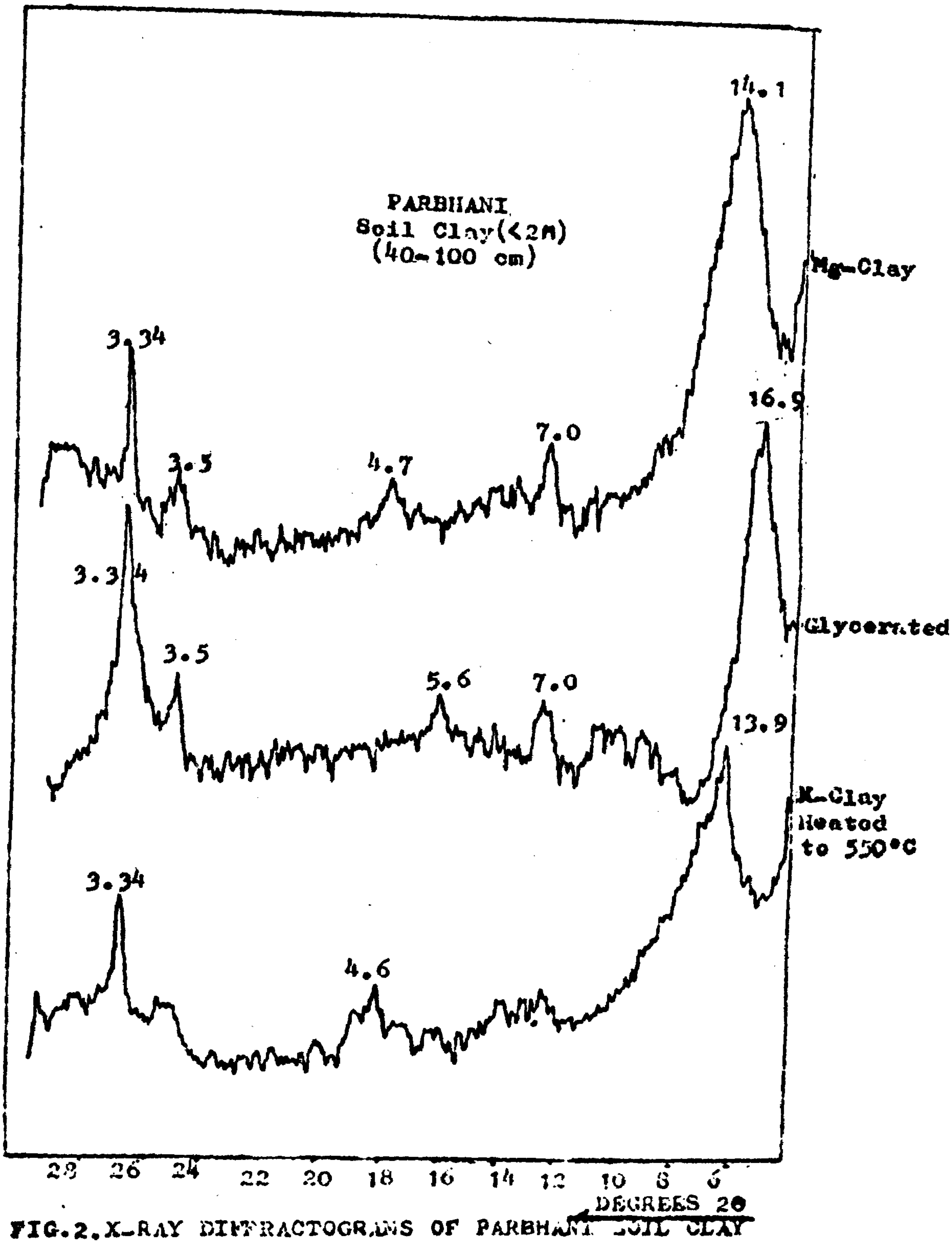


FIG.2. X-RAY DIFFRACTOGRAMS OF PARBHANI SOIL CLAY SEPARATED FROM 40-100 cm LAYER.

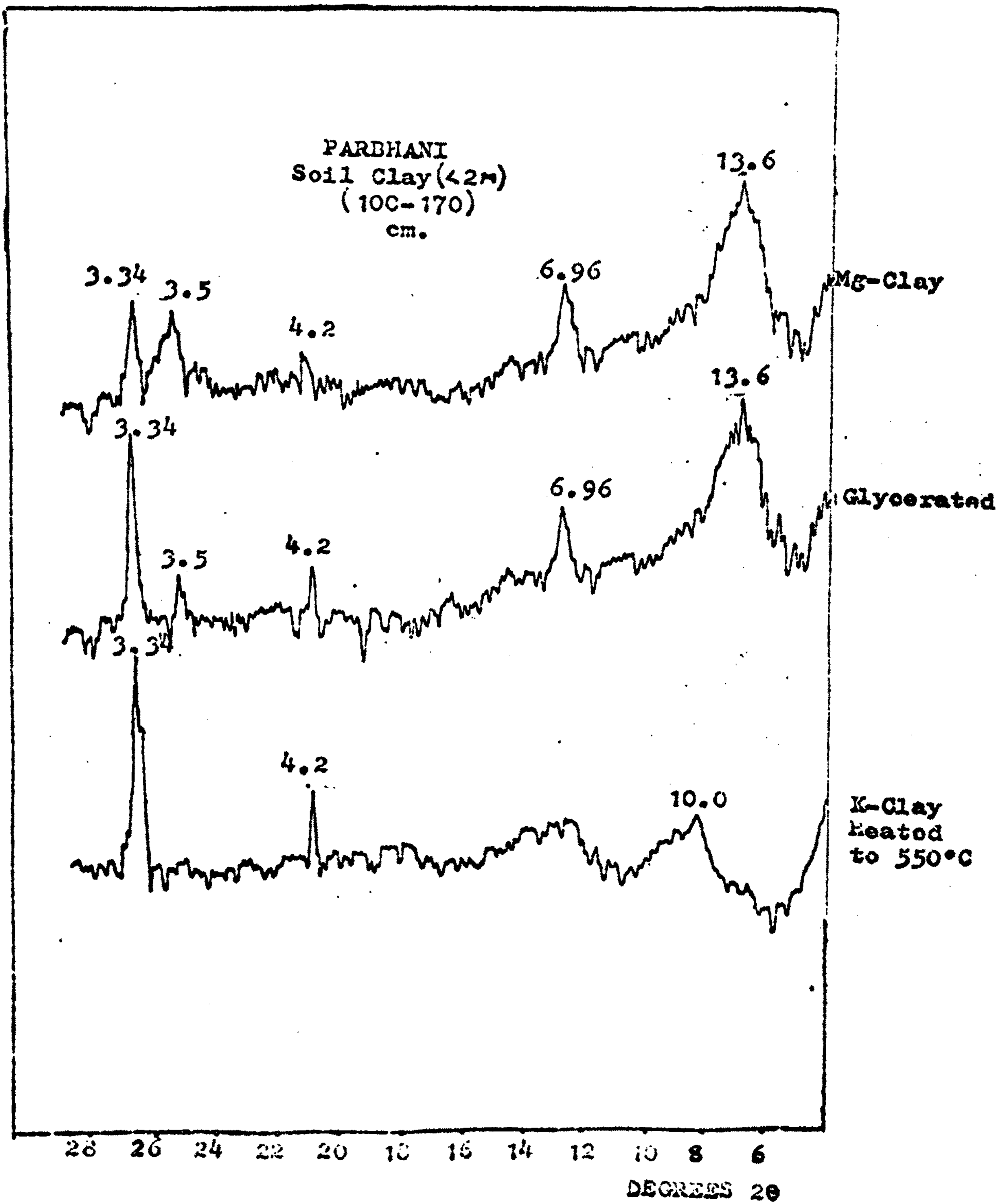


FIG. 3. X-RAY DIFFRACTOGRAMS OF PARBHANI SOIL CLAY SEPARATED FROM 100-170 cm. LAYER.

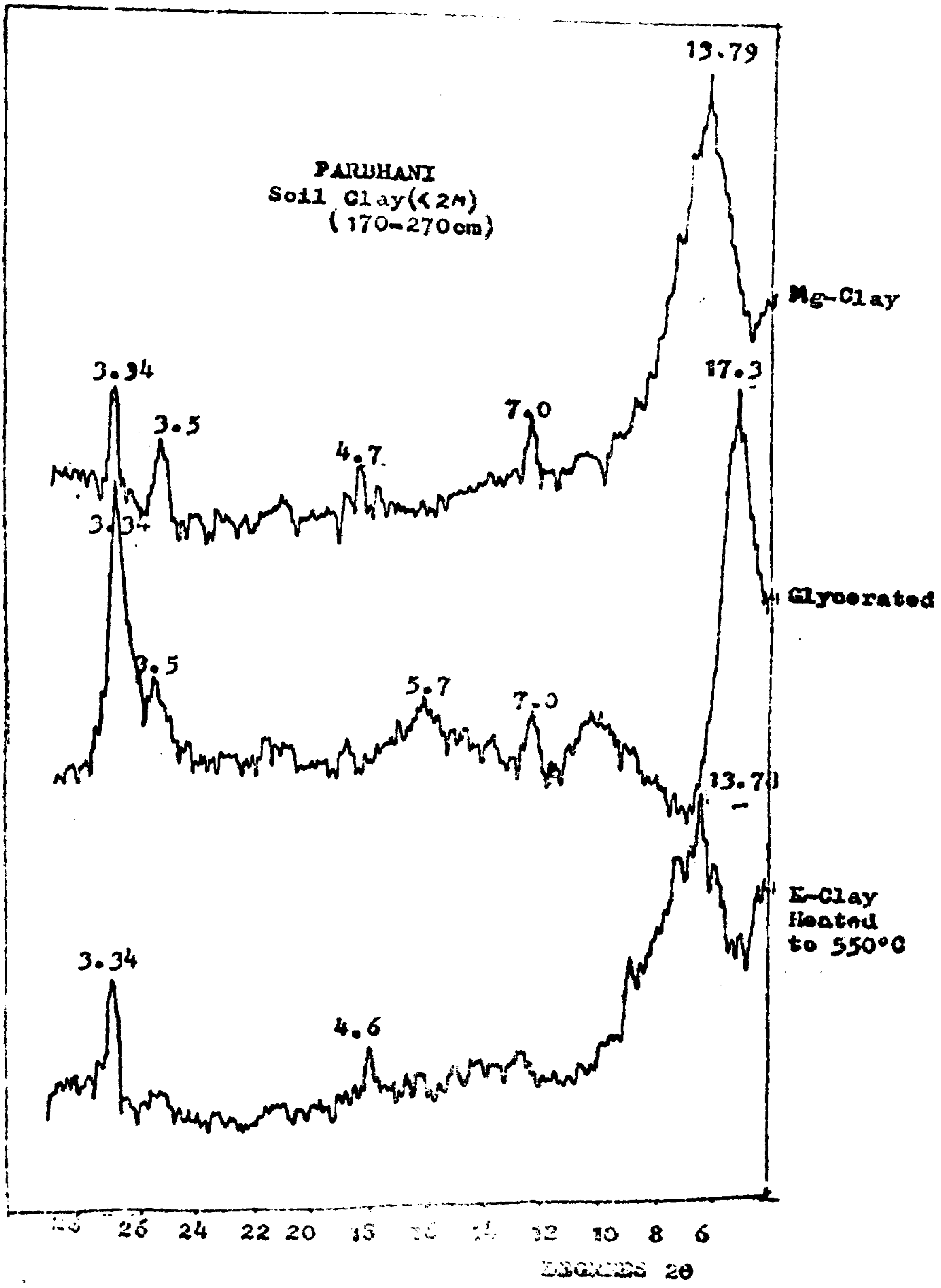


FIG.4.X-RAY DIFFRACTOGRAMS OF PARBHANI SOIL CLAY SEPARATED FROM 170-270 cm.LAYER.

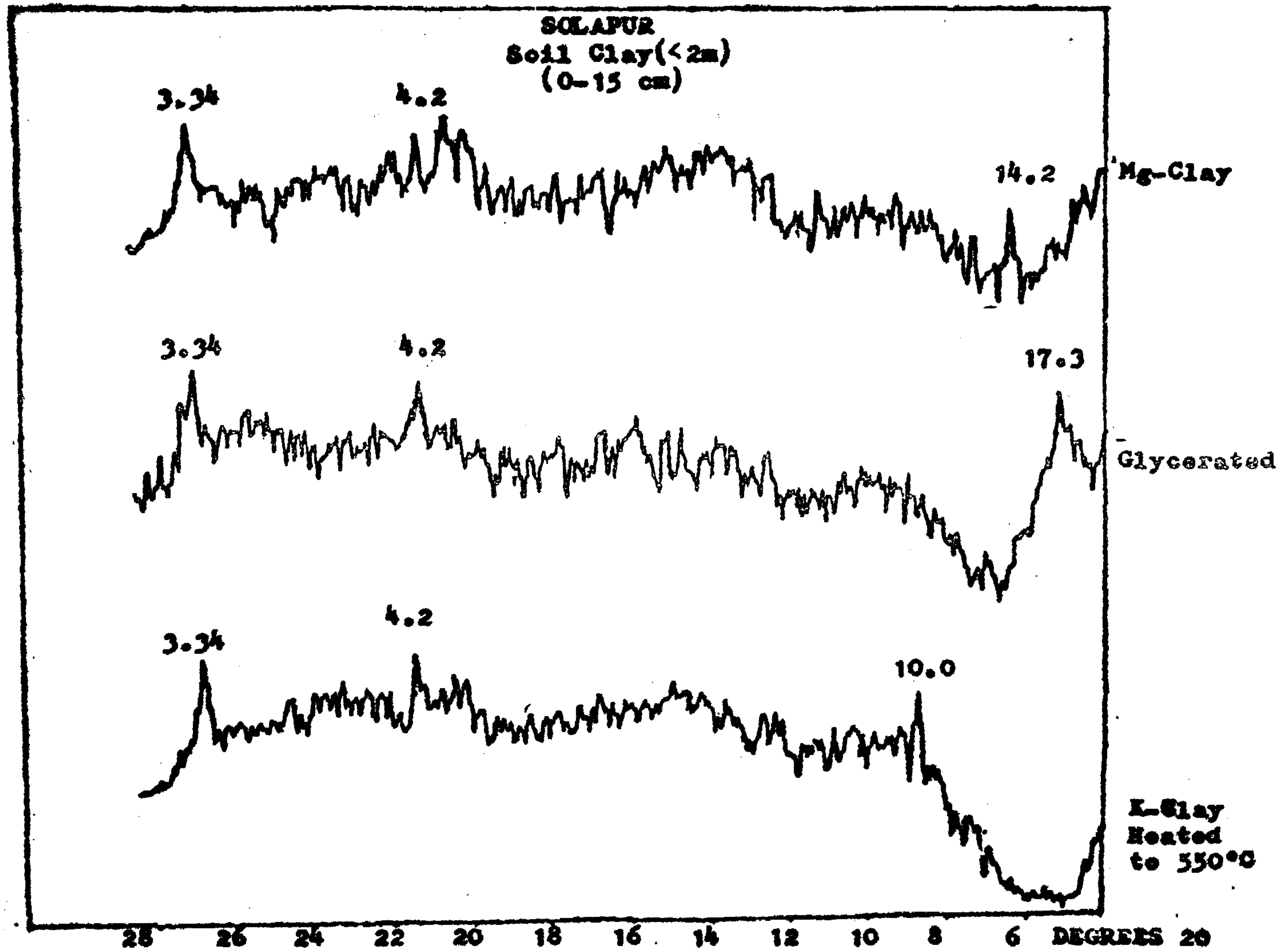


FIG.5. X-RAY DIFFRACTOGRAMS OF SOLAPUR SOIL CLAY SEPARATED FROM 0-15 cm LAYER

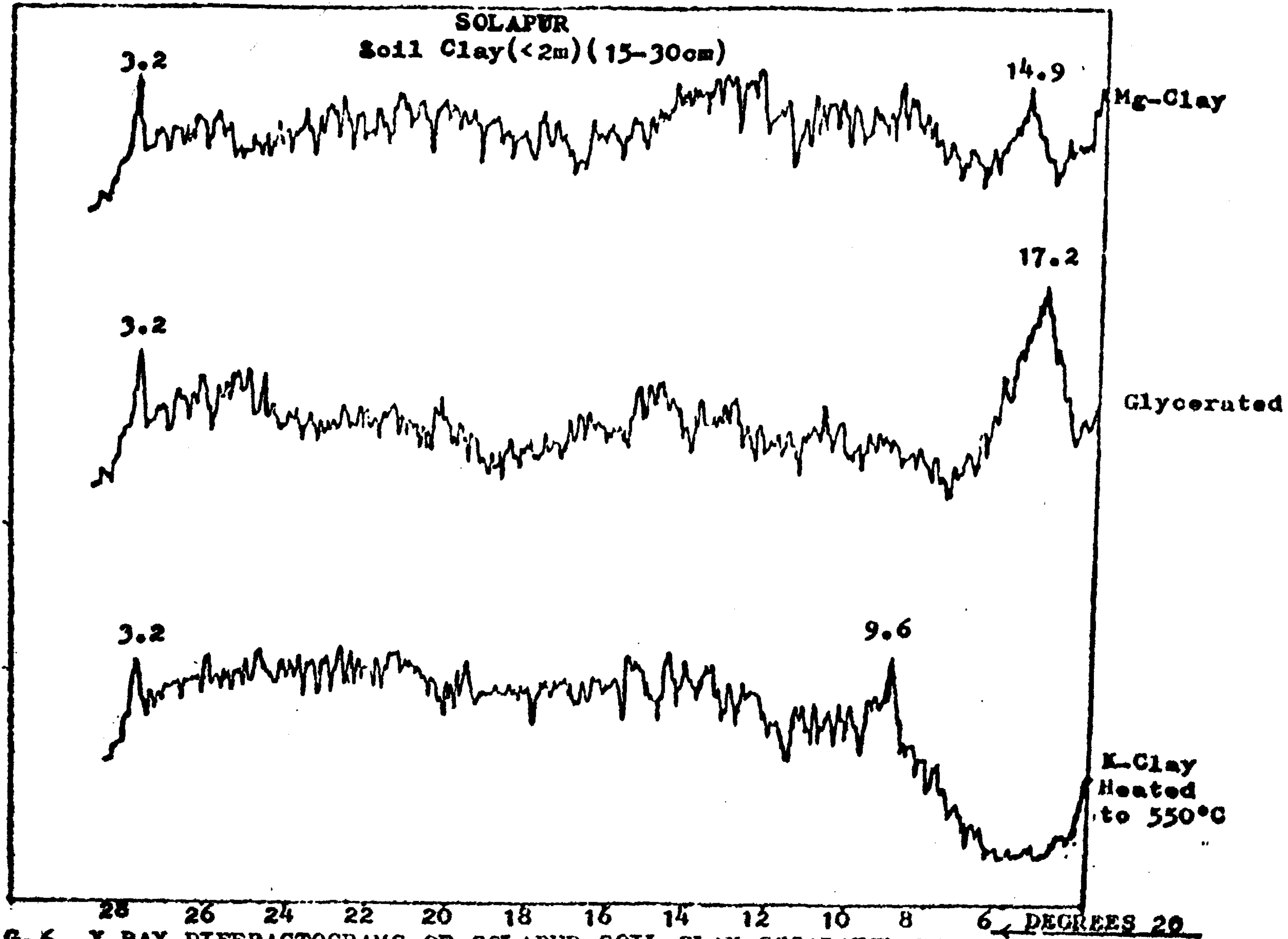


FIG.6. X-RAY DIFFRACTOGRAMS OF SOLAPUR SOIL CLAY SEPARATED FROM 15-30 cm LAYER.

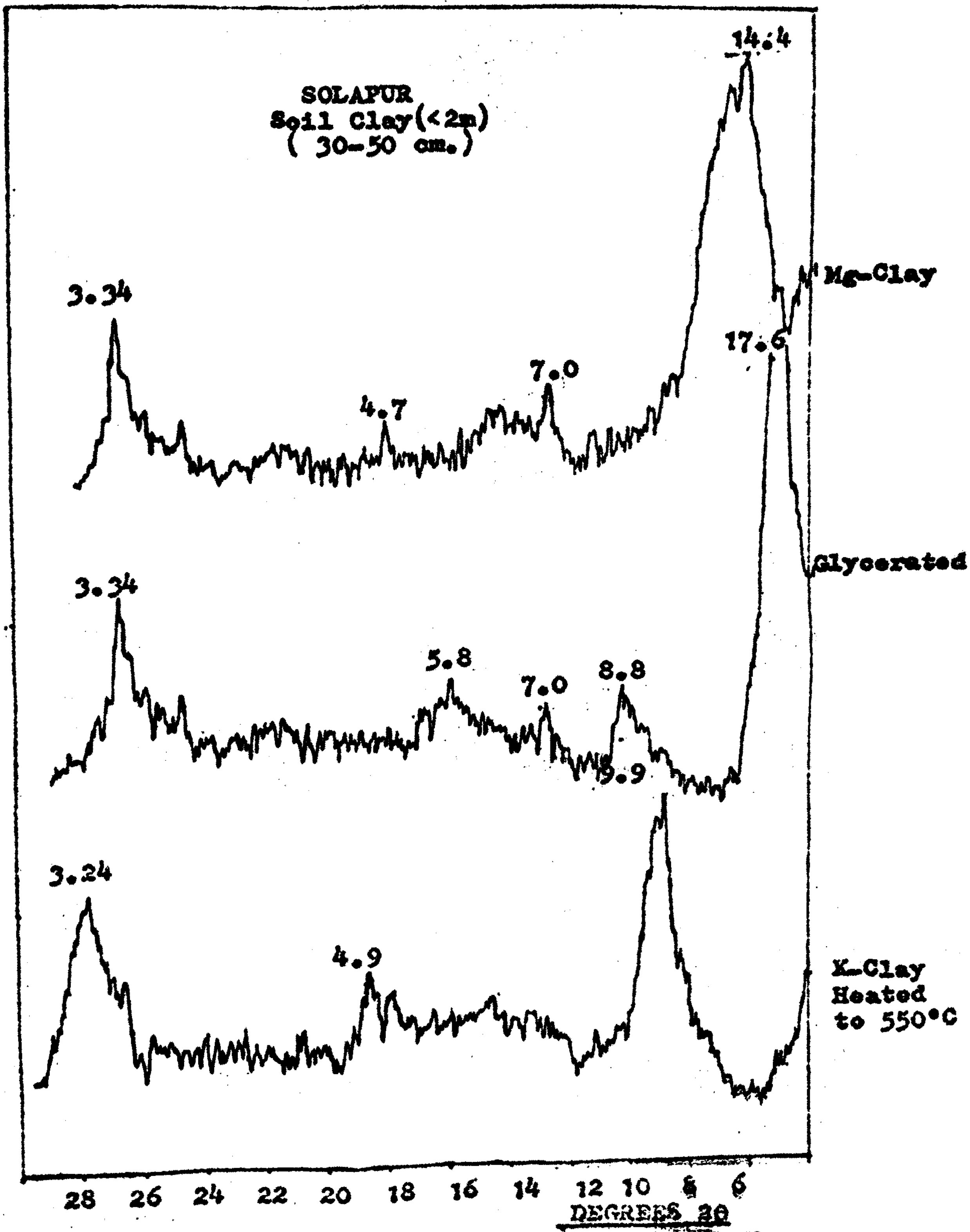


FIG.7. X-RAY DIFFRACTOGRAMS OF SOLAPUR SOIL CLAY SEPARATED FROM 30-50 cm. LAYER.

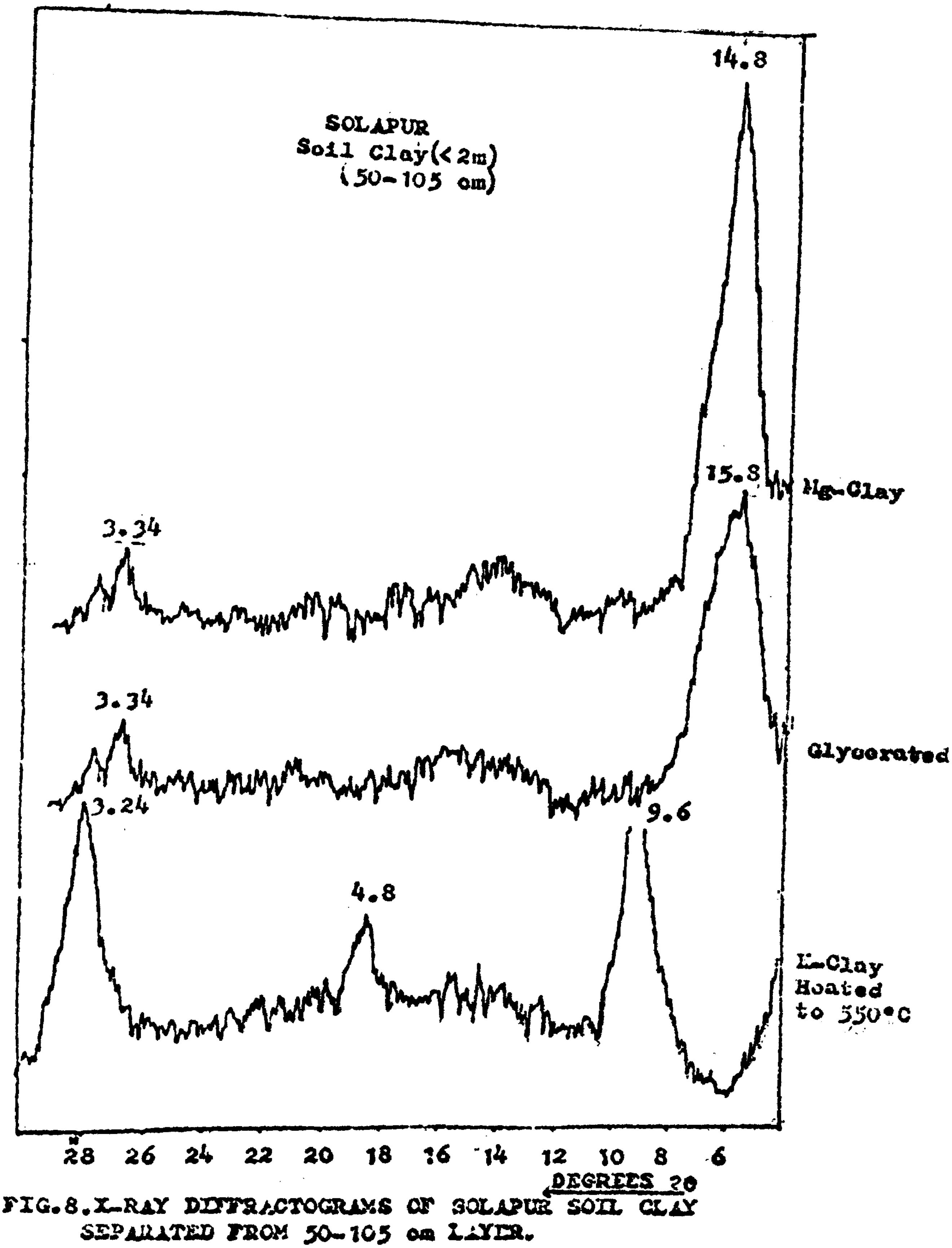


FIG.8.X-RAY DIFFRACTOGRAMS OF SOLAPUR SOIL CLAY SEPARATED FROM 50-105 cm LAYER.

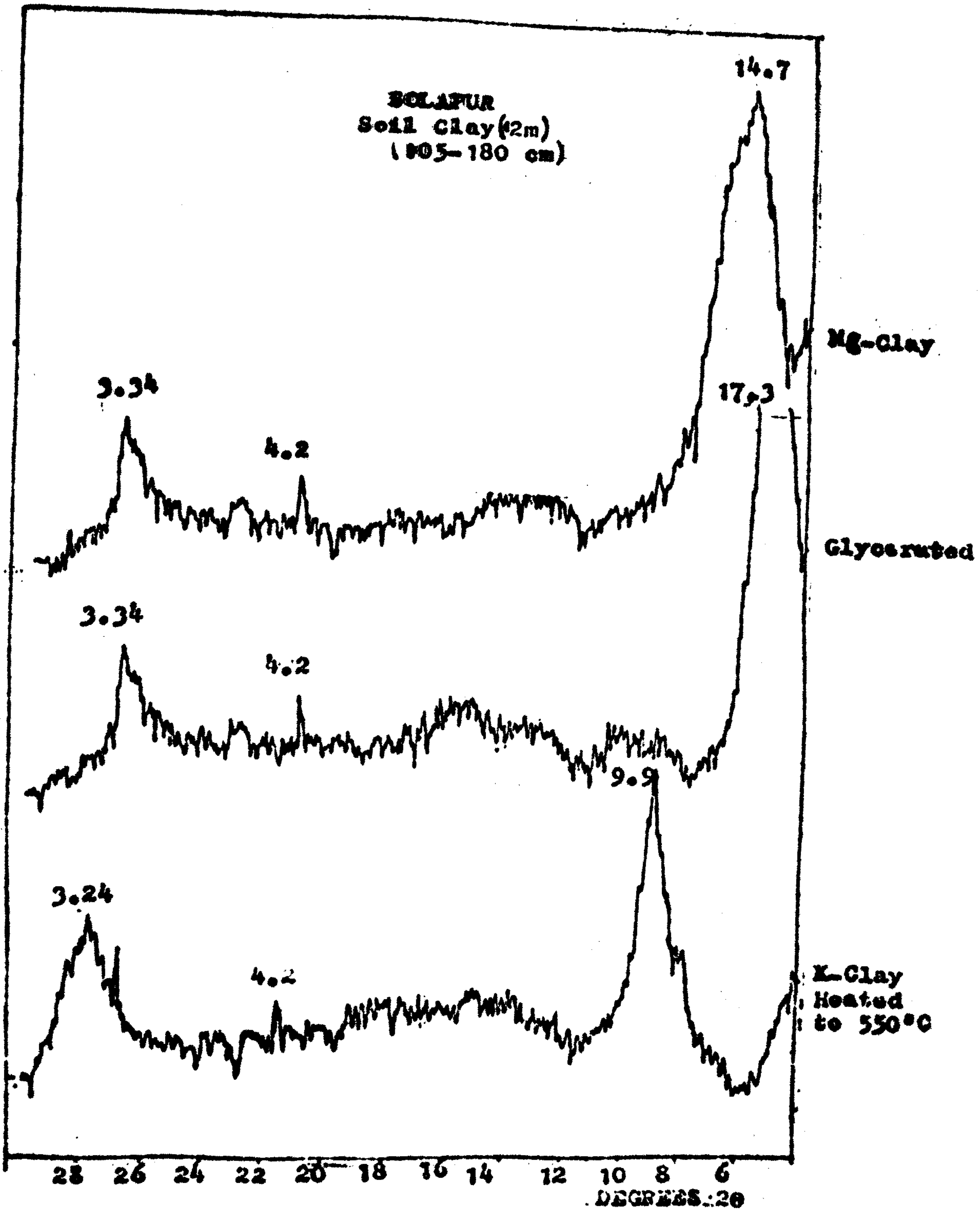


FIG. 9.X-RAY DIFFRACTOGRAMS OF SOLAPUR ←
SOIL CLAY SEPARATED FROM 105-180 cm. LAYER.

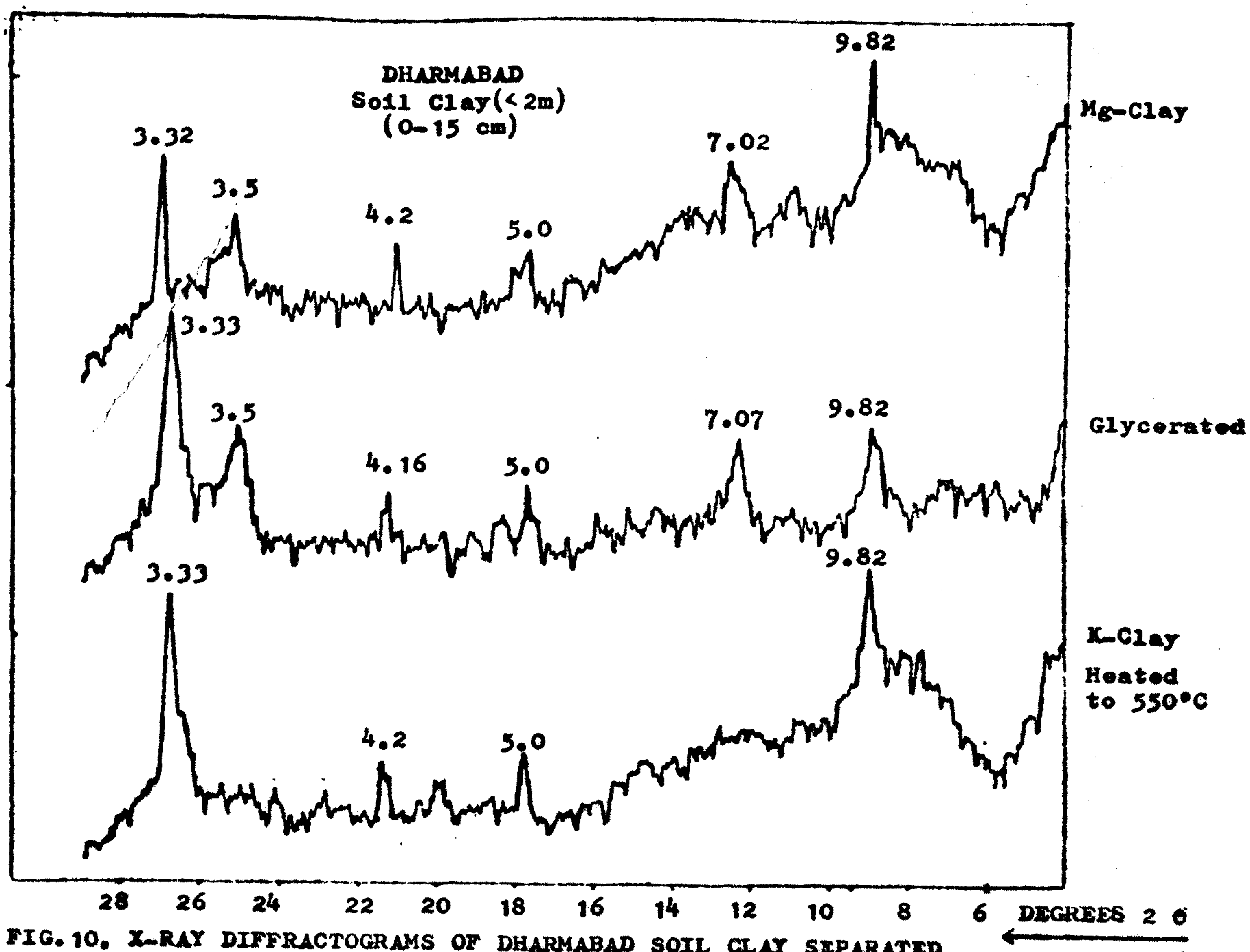


FIG. 10. X-RAY DIFFRACTOGRAMS OF DHARMABAD SOIL CLAY SEPARATED FROM 0-15 cm LAYER.

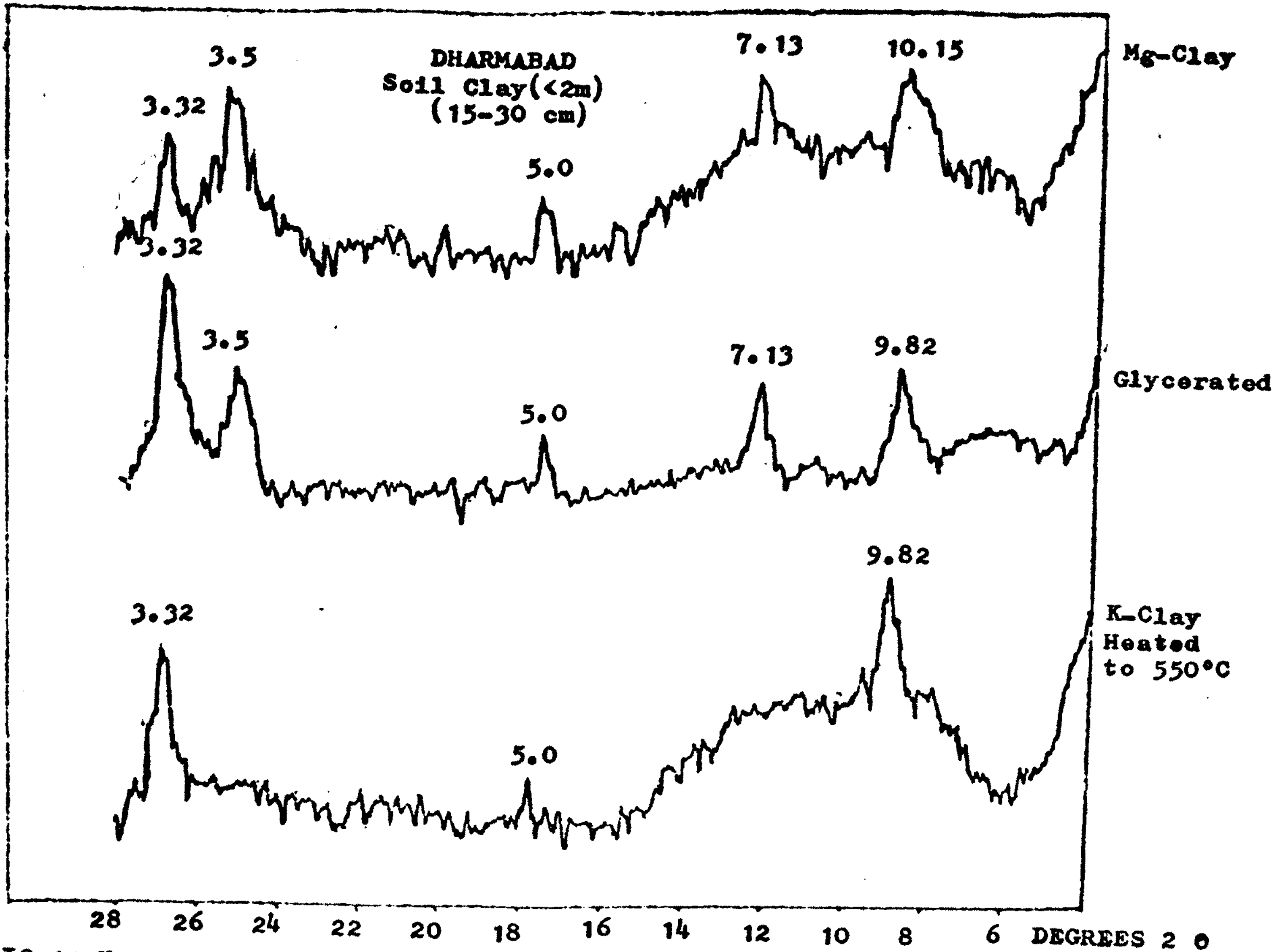


FIG.11.X-RAY DIFFRACTOGRAMS OF DHARMABAD SOIL CLAY SEPARATED FROM 15-30 cm LAYER.

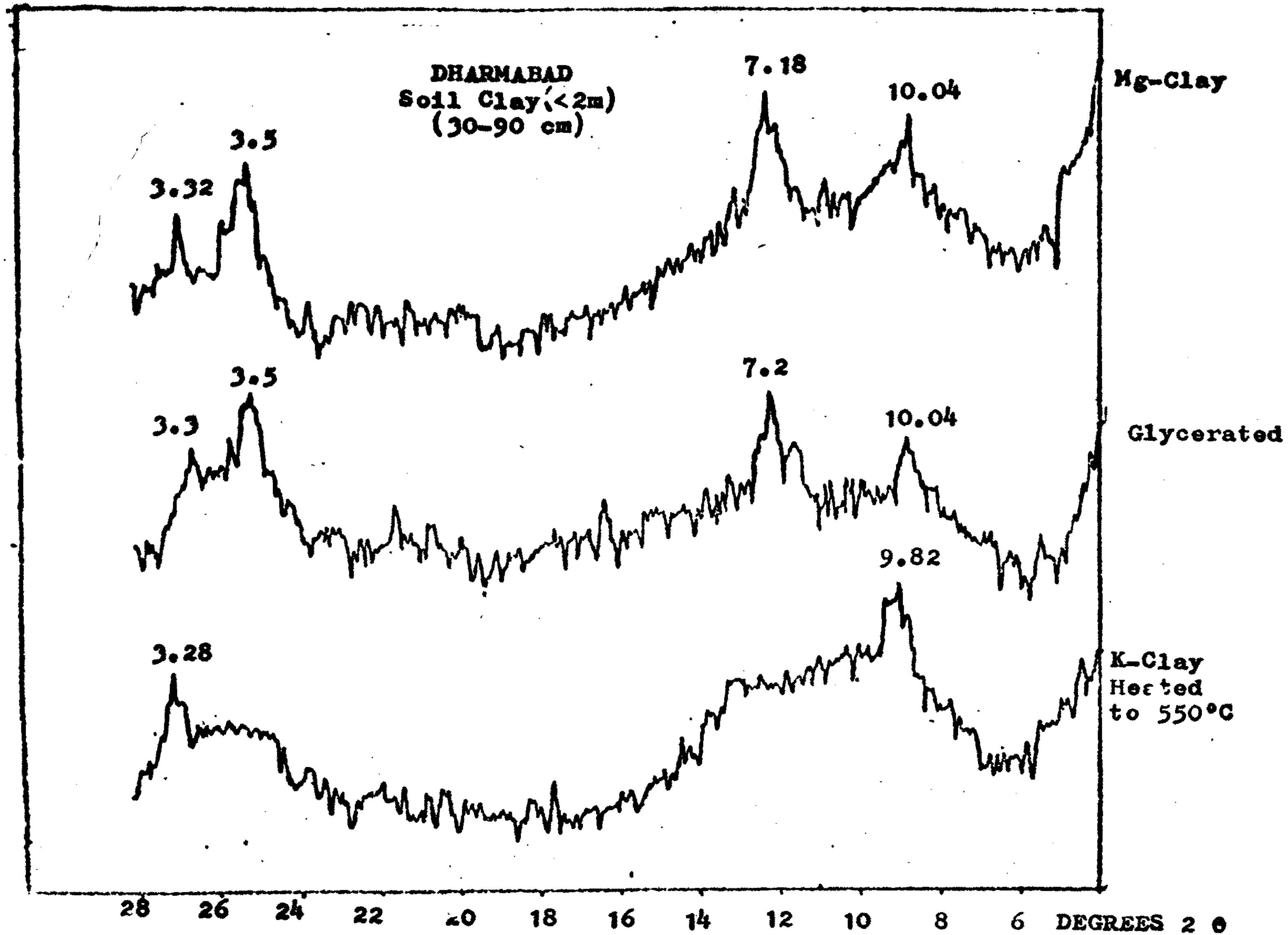


FIG. 12. X-RAY DIFFRACTOGRAMS OF DHARMABAD SOIL CLAY SEPARATED FROM 30-90 cm LAYER.

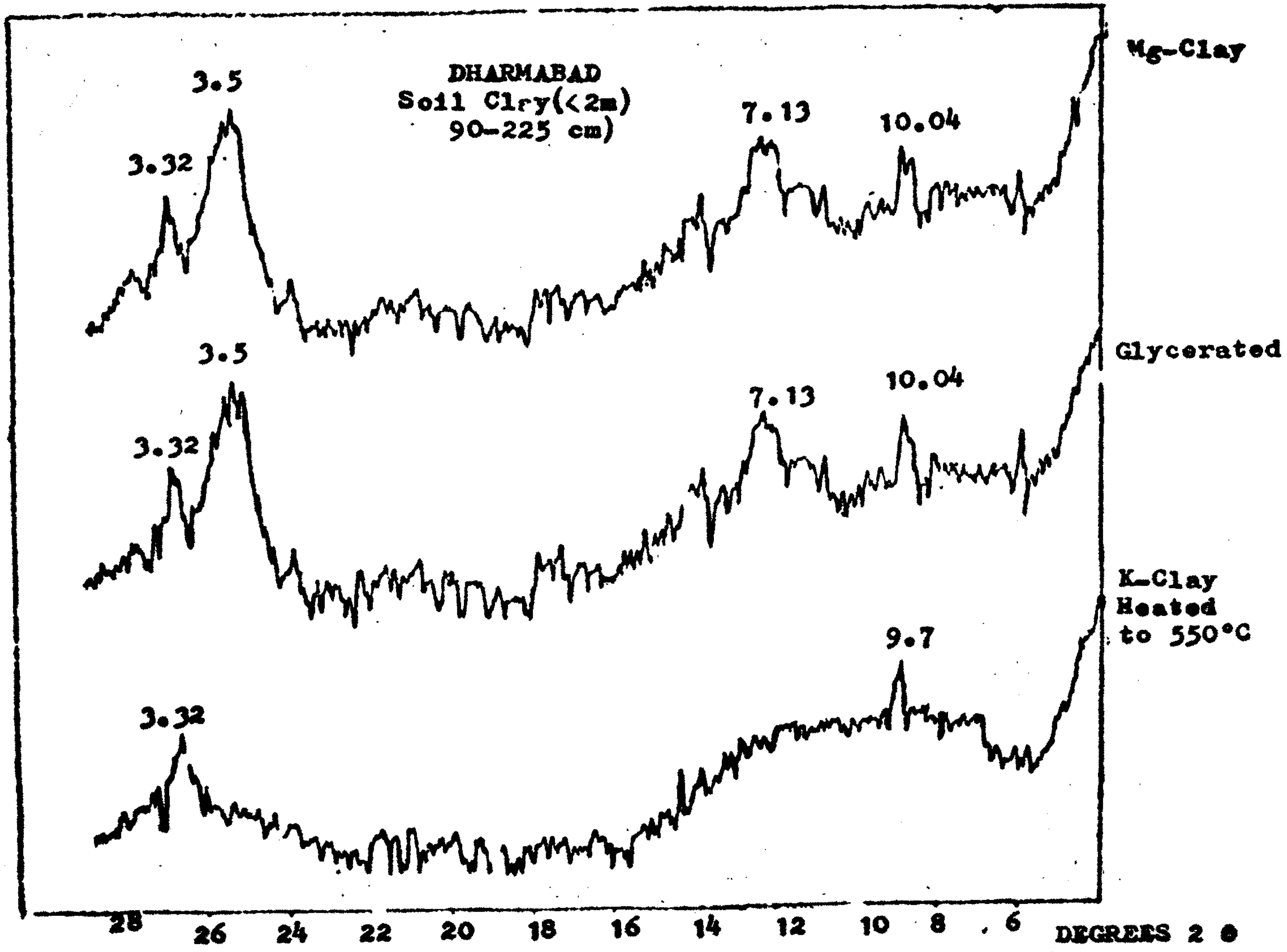


FIG. 13. X-RAY DIFFRACTOGRAMS OF DHARMABAD SOIL CLAY SEPARATED FROM 90-225 cm LAYER.

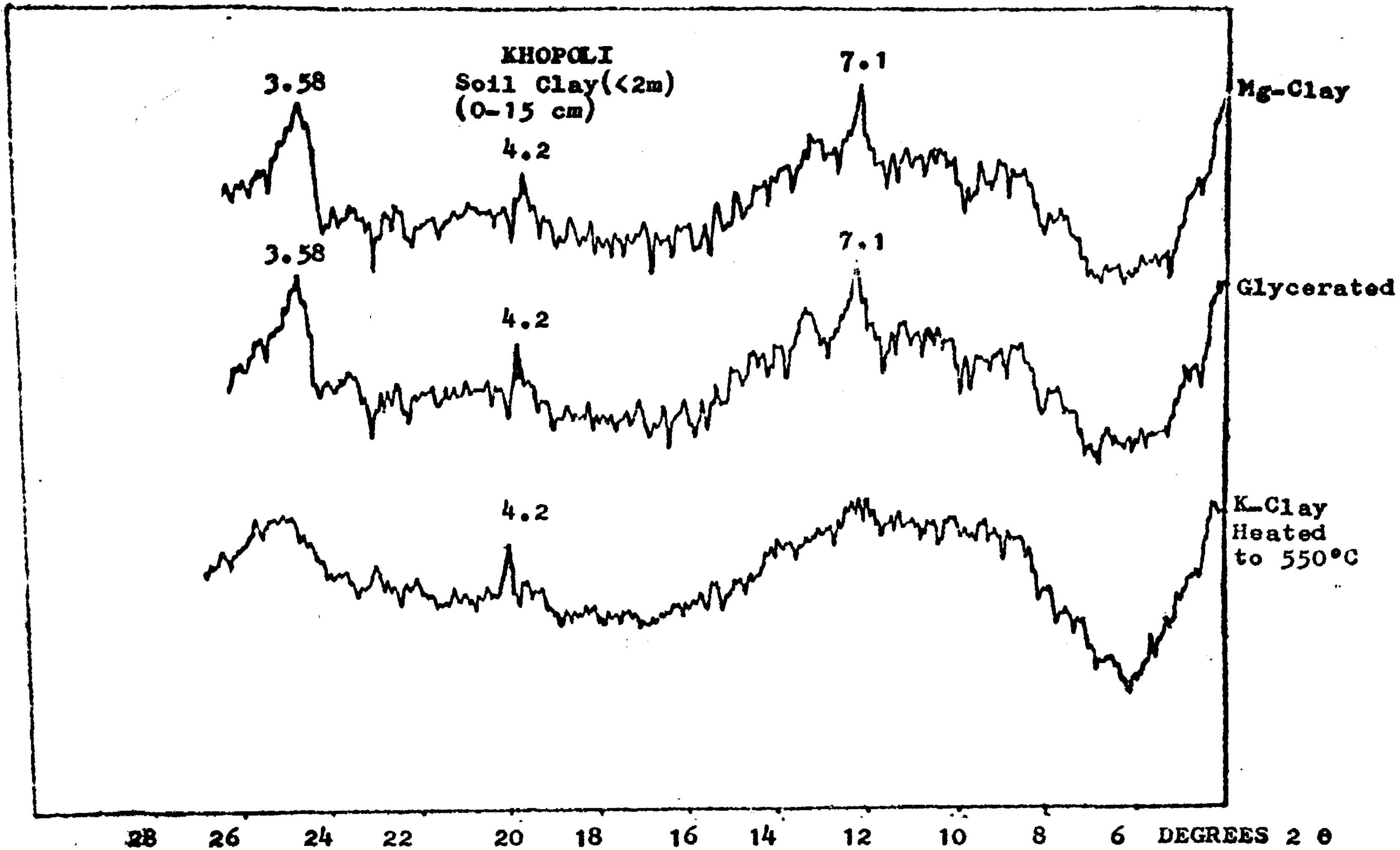


FIG. 14. X-RAY DIFFRACTOGRAMS OF KHOPOLI SOIL CLAY SEPARATED FROM 0-15 cm LAYER.

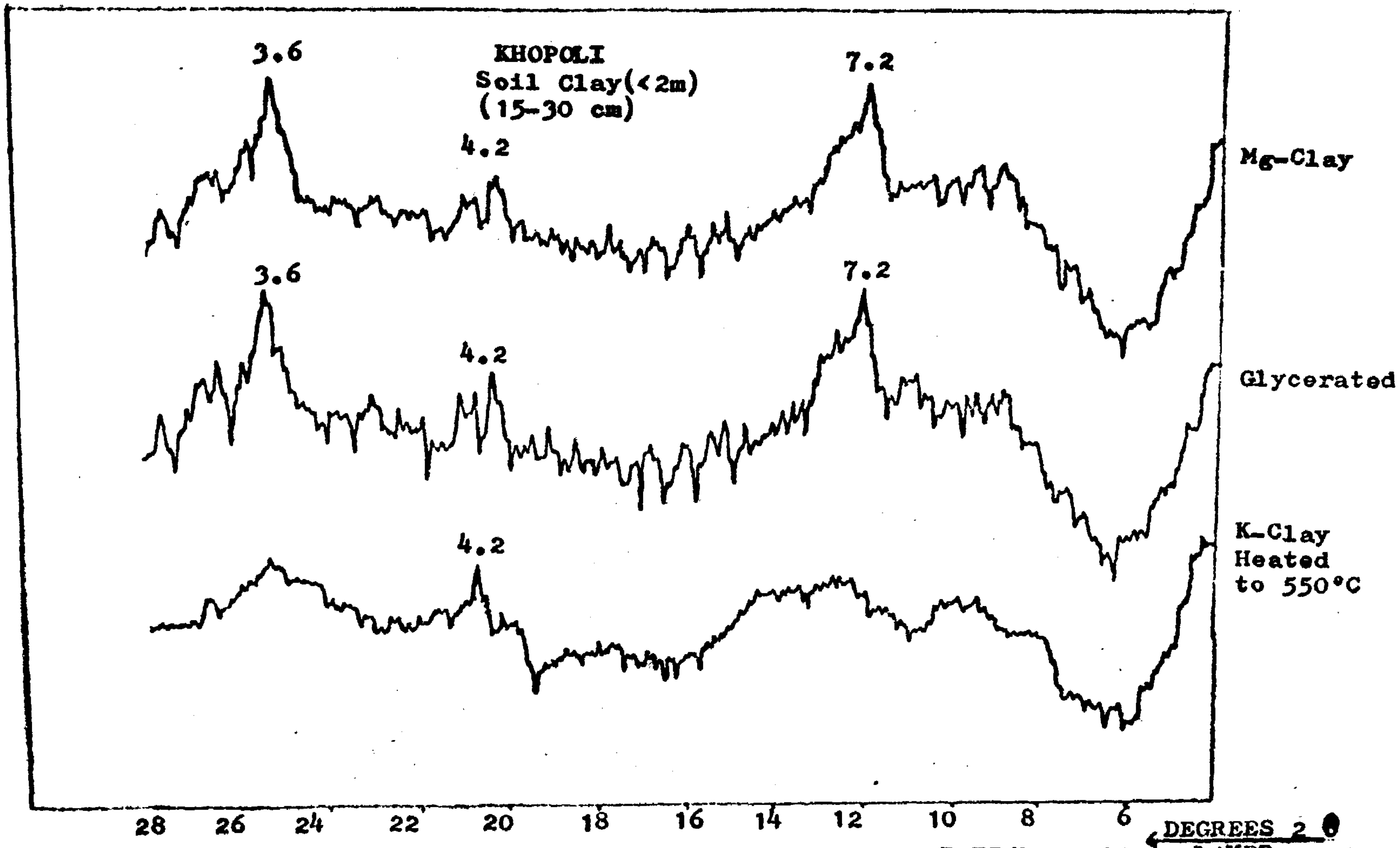


FIG. 15. X-RAY DIFFRACTOGRAMS OF KHOPOLI SOIL CLAY SEPARATED FROM 15-30 cm LAYER.

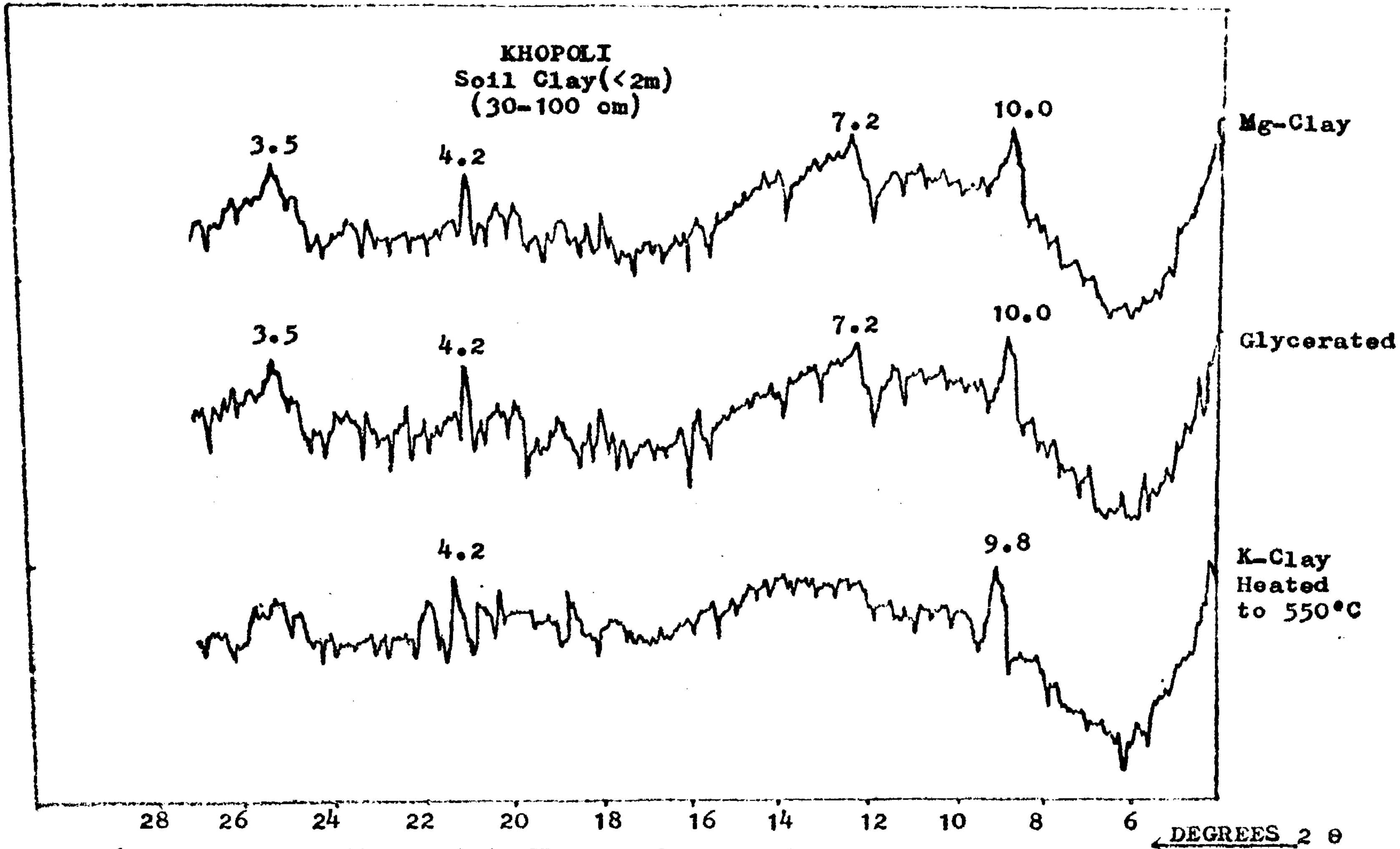


FIG.16. X-RAY DIFFRACTOGRAMS OF KHOPOLI SOIL CLAY SEPARATED FROM 30-100 cm LAYER.

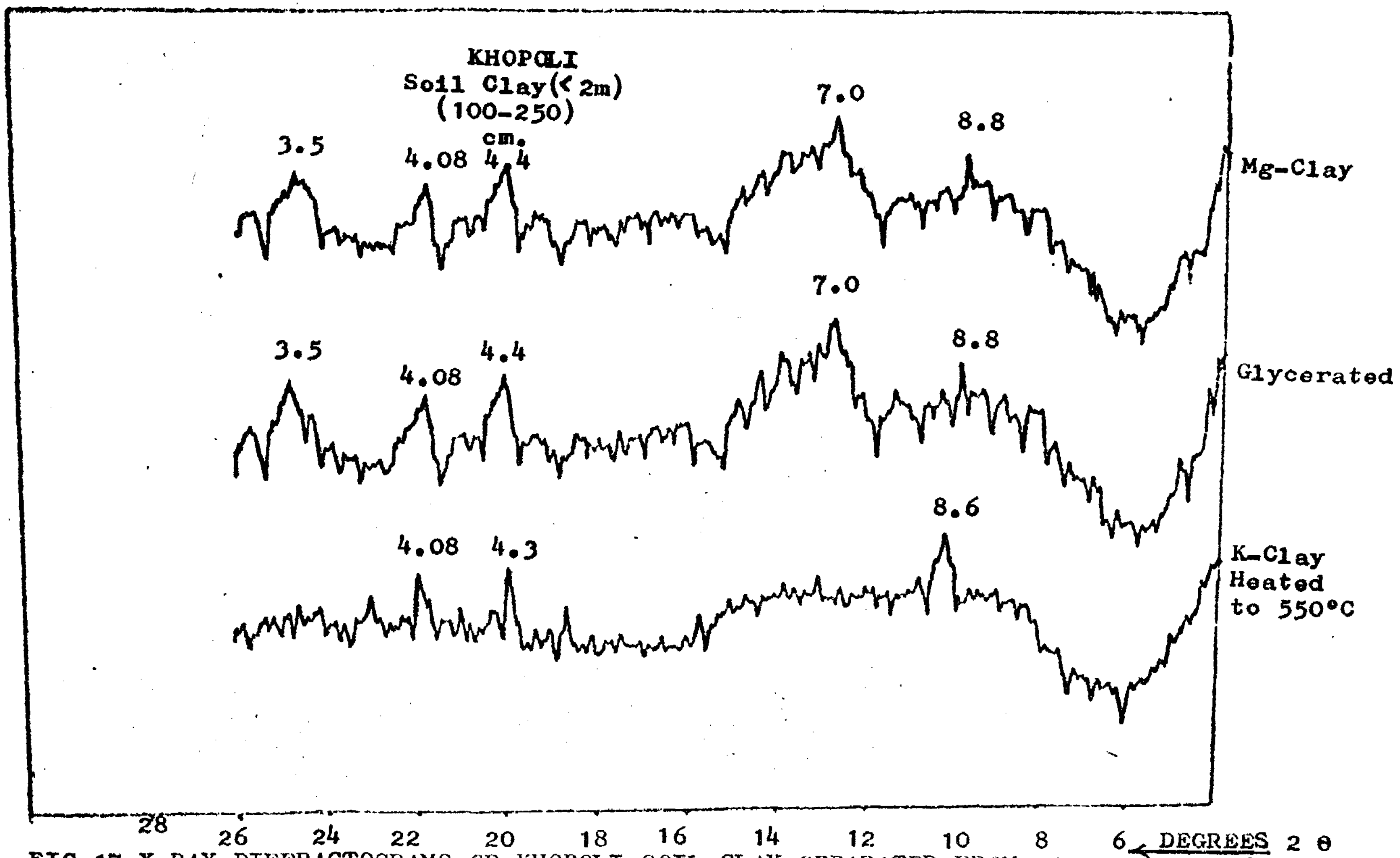


FIG.17.X-RAY DIFFRACTOGRAMS OF KHOPOLI SOIL CLAY SEPARATED FROM 100-250 cm LAYER.

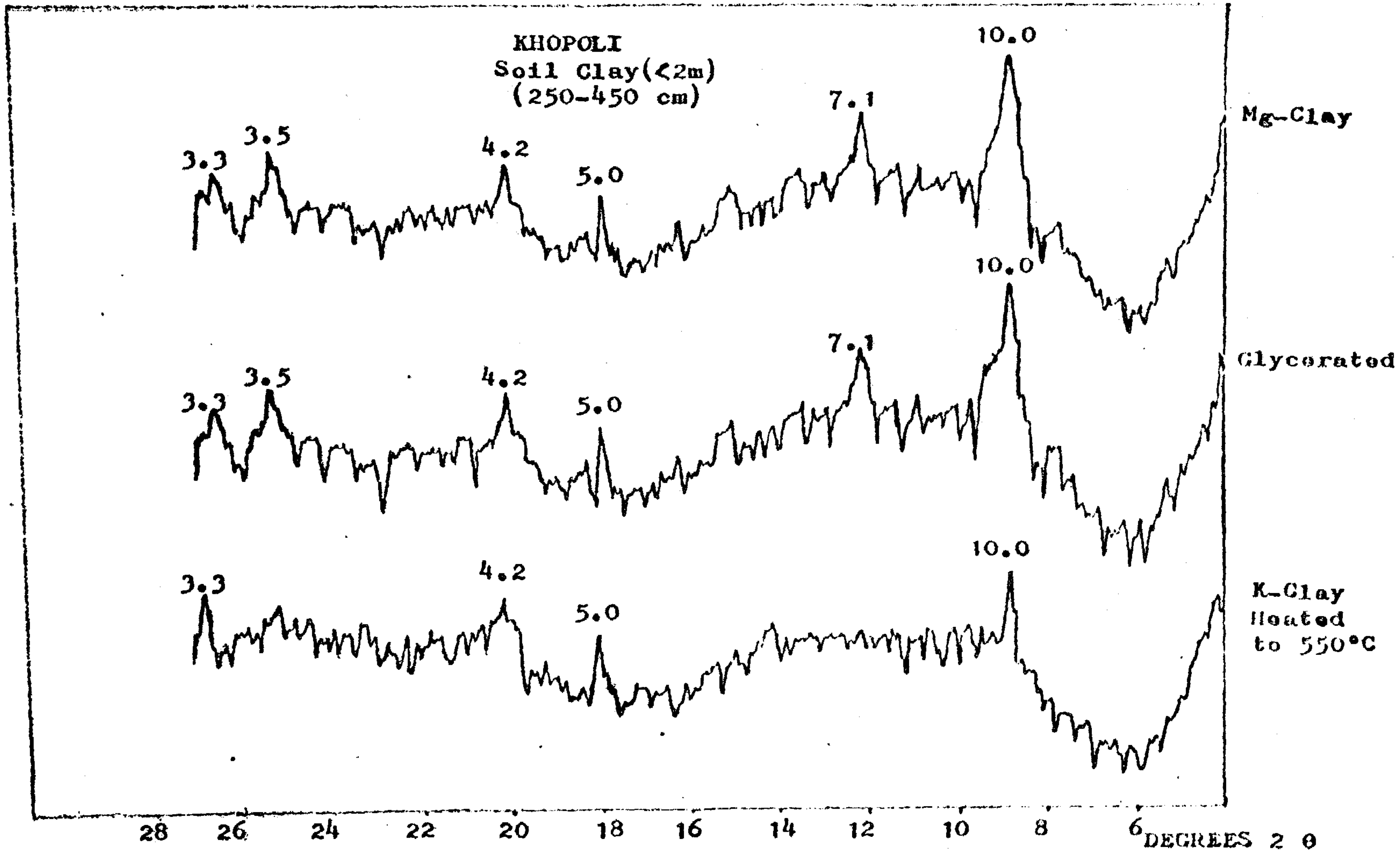


FIG. 18. X-RAY DIFFRACTOGRAMS OF KHOPOLI SOIL CLAY SEPARATED FROM 250-450 cm LAYER.

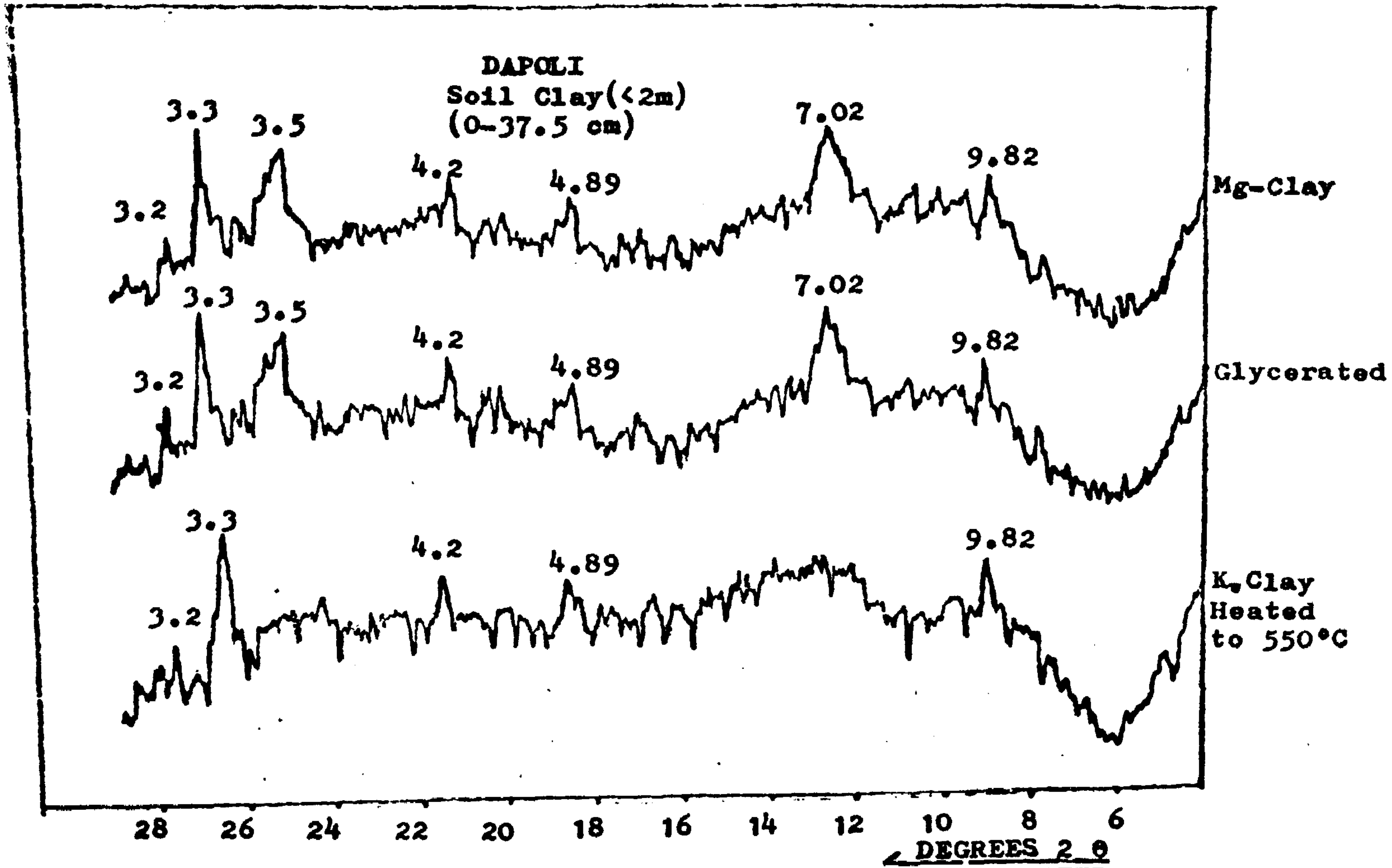


FIG. 19. X-RAY DIFFRACTOGRAMS OF DAPOLI SOIL CLAY SEPARATED FROM 0-37.5 cm. LAYER.

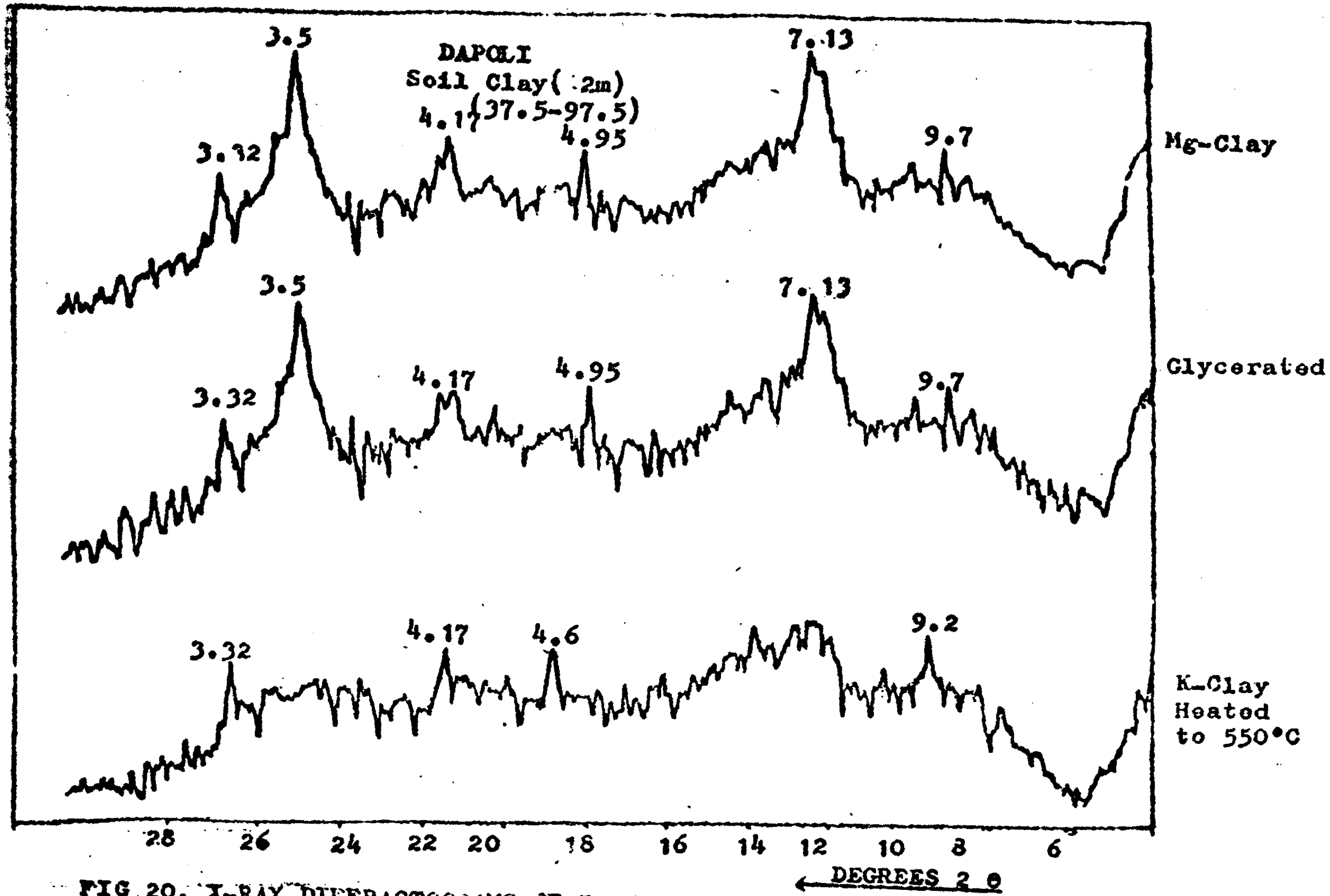


FIG.20. X-RAY DIFFRACTOGRAMS OF DAPOLI SOIL CLAY SEPARATED FROM 37.5-97.5 cm.LAYER

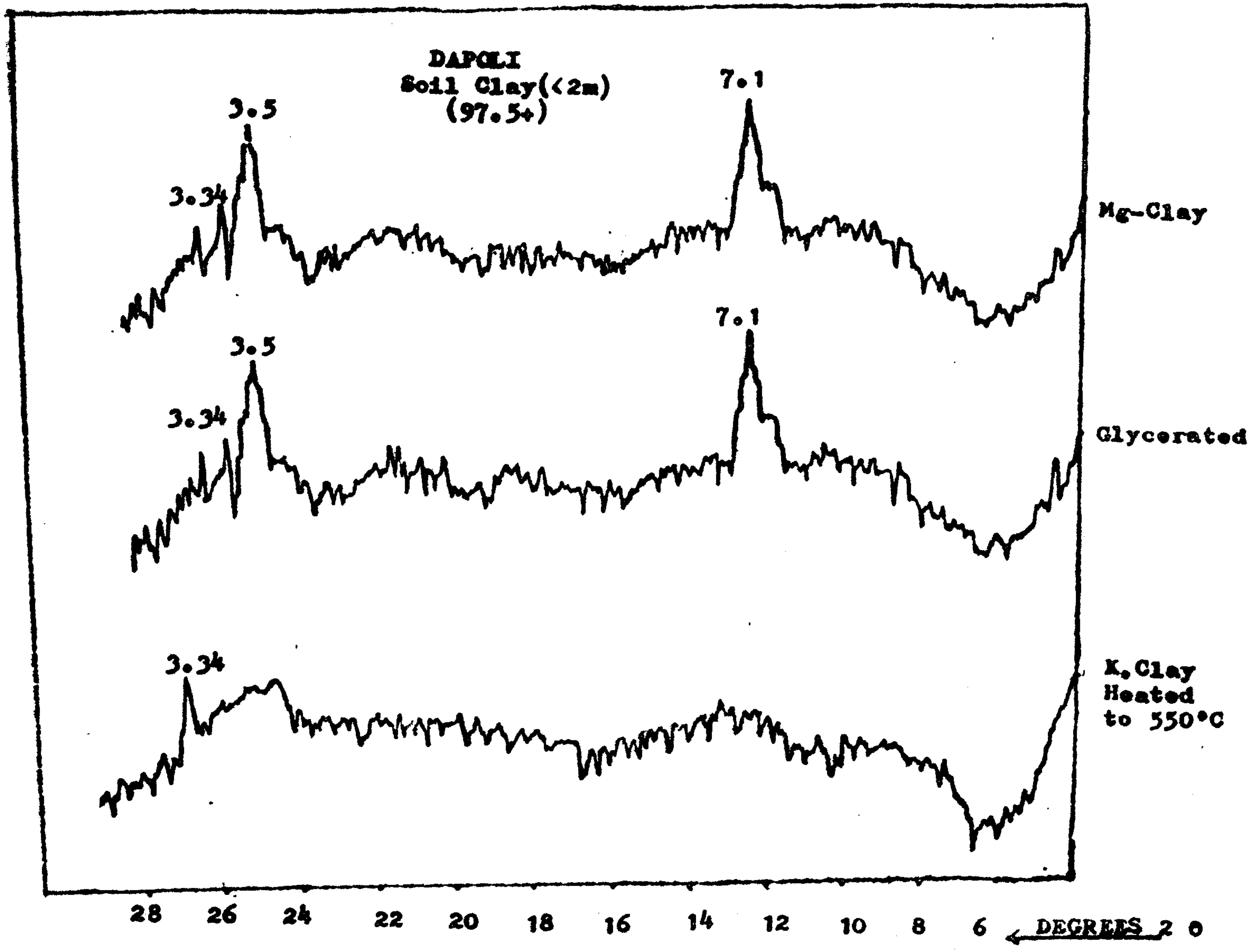


FIG.21. X-RAY DIFFRACTOGRAMS OF DAPOLI SOIL CLAY SEPARATED FROM 97.5+ LAYER

the presence of chlorite as a dominant clay mineral. Maniyar (1979) while working on normal and salt affected black soils of Parbhani district, has reported the presence of chlorite.

Kaolinite and geothite were reported in the laterite soil from Belgaum (Bagchi, 1951). Rao (1963) found kaolinite as the only mineral in Belgaum soil clay but in Ratnagiri illite was also present. A similar mineralogical composition of clays from Kadoli (Belgaum) was reported by Ghosh, Tomar and Datta (1972). Kaolinite and halloysite were the major clay minerals in the laterite soil clays in some area of Mysore and Kerala (Ghosh et al., 1962; Datta and Das, 1972). The laterite soils of Bihar contained kaolinite as the dominant mineral (Lal, 1955). The laterite soils, under all moisture regimes, in the central region of the Western Hills sloping westward in Kerala and Mysore states, were found (Gowaikar, 1972) to be dominated by the occurrence of kaolinite intermixed with small quantities of quartz.

The composition and texture of the parent rock are important in initial stages of weathering, but their importance decreases as the duration of weathering increases. Under conditions of drastic alteration, under humid conditions, the influence of parent rock is relatively short lived,whereas in aridic zonal soils it prevails almost indefinitely. It has been observed that soils containing kaolinite and soils containing smectite can both be developed on the same parent rock under different conditions of climate, topography and time.

The most important factor of composition in parent rocks is the content of alkalies and alkaline earths. Rocks containing no alkalies can yield only kaolinite or lateritic weathering products. The basalt rocks, which is the parent material in most of the soil profiles under investigation, are rich in iron and magnesium bearing minerals and calcic plagioclase feldspars. These minerals keep the base status and pH high, as long as they persist. The soil clay minerals tend to be kaolinite and halloysite if the soil is well drained, as seen in Khopoli and Dapoli profiles, but montmorillonite if the soil is poorly drained or is in a region with a distinct dry season, as evident from the Solapur soil profile.

From studies conducted on the effect of parent material and weathering environment on the genesis of clay minerals, Datta and Adhikari (1968a, 1968b, 1969) indicated that under pronounced acid leaching conditions with low content of alkali and alkaline earth cations in the weathering zone as is likely to be present as predominant clay mineral, but when K ion is fairly high in the weathering zone, illite will be the major clay constituted when the intensity of weathering is low or moderate, as in the case of semi-desert to semi-arid region, and the soil contains a high proportion exchangeable alkaline earth cations like Ca and Mg, montmorillonite or vermiculite type of clay mineral will be expected in the soil. Illite dominated clays are usually found to be associated with K bearing minerals in the soil.

4.7 Distribution of clay minerals in various soil profiles:

4.7.1 Parbhani profile:

Looking to the data in Table 5 and Figs. 1 to 4, it can be concluded that the dominant clay mineral in the surface horizon is chlorite. The quantitative chemical mineralogical analysis (Table 4) also confirm the presence of chlorite as dominant clay mineral in the surface horizon of Parbhani profile. The other clay minerals present along with chlorite are kaolinite, mica, vermiculite and quartz in lesser proportions. Chlorite dominates in all the horizon of Parbhani profile except the third layer (Fig.3) which indicates the dominance of vermiculite. In almost all the horizons, presence of kaolinite and quartz is noticed with an increase in the crystalinity of quartz down the profile.

4.7.2 Solapur profile:

The data in Table 5 and Figs. 5 to 9 indicate the presence of smectite as the dominant clay mineral in all the horizons of the Solapur profile. The other associated minerals found are mica, kaolinite and quartz. Presence of kaolinite can be observed in the third layer of the Solapur profile (Fig.7). The relative intensity of the smectite peaks is found to be increasing down the profile.

4.7.3 Dharmabad profile:

The 'd' values presented in Table 5 and the Figs. 10 to 13 denotes the presence of mica, kaolinite and quartz, kaolinite and mica dominates in almost all the horizons. Presence of kaolinite and mica in greater quantity can also be seen in Table 4. The same table also indicates the presence of vermiculite and feldspar in the surface horizon. The 002 reflections of kaolinite are stronger down the profile (Figs. 10 to 13).

4.7.4 Khopoli profile:

The 'd' spacings in Table 5 and the Figs. 14 to 18 indicates the presence of kaolinite, mica and quartz. Figures 14 and 15 shows the presence of kaolinite and quartz only, whereas Figs. 16 to 18 indicates the presence of mica, kaolinite and quartz. But the chemical quantitative mineralogical analysis (Table 4 demonstrates the presence of kaolinite, mica, vermiculite, quartz and feldspar in the surface horizon of the Khopoli profile. Kaolinite dominates in the top four layer, but dominance of mica can be observed in the bottom layer (Fig. 18).

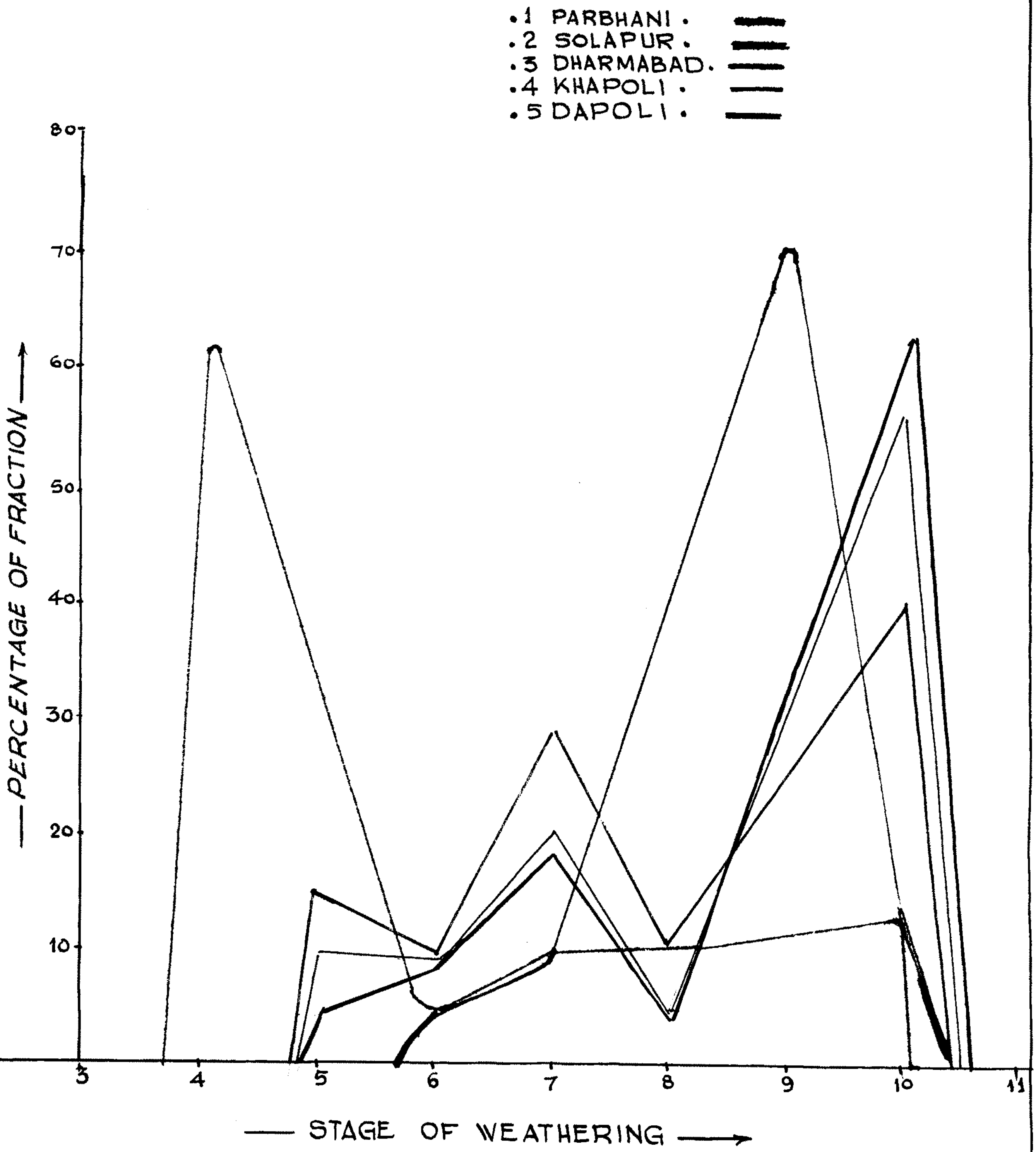
4.7.5 Dapoli profile:

Figures 19 and 20 and 'd' values in Table 5 show the presence of mica, kaolinite and quartz. Out of them kaolinite seems to be the dominant clay mineral. Figure 21 indicates the presence of only kaolinite and quartz in the bottom layer of Dapoli profile. Dominance of kaolinite clay mineral can also be confirmed from the data presented in Table 4. The other associated minerals found in the surface horizons are mica vermiculite, quartz and feldspar.

4.8 Frequency distribution curve of minerals in the surface soil clays from different profiles of Maharashtra State:

The frequency distribution curves have been plotted to assess the stage of weathering. Here the percentage composition of the clay size minerals have been plotted against weathering index (Jackson, 1964). The frequency distribution curves of minerals for the surface samples of five profiles from different agroclimatic zones of Maharashtra State (Fig. 22) indicates that the Parbhani profile gives two peaks, one at 4th stage of weathering and the other at 10th stage. The peak at 4th stage of weathering is the dominant one. Solapur profile has given only one peak and that too at 9th stage of weathering. The curve of surface sample of Dharmabad profile is characterised by three peaks of weathering indices 5, 7 and 10. The red and lateritic profiles of Khopoli and Dapoli are having two peaks each, one at 7th stage of weathering and the other at 10th stage of weathering. The weighted average of index numbers (weathering mean) for Parbhani, Solapur, Dharmabad, Khopoli and Dapoli profiles are 5.58, 8.80, 7.91, 8.43 and 8.71 respectively (Table 4) for surface samples. This mean increases as a function of the time and intensity of weathering of the soil. This is to say, the distribution curve moves to a position further to the right in Fig.22 as the soil reflects increased chemical weathering in its development. The chemical weathering can be written in the

•FIG: 22 •FREQUENCY DISTRIBUTION CURVE OF MINERALS IN THE SURFACE SOIL CLAYS FROM DIFFERENT PROFILES OF MAHARASHTRA STATE



order of Parbhani > Solapur > Dharmabad > Khopoli > Dapoli. Dapoli profile seems to be more matured and the Parbhani is least. The weathering mean values indicate that the weathering is slow in Parbhani profile and is comparatively greater in Dapoli soil profile.

4.9 Mineralogical analysis of fine sand fractions:

The importance of primary minerals comprising the rock in weathering and soil genesis is useful in the fact that mostly igneous rock which constitute the major part of the parent material, together with sedimentary and metamorphic rocks, are composed of these minerals. As primary minerals constitute the original source of all chemical elements and thereby determines a particular ionic environment under a particular type of climatic condition, the mineralogical composition of the non-clay fractions of soil comprising of a number of primary minerals with different degree of stability and chemical activity will contribute to the much needed information about the genetic correlation between rock and soil and the effect of weathering processes on the disintegration and disappearance of minerals and the formation of new secondary minerals or clay minerals.

The fine sand fraction (0.2 to 0.02 mm) of the soil from different horizons of the various profiles was subjected to the mineralogical analysis. After removal of iron oxide stains, it was separated into two groups. The heavies (specific gravity more than 2.85) and the lights (specific gravity less than 2.85). These fractions were mounted on glass slides for further examination under a petrographic microscope. The relative abundance of the minerals are reported in Table 6 and 7.

The analysis show an increase in the weatherable minerals and decrease in the resistant minerals down the profile in almost all the soil profiles under investigation, suggesting decreased weathering with depth. The only difference is that the intensity of weathering is more in Khopoli and Dapoli profiles as compared to rest. Olivine, which is more weatherable mineral, has completely disappeared in the surface horizons of Khopoli and Dapoli profiles suggesting its complete decomposition in the surface horizons of profiles receiving much higher amount of rainfall. Minerals having medium weatherability show an increase down the profile in Parbhani and Solapur profiles and a sharp decrease down the profiles of Dapoli and Khopoli.

On weathering feldspar gives rise to clay while most of Ca, Na and Si portion of the original mineral is leached off. The weathering products of augite are carbonates of Ca, Mg,Si, aluminous clays and iron hydroxide. Under high rainfall where the weatherability of the minerals tends to increase considerably, carbonates of Ca, Mg and Si form solution and thus most of them are removed from the soils. This increases the clay and iron-hydroxide (limonite) content. That is why iron-hydroxide show higher percentage in soils from high

Table 6: Occurrence of minerals in heavy sand fractions at different locations:

Profile	Depth in cms	Augite	Diop-side	Epidote	Horn-blende	Magne-tite ilmenite	Limo-nite	Zircon	Garnet	Tourma-line	Olivine
Parbhani	0-40	+	Tr	-	-	++	-	-	-	-	+
	40-100	++	+	Tr	Tr	+	Tr	-	-	-	++
	100-170	++	+	+	Tr	+	-	-	-	-	++
	170-270	+++	+++	+	-	Tr	Tr	-	-	-	+++
Solapur	0-15	-	-	-	-	++	-	-	-	-	+
	15-30	+	+	-	-	+	-	-	-	-	+
	30-50	++	+	Tr	Tr	+	Tr	-	-	-	++
	50-105	+++	++	+	Tr	+	Tr	-	-	-	++
	105-180	+++	+++	+	-	Tr	-	-	-	-	+++
Dharma-bad	0-15	-	-	-	Tr	Tr	Tr	-	++	+	-
	15-30	-	-	-	+	Tr	Tr	Tr	++++	+	-
	30-90	-	-	-	Tr	-	-	Tr	+++	-	-
	90-225	-	-	-	-	-	-	-	++	-	-
Khopoli	0-15	+++	+	Tr	-	+++	+++	++	-	++	-
	15-30	++	++	Tr	Tr	++	++++	+	-	+	-
	30-100	++	++	Tr	Tr	++	++	+	-	+	+
	100-250	+	+	-	-	+	+	Tr	-	+	+
	250-450	+	Tr	-	-	+	+	-	-	Tr	++
Dapoli	0-37.5	+++	++	+	-	++++	+++	++	-	++	-
	37.5-97.5	++	+	Tr	-	+++	++++	+	-	+	+
	97.5 +	+	Tr	Tr	-	++	+++	+	-	+	++

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Table 7: Occurrence of minerals in light sand fraction at different locations:

Profile	Depth in cms	Quartz	Feldspar	Zeolites	Mica
Parbhani	0-40	++++	++	Tr	+
	40-100	+++	++	+	+
	100-170	+++	+++	++	Tr
	170-270	++	+++	++	Tr
Solapur	0-15	++	++	Tr	+
	15-30	++++	++	+	Tr
	30-50	+++	+++	++	+
	50-105	+++	+++	++	+
	105-180	+++	++++	++	Tr
Dharmabad	0-15	++	++++	+	++
	15-30	+++	+++	+	+++
	30-90	+++	+++	+	+++
	90-225	++++	++	++	++++
Khopoli	0-15	++	++++	+	+
	15-30	++	+++	++	+
	30-100	+++	+++	+	+
	100-250	++++	++	+	++
	250-450	++++	++	Tr	++
Dapoli	0-37.5	++	++++	+	+
	37.5-97.5	+++	+++	+	+
	97.5 +	++++	++	Tr	+

++++ = Most abundant +++ = More abundant ++ = Abundant

\+ = Rare Tr = Traces -= Absent

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rainfall region. Most of the Si is leached away though a part of it crystalizes to form secondary quartz. The percentage of such quartz is also low in high rainfall region. In low rainfall regions, due to steady weathering, most of the soluble weathered products are retained in the soil and only partly they are leached, thereby allowing the retention of Ca,Mg and Si are higher in the soils from low rainfall region.

Mineralogical analysis of the sand fractions of soils under study reveals that in all the profiles except Dharmabad, minerals characteristically of a basaltic origin are present. This leads to the conclusion that all the soils (except Dharmabad) under investigation are derived from basaltic rocks. Presence of resistant minerals like garnet and a higher content of quartz and feldspar in Dharmabad profile denotes that these minerals are derived from granite-gneiss parent material. Similar results have also been reported by Godse (1957) and Karale (1958).

Sant and Tamhane (1958) while working on basaltic soils under varying rainfall conditions observed that under high rainfall conditions the intensity of weatherable minerals like pyroxenes and plagioclase feldspars show a marked decrease down the profile. Limonite occurring in high proportion at surface horizons decreases sharply at lower horizons, whereas, secondary quartz show a reverse trend. Under low rainfall conditions, however, the intensity of weathering of the various minerals show a steady decrease down the profile.

Presence of augite, plagioclase, magnetite, ilmenite in the basalts of Deccan has been shown by Tamhane and Sen (1954). Magnetite enrichment occurred in almost all samples. Tamhane and Sen (1954) reported the presence of acid minerals like tourmaline and zircon in heavy fraction of basaltic soils. Tamhane and Namjoshi (1959) reported the presence of pyroxene, magnetite, ilmenite, limonite and apatite in the basaltic soils of Ahmednagar. Tamhane and Karale (1958) reported the presence of augite, diopside and epidote with fair amounts of magnetite and traces of ilmenite and olivine in basaltic soils of Bombay. Presence of augite along with others like ilmenite, magnetite, olivine and plagioclase feldspar in sand fraction of soils confirms their basaltic percentage (Ross and Hendricks, 1945). Gurcharan Singh and Krishna Murti (1974) reported the presence of quartz, feldsper and augite in sand fractions of basaltic soils of Madhya Pradesh. Gaikwad *et al*. (1974) have reported the presence of feldsper, quartz and muscovite as light mineral and haematite, magnetite and ilmenite followed by epidote, augite, chlorite, hornblende and traces of zircon, tourmaline, rutile and apatite in sand fractions of Nagpur soils developed on basalt parent material.

It is evident from the mineralogical analysis that the weathering of the basaltic rock under varying climatic conditions has produced different types of soils. In Khopoli and Dapoli profiles, receiving higher amount of precipitation, easily weatherable minerals have been weathered to a greater extent thereby increasing, the clay content, and the contents of soil components less susceptible to weathering occur in appreciable quantity.

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5. SUMMARY

With a view to study the morphology, chemical and physical characteristics, mineralogy and finally genesis of soils developed under varied climatic set-up exist in the state, five representative soil profiles were excavated from Parbhani (Nankheda), Solapur (Degaon), Dharmabad, Khopoli and Dapoli, under assured, scarcity transitional (moderately high rainfall) and intensive rainfall areas, respectively. The results emerged out are summarised:

1) Varied climatic conditions prevailing at various locations have resulted in imparting different colour, texture, structure and particle size distribution to the soils. The black soils of Nankheda and Solapur appeared to be clayey to clay loam while soils of transitional zone i.e. Dharmabad and high rainfall area (Khopoli and Dapoli) are sandy loam to sandy clay loam in texture.

2) Structurally, soils of Nankheda and Solapur are more or less same having strong subangular and medium angular blocky structure at the top and subsurface horizon, respectively. However, Dharmabad, Dapoli and Khopoli soils varies greatly in the structure throughout the profile.

3) Mechanical analysis indicate that soils developed under less rainfall have large amount of clay rather than soils developed under intensive rainfall area.

Clay was distributed with a definite trend within the profile. Clay content of soils increases with depth and decrease with depth under high rainfall and low rainfall areas, respectively.

4) Distribution of silt in the profile reveal that silt decreases with depth under soils receiving high rainfall while it increases with depth under soils receiving low rainfall.

5) Relatively larger quantities of coarse and fine sand fractions are noticed under higher precipitation as compared to low precipitation. Thus, decrease in clay content and increase of sand fractions indicate decreased weathering activity.

6) Distinct variations are registered in the content of free calcium carbonate in the soil profiles. Soils of Nankheda and Solapur are very rich in $CaCO_3$, however, traces of $CaCO_3$ are noticed in the profiles collected from Dharmabad, Dapoli and Khopoli. Due to intense precipitation, $CaCO_3$ may have leached away in the said profiles.

7) Relatively higher accumulation of organic carbon is observed in soils of high rainfall zone as compared to low rainfall zone. Further, organic carbon is found to decrease with depth in all the profiles.

8) High pH of Nankheda and Solapur soils are mainly attributed to the presence of high amount of $CaCO_3$ and less intensity of leaching of bases. However, Dharmabad, Dapoli and Khopoli soils showed exactly opposite soil reaction trend. The values of electrical conductivity followed the same trend to that of soil pH.

9) Base exchange properties indicate that clay has a major bearing on the cation-exchange capacity followed by silt and fine sand fractions. Dharmabad, Dapoli and Khopoli soils are lower in CEC against that of Nankheda and Solapur. The lower CEC of Dharmabad, Dapoli and Khopoli soils may be attributed to the presence of kaolinite and micaceous minerals. Further, CEC is increases with depth in profiles of Dapoli and Khopoli. This may be due to accumulation of clay of sub-surface horizon.

10) Calcium is a dominating cation followed by magnesium in most of the profiles. However, Dharmabad soils are dominated in potassium. Calcium ranges from 8.50 to 48.75 me/100 g. soil while magnesium varies from 1.15 to 16.0 me/100 g soil. Thus, it could be concluded that parent material is a major contributing factor in enriching the bases. CEC followed the trend as that of exchangeable bases in the soils of various profiles. Climate has a great bearing on the exchangeable bases.

particularly under soils of high rainfall zone.

11) The silica is distributed uniformly throughout the profiles except that of Dapoli, where considerable accumulation of silica has been noticed at the lower layers. However, silica varies from 50.75 to 60.35 and 40.2 to 55.0 per cent under low rainfall and high rainfall zone, respectively. High content of silica in Nankheda and Solapur soils may be due to presence of appreciable quantities of quartz and montmorillonitic type of clay minerals.

12) Sesquioxide content varies in the range of 26.50 to 48.42 per cent in the studied profiles. Relatively, Dapoli and Khopoli profiles contain Sesquioxide in larger quantities than Nankheda and Solapur. Thus, it can be assumed that rainfall is a limiting factor on the content of sesquioxide, because under heavy precipitation loss of silica may occur and inturn sesquioxide content may increase.

13) No uniform distribution of iron oxides is observed in the profiles under study. However, higher concentration of iron oxides is registered under soils receiving more rainfall rather than soils receiving low rainfall. The values obtained are extraordinarily higher as compared to the values of $Fe_2 0_3$ reported earlier.

14) Content of calcium and magnesium oxide bear an inverse relationship with rainfall.

15) Presence of titanium oxide is considerably high in almost all the profiles under investigation. The surface soil contain ordinarily less TiO_2 as compared to sub-surface horizon and narrow variation within the profiles was depicted.

16) Chemical composition of clays indicate same trend as that of whole soil analysis in respect of CEC, silica, sesquioxide, aluminium oxide, iron oxide, calcium oxide and magnesium oxide. However, clays derived from gneiss (Dharmabad) contain higher K_2O than those derived from basalt.

17) Obviously, lowering of silica/sesquoxide was observed under high rainfall conditions. Further, SiO_2/R_2O_3 ratio of Nankheda and Solapur profile reveals the presence of 2:1 type of lattice minerals. Low Al_2O_3/MgO ratio of clays of two profiles indicates 2:1 type minerals which is further confirmed by highest CEC possessing by these soils. However, molar ratios observed under Dapoli, Khopoli soils are still of lower magnitude, which lead to conclude the presence of kaolinitic type of clays. The narrower SiO_2/R_2O_3 and SiO_2/Al_2O_3 and high Al_2O_3/MgO ratios of soil clays depict a direct relationship with rainfall in Dapoli and Khopoli soils.

18) X-ray diffractograms indicate distinct variation in clay mineral assemblage under low and high rainfall zones. The Nankheda and Solapur which comes under low rainfall/ assured rainfall zone also differs in clay mineral assemblage.

19) Dominance of swelling chlorite has been registered followed chlorite, kaolinite, quartz and mica in traces. In sub-surface layer dominance of vermiculite was detected along with small quantities of kaolinite and quartz.

20) Black soil profile collected from Solapur indicate predominance of smectite followed by quartz and traces of kaolinite.

21) The diffractogram studies of Dharmabad, Dapoli and Khopoli reveal more or less similar clay mineral assemblage. Kaolinite and quartz minerals were the major fractions of clay with presence or absence of mica throughout the profiles.

22) Frequency distribution curve indicate the stage and intensity of weathering. This study reveals that weathering is low in Parbhani while it is highest in Dapoli. The magnitude of chemical weathering is in the order of Parbhani > Solapur > Dharmabad > Khopoli Dapoli.

23) Further, the primary mineral analysis shows an increase in weatherable mineral and decrease in resistant

minerals down the profiles which leads to conclude that weathering decreases with depth.

24) Primary mineral analysis depicts that except Dharmabad, other profiles constitutes of minerals characteristically of basaltic origin. Presence of resistant minerals like garnet, higher content of quartz and feldspar in Dharmabad profile denotes that these minerals may have derived from gratnite-gneiss parent material. Olivine, feldspar, augite are the major mineral components observed in the soils derived from basaltic parent material.

25) From these studies it would be concluded that weathering of basaltic rock under varying climatic conditions have resulted in formation of different types of soils with varied physico-chemical and mineralogical properties.

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*Originals not seen.

APPENDIX I

Nankheda profile (Nkd)

Soils of Nankheda series are very deep, moderately drained, clayey and dark brown in colour, developed on weathered basalt. They occur on midlands having nearly level to gently sloping lands, develop wide and deep cracks. Nankheda profile comprises members of fine, montmorillonitic hyperthermic family of typic chromusters.

Typifying pedon:

Nankheda I

Horizon	Depth in cms	Description
Ap	0–40	Dark greyish brown (10 YR 3.5/2) very dark greyish brown (10 YR 3/2) when moist, clayey; coarse strong subangular blocky, hard, moist firm, wet sticky and plastic, irregular lime concretions; strong offervescence; few fine roots, 2 cm wide cracks extending up to 1 meter, moderate permeability, clear smooth boundry (pH 7.4).
A_{12}	40–100	Very dark greyish brown (10 YR 3/2); dark brown (10 YR 3/3) when moist; clayey; coarse medium subangular blocky; dry

Continued

Horizon	Depth in cm	Description
		hard, moist firm, wet sticky and plastic, few fine irregular lime concretions, strong effervescence; few fine roots 2 cm wide cracks extending up to 60 cm abundant slicken sides; moderately slow permeability; gradual wavy boundry (pH 7.4).
A_{13}	100-170	Dark brown (10 YR 3/3 moist); clayey; medium angular blocky; dry very hard, moist very firm, wet very sticky and very plastic; abundant slicken-sides, few fine roots; 1 cm wide cracks extending up to 25 cms; very slow permeability, wavy boundry (pH 7.3).
A_{14}	170-270	Greyish brown (10 YR 5/2 moist); clay loam; moist friable wet slightly sticky; yellowish brown mottling concretions cemented with clay; clear smooth boundry (pH 7.5).
I C	270-400	Weathered material containing gluconite, very little amount of clay, greenish bluish layer containing lime concretions and blue rock pieces, wavy boundry pH 7.55.
II C	400-550	Less weathered material with stone fragments. No clay, hard

Continued

Horizon	Depth in cm	Description
		layer containing green rock platy structure; wavy boundry pH 7.8.
III C	550-680	Reddish rock mixed with hard murum and greyish reddish concretion, platy structure dark green irregular spots with white patches. No clay; wavy boundry (pH 8.0).
	680-980	Black rock (basalt) with white and green colour patches.
	980 +	Water table.

<u>Range in characteristics</u>:

The average thickness of the solum ranges from 0 to 270 cms. The content of clay varies from 22.5 to 62.5 per cent. Calcium carbonate within this depth is 16.0 per cent. The colour of the soil in Ap horizon is in hue of 10-YR with values ranging from 3 to 2.5 and chroma 2 to 3 both for dry and moist soils. The texture of fine earth in Ap horizon is generally clay loam to clay. The effective rooting depth is 1 meter from the surface. The pH varies from 7.35 to 8.0.

<u>Drainage and permeability</u>:

Moderately well drained with moderate to slow permeability. Topography: gently sloping with slight erosion. The water table is at 9.8 meters.

Use and vegetation:

These soils are commonly cultivated to green gram , sorghum and cotton and the natural vegetation are mango and babul (Acacia arebica).

Series identified:

Village: Nankheda; taluka and district: Parbhani (M.S.).

Type location:

Survey No. 14; Village: Nankheda; taluka and district: Parbhani (M.S.).

Analytical data:

Physico-chemical analysis of the soil: As given in Table 1.

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APPENDIX II

Solapur profile (Sol.)

Solapur series consists of moderately well drained, shallow to moderately deep soils, light brown to dark brown, silty loam to clay loam in texture and contains fairly larger amount of lime nodules. These soils are developed on weathered basalt and occur on nearly level to gentle slope.

Typifying pedon:

Horizon	Depth in cm	Description
Ap	0-15	Light brown (7.5 YR 6/4); clayey; weak sub-angular blocky; calcareous; dry soft, moist friable, wet sticky; fine roots; abrupt smooth boundry, pH 7.35.
A_1	15-30	Light brown (7.5 YR 6/4); clayey; medium subangular blocky, hard, calcareous, wet slightly sticky and slightly plastic, fine roots, fine cracks, gradual wavy boundry, pH 7.30.
A_{11}	30-50	Very dark grey brown (10 YR 3.5/2); clayey, coarse, medium angular blocky, dry hard, moist firm, wet plastic, irregular lime concretions, few fine roots, fine cracks, moderate permeability gradual wavy boundry, pH 7.4.

Continued

Horizon	Depth in cm	Description
I C	50-105	Very pale brown (10 YR 7/4); weathered parent material cemented with clay, slightly sticky; abrupt wavy boundry; pH 7.35.
II C	105-180	Slighty hard to hard layer with greenish spots, lime occurs throughout the horizon pH 7.55.
III C	180-330	Hard weathered rock, platy in structure, iron concretions are present, calcium carbonate occurs in patches (pH- 7.5).
IV C	330-600	Grey hard weathered basalt with fragments of partly decomposed rock.

Range in characteristics:

These soils are developed on basalt. They are light brown (7.5 YR 6/4) to dark brown (10 YR 3.5/2) in colour. The pH of these soils vaties from 7.30 to 7.55. These soils are clay loam to sandy loam in texture with abundant calcium carbonate accumulation in parent material.

Drainage and permeability:

Moderately well drained with slow to moderate permeability.

Topography:

Nearly level to very gently sloping.

Use and vegetation:

Commonly cultivated to jowar (*Sorghum bicolor* (L.) Moench) and bajra. The natural vegetation is babul (*Acacia arebica*) and neem (*Azardichatta indica*).

Series identified:

Village: Degaon; taluka and district: Solapur (M.S.).

Type location:

Survey No. 12; Village: Degaon; taluka and district: Solapur.

Analytical data:

Physico-chemical analysis of the soil is given in Table 1.

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APPENDIX III

Dharmabad profile (Dbd):

Dharmabad series represents shallow soil. It is a zone of transition, to its east is red lateritic soils of Nizamabad district (Andhra Pradesh) and to west is black soils of Nanded district (Maharashtra). The soils have been formed from weathered gneisses and granites. The area has a hilly topography with moderately steep slope. These soils are moderately deep to deep and having much higher degree of horizonization. They are light coloured varying yellowish red to dark reddish brown and more friable and sandy loam in texture. Having enough calcium carbonate at the depth of 30 to 100 cm. The pH varies from 6.8 at the top to 7.3 at the bottom. These soils are well drained.

Typifying pedon:

Horizon	Depth in cm	Description
Ap	0-15	Yellowish red (5 YR 4/6 moist) sandy loam, medium granular, dry loose, moist friable, wet slightly sticky and non-plastic, fine roots, clear smooth boundry pH-6.8.
B 1	15-30	Dark reddish brown (5 YR 3/3 when moist), sandy clay loam, weak, fine crumb, dry loose, moist friable, wet plastic few fine roots, diffused wavy boundry, pH -6.35.

Horizon	Depth in cms	Description
B 2	30-90	Reddish brown (5 YR 3.5/4) medium subangular blocky, moist friable, wet plastic, abundant small $CaCO_3$ concretions of 1 mm, diffused wavy boundry pH-6.1.
I C	90-225	Greyish red coloured weathered rock, platy structure with black spots; acidic in reaction,clear boundry.
II C	225-450	Hard weathered rock with platy structure, reddish and greenish spots; wavy boundry.
III C	450-765	Very hard weathered rock with greenish spots, wavy boundry.
IV C	765-855	Hard rock with green and red colour spots mixed with each other in a artistic way, clear smooth boundry.
VC	855-970	Weathered grey material with green spots.
D	970 +	Rock (gniess) having dark green colour with shining white spots mixed with pinkish tinge.

Range in characteristics:

The thickness of the solum is 100 cm. Texture of the solum varies from sandy loam to sandy clay loam. The colour of the soil in surface horizon is in hue of 5 YR with a value of four and chroma six. The colour of the soil in B horizon is dark red and is in hue of 5 YR with the values ranging from 3 to 3.5 and chroma 3 to 4. The effective rooting depth is up to 38 cms from the surface. The soils generally contain some gravel. The pH of these soils ranges from 6.1 to 7.3.

Topography:

Moderately steep to steep slopes commonly range from 15 to 25 per cent.

Drainage:

Well drained with medium to rapid run-off. Water table in the adjacent well is at 9.5 meters from surface.

Use and vegetation:

These soils are commonly cultivated to groundnut, tur and urid. The only natural vegetation is babul (*Acacia arebica*).

Series established:

Village: Dharmabad; Taluka: Biloli; District: Nanded (M.S.).

Type of location:

Survey No: 88; Village: Dharmabad; Taluka: Biloli; District: Nanded (M.S.).

Analytical data:

Physico-chemical characteristics as given in Table 1.

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APPENDIX IV

Khopoli profile (Kpl).

The soils of Khopoli series are under forest. The topography is hilly having steep slope, therefore, are heavily eroded and shallow. The average rainfall of the area is 3128 mm most of which receives during June and August. The colour of these soils is yellowish red to red. The texture of the soil is sandy loam. They are acidic in reaction and developed on basalt.

Typifying pedon:

Horizons	Depth in cm	Description
A_{11}	0-15	Yellowish red (5 YR 4/6 moist), sandy loam, single grained, dry loose wet slightly sticky and plastic, abundant coarse roots 2 cm wide cracks, clear smooth boundry, pH 6.0.
A_{12}	15-30	Reddish brown (5 YR 4/3), clay loam, weak fine weak subangular blocky, dry loose, wet sticky and plastic, 1 cm wide cracks, few fine roots, gradual wavy boundry, pH-6.0.
A_{13}	30-100	Red clay (2.5 YR 4/6), sandy clay, weak fine single grain, dry loose, wet slightly slicky and non-plastic, few fine roots, wavy boundry, pH-6.1

Continued

Horizon	Depth in cm	Description
IC	100-250	Grey weathered material, non-sticky and non-plastic, wavy boundry, pH-6.5.
IIC	250-450	Grey and green colour weathered rock, platy in structure.
IIIC	450-850	Slightly weathered black rock
D	850 +	Basalt rock.

Range in characteristics:

The thickness of the solumn is 90 cm. The texture of the surface layer is sandy loam and that of downward layer is sandy clay. The pH ranges from 6.0 at the top to 6.9 at the bottom. The colour of the soil is yellowish red to red. The effective rooting depth is 90 cm.

Drainage:

The soils are well drained with rapid run-off. Water table is at 1050 cm.

Topography:

The topography is hilly having steep slope vegetation is mango, tamarind and kaju.

Series identified:

Village:Khopoli, Taluka & District: Kolaba (M.S.).

Type location:

Forest area, Khopoli village, Taluka and District: Kolaba (M.S.).

Note: Layer of leaves accumulation on the surface was observed that was removed while describing the profile.

Analytical data:

Physico-chemical characteristics of all layers, as given in Table 1.

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APPENDIX V

Dapoli profile (Dp1)

Dapoli series represents laterite soils. These are well drained, moderately deep to deep, yellowish red to dark red, sandy loam to sandy clay loam in texture, occurring on undulating and slightly rolling uplands. Permeability is moderately rapid in surface and moderately slow to slow in the lower horizons. Parent material is of lateritic material containing hydrated oxides of iron and aluminium. The pH of the soils ranges from 5.35 to 6.2.

Typifying pedon:

Horizon	Depth in cm	Description
A	0-37.5	Yellowish red (5 YR 4/6), sandy loam, medium single grained blocky, dry loose, moist friable, wet slightly sticky and non-plastic, few roots, clear smooth boundry, pH-6.2.
B	37.5-97.5	Dark reddish brown (5 YR 3/3), clay loam, moderate medium and coarse crumb, dry loose, moist friable, wet slightly sticky and slightly plastic, few, fine roots clear smooth boundry, pH-5.35
C	97.5+	Dark red (2.5 YR 3/6), weathered parent material.

Range in characteristics:

Dapoli soils are medium to strongly acid throughout the profile. The combined thickness of the A and B horizon is 97.5 cm. These soils have a three colour pattern of yellowish red, dark reddish brown and dark red. The texture of A layer is sandy loam and that of B horizon is sandy clay loam. The effective rooting depth is 97.5 cm.

Topography:

Undulating to rolling.

Drainage:

Well drained, permeability is moderately rapid on top and moderately slow to slow in the lower layer .

Use:

The soil is used for growing horticultural crops like coconut and citrus.

Series established:

Village: Dapoli; Taluka: Dapoli, District:Ratnagiri(M.S.).

Type location:

Horticultural section of KKV, Village & Taluka: Dapoli, District: Ratnagiri (M.S.).

Analytical data:

Physico-chemical characteristics of all layers is given in Table 1.