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GENESIS AND CLASSIFICATION OF SOME SELECTED
SOILS OF IRBID REGION

BY

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The examining committee considers this thesis satisfactory and acceptable for award of the degree of Master of Science in Soils and Irrigation.

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ABSTRACT

This study is focussed on formation and classification of some soils of Irbid Region. The objectives of this investigation are:

1) To hypothesize their formation.

2) To apply modern soil classification.

Eight pedons within Irbid area were selected according to established criteria. Laboratory investigation included chemical, physical and mineralogical analyses.

Multiple genetic hypotheses were proposed as explanations of observed or measured properties and expressed as sequential models; each one depicting an alternate mode of soil development.

Results showed that climate had changed at least four major cycles; from humid or very humid to arid, then humid again, finally to present arid. Obtained results showed also, that this area is exposed to desertification and active erosion by water and wind.

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CHAPTER I

INTRODUCTION

The total area of the Hashemite Kingdom of Jordan is about 96500 Km^2. Nine percent of the total area is arable land. Rainfed area occupied 95% of the total arable land.

This study had been focussed on soils of Irbid Region, which are of the most important rainfed zone in the northern portion of Jordan.

The importance of this study (Genesis and classification of some selected soils of Irbid Region) had come from its consideration as a step in characterizing, and classifying soils according to the internationaly recognized system of soil classification.

Studying genesis of rainfed area (Irbid Region) will lead to know the dominating soil forming processes under the influence of the present soil forming factors, beside knowing the historical development of these soils.

This type of soil investigation will reveal any degradation process in these soils. Accordingly, suitable solutions to stop/or minimize this degradation can be recommended.

Soil classification can make use of all available knowledge about soil properties in organizing these soils in different types. These different soil types can be shown graphically on soil maps. Such soil maps can be interpreted by soil users to draw reliable statements about the best use for these soils, especially under rainfed conditions.

The objectives of this investigation are:

1) Hypothesizing their mode of formation.

2) Applying modern soil classification.

CHAPTER II

Literature Review

Soil is a natural three dimensional body that results from the integral effect of living organisms acting upon parent material as modified by relief and climate through time, and provides plants with proper amounts of nutrients and mechanical support. Its upper limit is air or shallow water. At its margins, the soil grades to deep water or to barren areas of rock or ice. Its lower limit to the not soil beneath and perhaps the most difficult to define (55).

Multiple genetic hypotheses proposed as explanations of observed soil features may be expressed as sequential models, each one depicting an alternate mode of soil development. Through this hypothesis, changes in the course of soil development may be readily considered as changes in the relative rates of discrete, but related processes (3,51). The presence of a soil profile at a surface is an indication of a period during which there was negligible modification of the form of that surface by erosion or deposition, such ground-surfaces, with their specificity with regard to soils and time, offer the possibility of detection of the absolute steps or increments by which landscape development has proceeded (15). Soils are a part of the landscape, and zero time of soil development begins with the formation of the land surface. All landscapes are constructional or erosional, or a combination of these two. The terrain is built up or torn down. However, it could be torn down at one place and built up at an adjoining place. In one case, the land surface stabilizes at some point in time (46).

Repetitive events characterized the Quaternary, whether in the glaciated or nonglaciated regions. Numerous drift sheets and loesses were constructed and superimposed like layers of a cake. Paleosols and soils surmount and, in places, separate most of the layers. In nonglaciated regions, erosional and depositional surfaces are arranged in stepped sequence. Hillslopes evolved later on many of these landscapes and added complexity to the pattern. Soils cross the array in time. Soils related to any stratigraphic or geomorphic part form a pedogenic cycle in the Quaternary. Zero time of soil formation of any cycle may be determined by relative or absolute dating methods or both (46). The Australian scientists suggest that Pleistocene glaciations in the northern hemisphere correlate with pluvial periods in at least the southern higher rainfall areas in Australia. Periods of soil formation represent relatively humid and perhaps cool climates related to glacial periods, while the interglacial periods were warmer and dryer resulting in landscape instability and erosion and deposition by both water and wind action (40). Also, it was indicated that the Pleistocene probably included periods of greater effective moisture in what are presently arid lands (22). Evidence indicates that the present climate is warmer and drier than the pluvial climates of the Pleistocene (12). The rates of soil formation processes have been lowered during Holocene time than they were during the Pleistocene (22). Soils of Pleistocene age can have distinct argillic horizons and strong horizons of carbonate accumulation (12). Many of the burried Pleistocene soils have prominent clay in their argillic horizons. It is apparent that processes operating since late Pleistocene favored disruption of clay skins. It was indicated that the wetter climates of Pleistocence pluvials associated with thicker vegetative cover and landscape stability, which were required for development of argillic horizons in these highly calcareous parent materials (11, 12).

Eaolian sediments are of paramount significance to soil development during the Quaternary, because the eolian materials added to soil parent material by accretion from the top (56). The intracontinental accretion of loess during the Quaternary is well known. Oxygen isotopic measurements of the marker mineral, quartz, reveals loess accretion in places and to depths not previously known (33). Aerosol silt carried intercontinentally has been traced by the oxygen isotopes of quartz. Two systems, one crossing the north pacific ocean on the jet stream from arid lands of Asia, and the other coming from the Sahara across the Central Atlantic Ocean on the Trade Winds to deposit in the Caribbian and on the North American Coast, illustrate atmosphere - soil development interactions during the Quaternary (33). Loess deposits, abundant in periglacial areas, have been the parent material for development of extensive soils. Coarse silt-sized eolian material has been mixed into soils developed on a wide variety of other materials. A yet finer eolian component, referred to as aerosol has a global distribution. Because loess is considerably coarser than aerosolic dust, its distribution is more limited and is related primarily to regional wind movements giving an adequate supply of material exposed to eolian transport during the Quaternary. In contrast, aerosolic dust has a global distribution and deposition is largely by rain. The aerosolic dusts contain micaceous vermiculite (56).

The volcanics, including, in addition to plateau basalts, some volcanic ash, e.g., near Azraq, are of varying age; Recent to Miocene. The largest amount of basalt is found east of Mafraq. This immense lava area belongs to the main basalt region of Jebel Druze. Besides this basalt area, smaller spots with basalt are found along the Rift Valley; one of the largest being the basalt Plateau of the Jebel Shihan (38). An enormous amount of extrusive rock erupted from many fissures; many vents are still visible as long rows of low cones. Basalt and some tuff also were extruded from clusters of isolated eruption cones. Six different phases of major emissions can be distinguished (5). A fifth flow, which is as much as 25 m thick - (may be much thicker toward the center of the eruptions) - is the most extensive flow of the Northeast Jordan plateau basalts. This fifth flow covers older flows and Paleogene and Miocene sediments. It can be correlated with the basalts on the limestone plateau of the Yarmuk River area and has undergone late Pleistocene erosion. The main tuff eruptions started after the extrusion of the fifth lava flow. The basalts of the sixth extrusive phase form north trending flows many kilometers long, exposed, they are as much as 30m thick and their surfaces do not show any evidence of weathering. They most probably correlate with the basalts that flowed down the Yarmuk River Valley to the west where they overlie Pleistocene fluviatile gravels and fossil landslides. On the basis of archaeological evidence, Picard (44) placed the basalts of the Yarmuk River Valley in the middle Pleistocene, The long rows of low basalt cones, which apparently are fissure effusions, also are part of the sixth eruption phase, because they cross the flows of the fourth and fifth phases (5).

Arid and semiarid regions are those areas have annual moisture dificit between potential evapotranspiration and precipitation which is usually lesser than 500 mm per year. The soil forming factors of these regions are the same as those in any other part of the world, but the relative intensities of the various soil forming factors in arid and semiarid regions, however, result in some processes that are unique characteristic of these regions (12,42). One of the most striking feature in arid and semiarid soils is the carbonate - enriched layer that tends to develop at the bottom of the illuvial horizon, when these soils were derived from parent materials containing carbonate. Ca-horizons of desert soils differ widely in carbonate content, bulkdensity, consistence, texture, and manner of carbonate occurrence. Carbonate may be distributed throughout the horizon, or may be segregated within the horizon. K-horizon was proposed for carbonate horizons strongly carbonate impregnated that their morphology is determined by the carbonate (12,23,24). There are different theories to explain the genesis of this layer. The occurrence of calcium carbonate in the surface horizons is probably of aeolian origin (17). They form in a developmental sequence which is related to time. The increase in soil development with age is shown by increasing carbonate accumulation. It is postulated that in more moist portion of the arid and semi-arid regions tend to prefer a theory calling for the translocation of carbonate from the upper to the lower part of the profile (12). In drier areas of the regions, several other processes appear more likely. In a study of a mohave sandy loam profile (11), which is a representative of red desert soils, in order to determine its pedogenesis, it was concluded that the extensive caliche layer, associated with lower lithologic material, has to be accounted for in some way other than by leaching from the surface (12,17,24,26). If the horizon has certain morphological characteristics and contains certain amounts of carbonates it is recognized in the new system of soil classification as a calcic horizon if it is not cemented and as a petrocalcic horizon if it is (55). Petrocalcic horizons are restricted to soils of arid and semiarid lands. Sources of the carbonate are carbonate rocks in the parent materials, calcareous dust and, in some instances, authigenic carbonates in the soils. In well-drained soils, carbonates accumulate at a depth to which the profile gets wet frequently and in places most accessible to percolating water. Thus, carbonates first precipitate on the surfaces of ped or pebbles and on the peripheries of channels formed by roots or soil fauna. With increasing accumulation of carbonates, isolated zones consisting of more prominent carbonate concentrations are formed. Increasing accumulation leads to more continuous, more uniform distribution throughout the horizon. Not only do individual nodules grow and, finally, merge, they also represent zones of restricted hydraulic conductivity, funneling the carbonate-saturated soil solution to previously non cemented parts of the horizon. Eventually, a dense, nearly continuous and nearly impervious plugged horizon is formed (22). Along the Rio Grande Valley in southern New Mexico, petrocalcic horizons occur in soils of late Pleistocene age in very gravelly parent materials, but are restricted to mid-Pleistocene or older soils in non gravelly parent materials (26). Such soils are paleargids or paleorthids in the new classification system (55).

An increase in clay content in the subsoil of many soils in the arid and semiarid regions is a pronounced feature. It was concluded that the clay in the B-horizon is formed in situ and not illuviated (3). Brewer, however, indicated (10) that clay translocation is not necessarily a major factor in the development of some argillic horizons. He concluded from his study of Australian soil that mechanisms other than clay illuviation and eluviation must be involved, and suggested differential weathering as a possible explanation. But, clay translocation was found to play a major role in the development of many argillic horizons in post-Wisconsin soils (36). Thus clay formation in situ is not the only process responsible for the development of an argillic horizon in the arid and semiarid soils. More likely, both clay formation in situ and enrichment by illuviation of fine clay are responsible for the development of argillic horizon in soils of arid and semiarid regions (22). Horizons of clay accumulation are considered to be argillic horizons, although clay skins on ped surfaces and on pore walls are usually absent (12). Although the clay content of an argillic horizon must exceed that of the overlying horizon by a specified amount, a higher content of clay in a B-horizon is not sufficient evidence of clay translocation (36). The presence of clay skins on soil features that formed in place, such as peds, indicates clay movement subsequent to parent material deposition. Evidence of illuvial clay is indicated by few clay skins. It appears that if a clay suspension passes into soil material, clay cutans will develop on the surfaces of grains or peds where the downward movement of water is arrested. It is possible, however, that the orientation of the clay in a clay skin could have been disrupted during extensive dessication known to occur in such soils of arid and semiarid regions (3, 21,36). It appears that turbation, probably by wetting and drying, destroys such clay skins. Clay skins are absent in horizons of high shrink-swell potential (36).

Upon weathering, basalt will give a residual material rich in clay minerals and oxides. Basaltic residue is rich in ferromagnesian minerals (18,21,31,53). In the dry areas the weathering of the basalt sheets has been relatively not important and the surface of the soils here is characterized by numerous basalt boulders. Weathering of the basalt and volcanic ash in the arid areas gives rise to a yellowish brown, extremely calcareous, silty clay. Weathering in the moister areas gives a reddish brown calcareous clay which on the whole shows the same characteristics as the limestone dissolution clay. In some cases, e.g., Near Irbid, the basalt weathers to a dark greyish brown calcareous clay. The soil-profile developed from this type of parent material would be strongly stained with iron (38,53).

On the other hand, limestone is a sedimentary rock, composed mainly of calcite, beside some impurities such as oxides and clay minerals. On weathering, the $CaCO_3$ is dissolved and the residue is a strongly calcareous clay or silty clay, which is an important soil forming material in East Jordan. In the wet areas this clay has a typical reddish brown color. In the dryer areas, leaching of the lime is not completed and the clay contains numerous limestone debris and its lime content is generally higher than is the preceding case. The clay in the dry steppic and desertic areas is yellowish brown and has a coarser texture than the limestone clay in the areas with

Mediterranean climate (13,38).

The basic igneous rock when contains considerable magnesium, and weathers under poor drainage or low rainfall, permit the released magnesium to remain in the weathering zone, smectite will be the weathering product. If however, because of high rainfall and good drainage, the magnesium is removed as soon as it is released from the parent mineral, kaolinite will be the weathering product, because the leaching of magnesium is relatively rapid and smectite will be an initial stage of weathering and kaolinite a later stage (18,27,28). Study of clay formation from basic volcanic rocks in a humid mediterranean climate indicated that clay from basalt derived soils contains kaolinite and dioctahedral vermiculite partially interlayered with Al and Fe hydroxy layers, and some illite and quartz in the surfacial horizons. The presence of illite and quartz in the upper soil horizons is explained by aeolian accretion (54).

Clay mineral and thus perhaps the chief silicate minerals, present in calcareous sediments (including dolomite) are illites and smectites. In the weathering of calcareous sediments, there is substantially no alteration of silicates until the carbonate is completely brocken down and the calcium removed from the environment (18,27,28).

The kind of alkali or alkaline earth is also important, since potash leads to the formation of illite, magnesium to the formation of smectite, and calcium probably to the formation of smectite, with an added tendency to block the formation of kaolinite (27,28). Shadfan (49), indicated an increase of smectitic, less illitic and more chloritic interstratification, and constancy of kaolinite with increasing rainfall in the Irbid soils, and less smectite and more illite and kaolinite in the Jordan Valley than in the Irbid soils. He concluded that under high rainfall conditions smectite type and interstratified clay mineral smectite/chlorite dominating increased as the clay content of Irbid soil increased, whereas the interstratified mineral mica/smectite/chlorite as well as smectite dominated the clay minerals under low rainfall conditions (50).

CHAPTER III

MATERIALS AND METHODS

3.1 Location of the studied area

The study area is located within Irbid region, northern of Jordan. The selected locations for sampling are shown in Figures (1,2). Sampling was carried during July, 1981.

3.2 Background

3.2.1 Soil forming factors

3.2.1.1 Geology

The geological map of Jordan, 1968., scale 1:250,000 indicates that the following geological formations are distributed through the study area;

tt : Limestones, chalky limestones, marls, cherts, and locally bituminous; Tertiary, undifferentiated; Cenozoic.

C_2+tt : Limestones, marls, chalky limestones; lower Tertiary-Upper Cretaceous.

q_5 : Fluviatile deposits, eolian sands, caliche, loess-like sediments, and mantle rocks; Quaternary undifferentiated; Cenozoic.

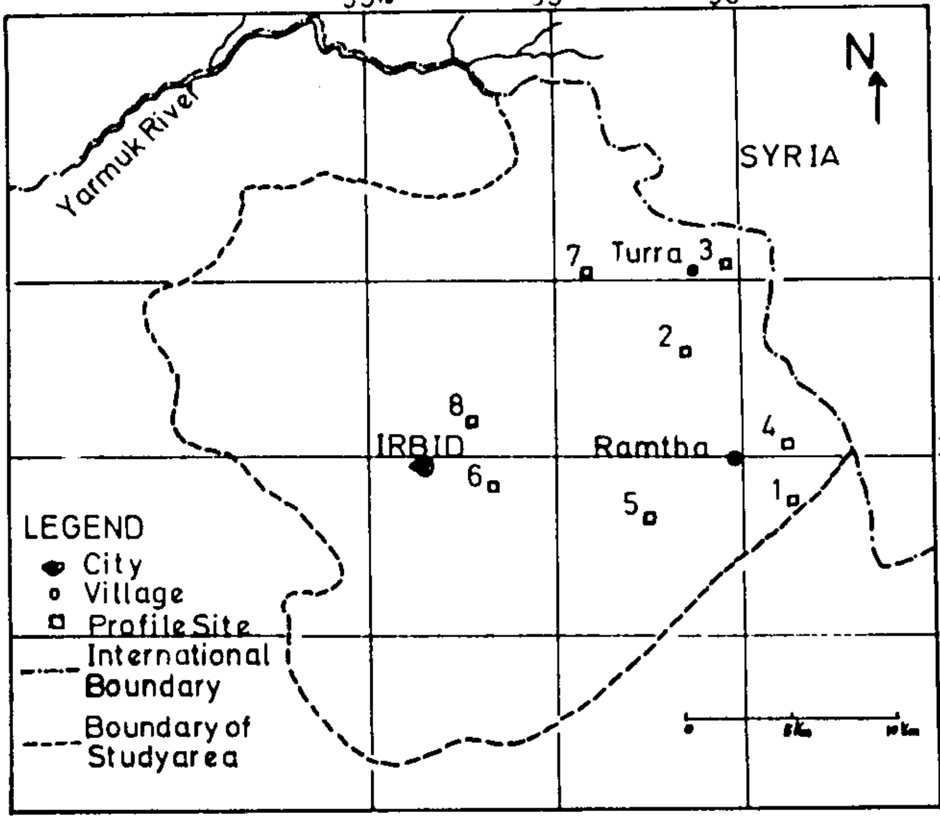

Fig. 1. Selected sites within Irbid Region.

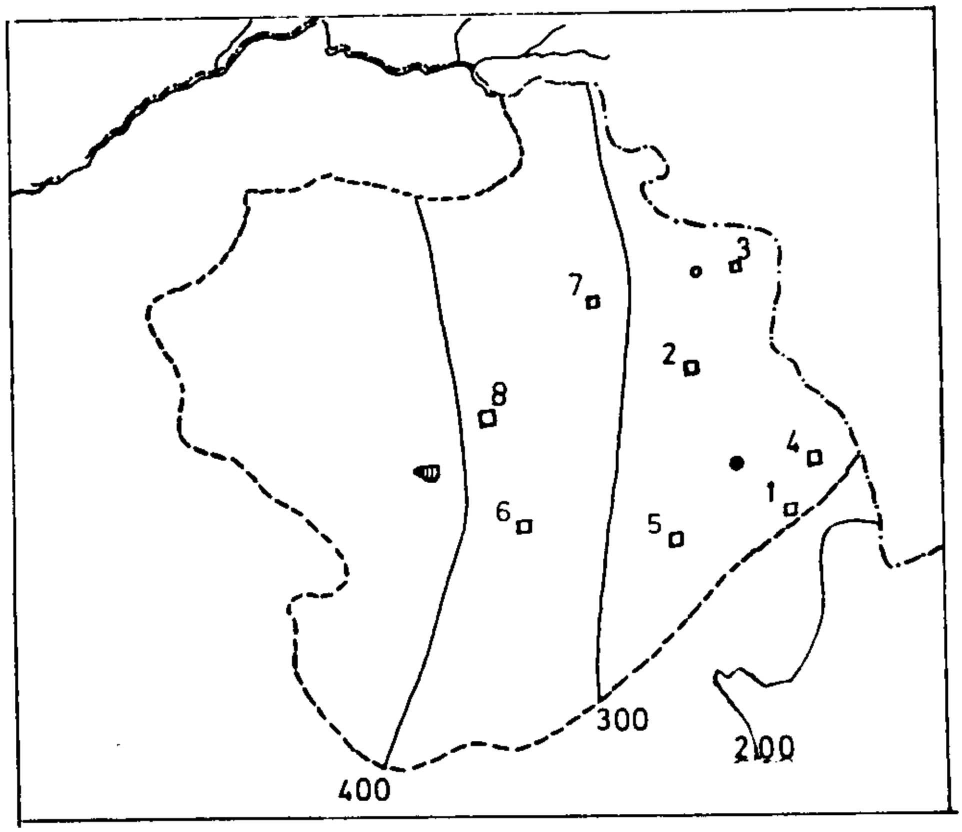

Fig. 2. Mean annual precipitation within Irbid Region.

B : Basalts and basalt tuffs, undifferentiated, Quaternary-? Neogene; Cenozoic.

The Geological map of Irbid area, (Fig. 3), (5), shows that all the studied profiles are located in the Quaternary deposits. The parent materials of the selected soils are colluvium sediments which were laid down on the lower part of slopes. The composition of these colluvium sediments is related to the rocks from which these materials were derived i.e. limestone and / or limestone associated with basalt. The eolian sediments added to soil parent materials by accretion from the top, and the intracontinental accretion of loess during the Quaternary as well (56).

3.2.1.2 Relief:

The elevation of Irbid region is about 529 m. above the sea level. It has an undulating topography on extensive plain area with gentle slopes and differences of altitude in a short distance which rarely exceed 50 m. The selected sites were located in the most level portions through the region. Soil erosion is assumed to be minimum in comparison with the immediate vicinity, and runoff is assumed to be medium to slow.

3.2.1.3 Climate:

Irbid region belongs to East Mediterranean climate, which as an essential feature, has a rainy cold winter with a hot dry summer. The winter precipitation is characteri-

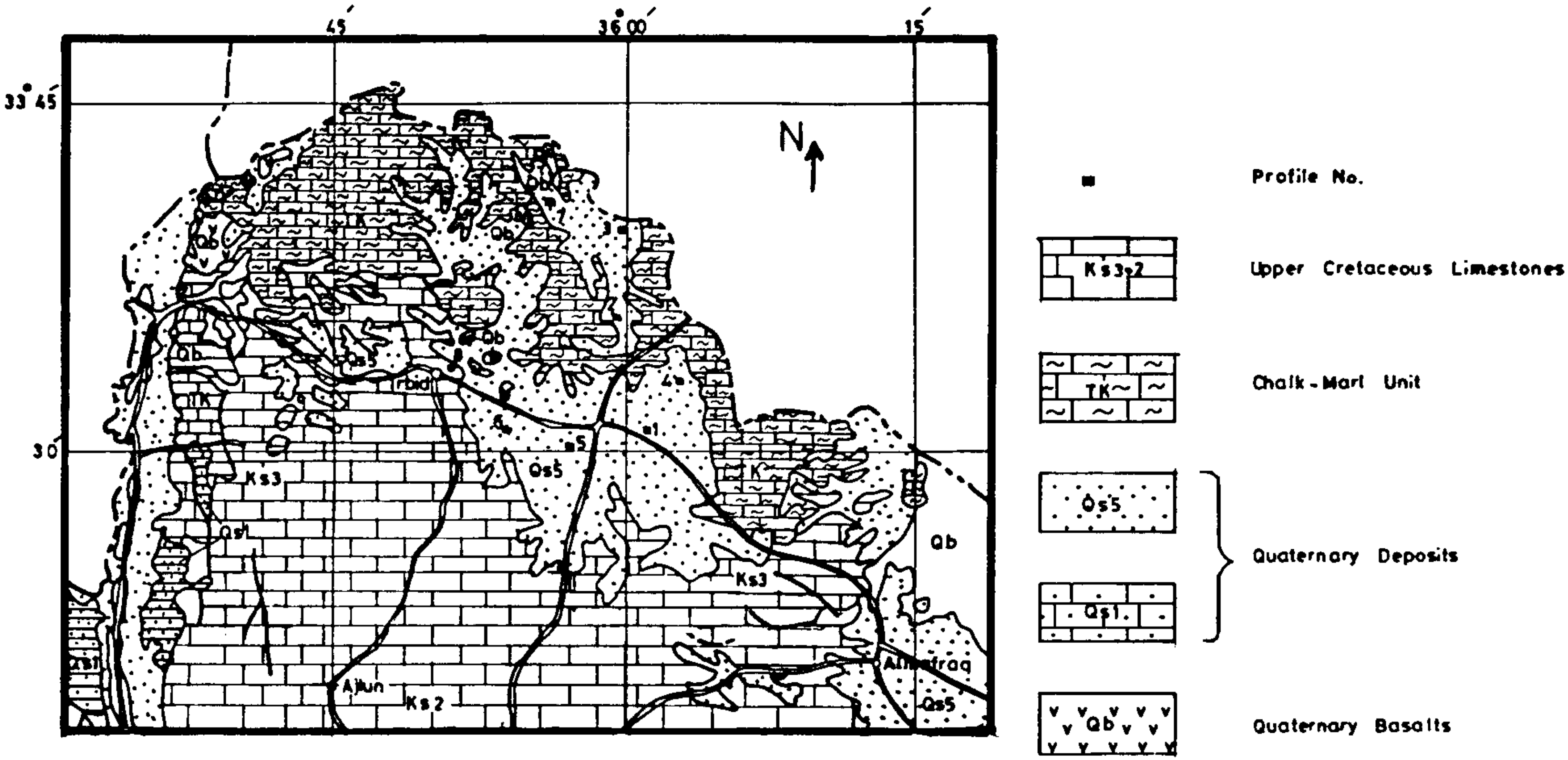

Fig. (3) Geological map of Irbid area (from Bender 1975)

Scale 1: 500000

zed by irregularity and different intensities. The mean annual precipitation varies from 200 mm to 400 mm. (Fig. 2) and increases from East to West and From South to North. The mean summer temperature varies from [illegible]°c to 25°c. The mean winter temperature varies from 7°c to 10°c. The soil moisture regime is xeric in the West and aridic in the East. Soil temperature regime is thermic.

3.2.1.4 Vegetation

The natural vegetation is absent within the selected sites. Cereals, legumes, and summer vegetables are the main crops grown in the area. The natural forestry trees in the West and South portions of the studied area are: *Pinus halepenesis*; *Pistacia atlantica*; *P. terebinthus*; *Quercus calliprinos*; *Q. infectoria*; *Acacia faruesiana*; *Quercus aegilops*; *Amygdalus communis*; *Ceratomia siliqua* and *Cercis siliquastrum*. Most common scattered brushes in the whole area are: *P. lentiscus*; *Crataegus azarolus*; *Rhamnus palaestina*; *Poterium spinosum*; *Styrax officinalis*; *Calecatome duriaei* and *Cistus salvifolius* (1).

3.3 Origin and formation of Irbid landscape

Soils of studied area are the result of past climate that is presumed to be more humid and cooler than the prevailing one. This is indicated by the great depth of these soils and high clay content. While incepient petrocalcic horizon is present at a certain location, it can be postulated that these soils may refer to late to mid-Pleistocene (26). Picard (44) placed the basalts of the Yarmuk River Valley in the middle Pleistocene on the basis of archoeological evidence. Also, there is an evidence indicating that the present climate - arid to semiarid - is warmer and drier than the Pleistocene pluvial climates (12). Soils of Irbid area are a part of the landscape and - zero time - of soil development begins with the formation of the landscape (46). When the Rift Province had been lowered by continuous structural subsidence, the mountain ridge and Northern Highlands east of the Rift apprea-red as a coherent physiographic feature. When the base level of the erosion was lowered in the Rift Province, the westward drainage had been rejuvenated (14). During Pleistocene periods of higher rainfall that today were assumed to have taken place, thus erosion by water predominated. Streams like Yarmuk and Zarqa River cut further eastward into the Central Plateau capturing additional catchments for the drainage basin of the Valley (14). Fluviatile - lacustrine sediments were deposited in basins and depressions during the Pleistocene.

Fluviatile gravels covered extensive areas of the eastern slopes of the Mountain Ridge Province (8). Thus, it can be easily foreseen, accordingly that, soils of Irbid area had been transported from the surroundings after or during in situ formation by water from higher places coupled with wind activity when climate changes from wet to dry. Evidences indicate that eolian sediments are of paramount significance to soil development during the Quaternary in Irbid area (56).

Field investigation

Eight soil profiles were selected and sampled within Irbid district to represent the different soil series established by the Ministry of Agriculture (1). The profiles were located according to an East-West transects running through different precipitation zones. They were located in the most level sites within the study area. The soil profiles were representative of most predominant parent materials; limestone, and limestone associated with basalt- derived materials. Soil profiles were selected according to the following criteria:

1- Parent material.

2- Color of the surface.

3- Mean annual precipitation.

On the basis of parent materials; soil profiles No. 3,6 and 8 were developed in colluvium materials derived from limestone associated with basalt, while the rest developed in colluvium materials derived from limestone.

3.4 Field investigation

3.4.1 Soil profile descriptions

3.4.1.1 Profile No. 1

General information

Classification	: Fine, Mixed, Thermic, Typic Palexeralfs. Or, Fine, Mixed, Thermic, Typic Xerochrepts.
Location	: It lies on the left side of the road which extends from Ramtha cross-roads to Mafraq, north of Yarmuk-University Site.
Present land use	: Summer, Winter crops.
Time of sampling	: July, 1981.
Relief	: Flat plain-gently undulating. 1-3% slope.
Parent material	: Calcareous derived colluvium material.
Climatic data	: Climate is arid to semiarid with an average precipitation of 250 mm/year. The mean January air temperature is 10^{o}c and the mean June air temperature is 24^{o}c.
Remarks	: Moist colors.

Profile description

AP	0-28 cm.	Dark brown (7.5 YR4/4), clay, weak medium subangular blocky, s. hard, s. firm, s. sticky, s. plastic, many fine roots, few limestone gravels with rounded edges, clear boundary.

B21 28-75cm. Yellowish red (5YR4/6), clay, moderate coarse prismatic breaks to weak medium subangular blocky and angular blocky, v. hard, friable, sticky, plastic, many fine roots, crotovina, very few fine to medium distinct carbonate concretions, angular chert pieces, and limestone round-edged gravels, clay, oxides, and organic matter coatings (clay coatings are less distinct than the oxide coatings), gradual boundary.

B22 75-100cm. Strong brown (7.5YR5/6), clay, moderate coarse subangular to angular blocky, hard, firm, sticky, plastic, few fine roots crotovina, few medium distinct carbonate concretions, angular chert pieces, clay and oxide coatings (the clay coatings are less distinct than the oxide coatings), clear boundary.

IIB23Ca 100-145cm. Dark brown (7.5YR4/4), clay, moderate medium subangular to angular blocky, hard, friable, sticky, plastic, many coarse distinct carbonate concretions, angular chert pieces, clay and oxide coatings (the clay coatings are less distinct than the oxide coatings).

3.4.1.2 Profile No. 2

General information

Classification : Fine, Mixed, Thermic, Typic Xerochrepts.

Location : It is located on the left side of the main road from Ramtha to Turra.

Present land use : Summer, Winter crops.

Time of sampling : July, 1981.

Relief : Nearly level site through hilly-undulating area. 1-2% slope.

Parent material : Limestone derived colluvium material.

Climatic data : The annual average precipitation is approximately 300 mm. The average of air temperature during January is about 10^{o}c., and during June is about 24-25^{o}c.

Remarks : Moist colors.

Profile description

AP 0-30 cm. Dark reddish brown (5YR3/4), clay, moderate coarse prismatic breaks to subangular blocky, hard, firm, sticky, plastic, common fine to moderate roots, 1%, 1-2 mm in diameter limestone gravels, some shells, gradual boundary.

B21	30-50 cm.	Dark reddish brown (5YR3/4), clay, moderate coarse subangular blocky, hard, firm, sticky, plastic, few fine roots, 2-3 mm., wide cracks extend to 50 cm., clay coatings are less distinct than clay coatings of the next horizon, gradual boundary.
B22Ca	50-130cm.	Dark reddish brown (5YR3/4), clay, strong coarse prismatic breaks to subangular and angular blocky, extremely hard, firm, sticky, plastic, common fine roots, crotovina, shells, many medium limestone gravels, common medium distinct carbonate concretions, clay and organic matter coatings, abrupt boundary.
IIB23Ca	130+cm.	Reddish brown(5YR4/4), clay moderate medium subangular blocky, hard, firm, sticky, plastic, many medium distinct carbonate concretions, clay coatings, 2-3% fine hard limestone gravels.

3.4.1.3 Profile No. 3

General information

Classification : Fine, Smectitic, Thermic, Typic Chromoxerts.

Location : It lies on the right side of the eastern road between Turra and Ramtha.

Present land use : Summer, Winter crops.

Time of sampling : July, 1981.

Relief : Level site through undulating area. 1-3% slope.

Parent material : Limestone associated with basalt derived colluvium material.

Climatic data : Potential evapotranspiration is 1600 mm/ year. The annual precipitation is 300 mm. The average air temperature during January is about 10^{o}c., and during June is 24-26^{o}c.

Remarks : Moist colors.

Profile description

AP 0-40 cm. Dark reddish brown (5YR3/4), clay, large clods that break to weak coarse subangular blocky, v. hard, friable to s. firm, s. plastic, common to many fine roots, some angular limestone gravels, small rounded basalt fragments, depth of cracks and oblique slickensides that covering

		both sides of the ped is 160 cm, clear boundary.
B21	40-90 cm.	Dark reddish brown (5YR3/4), clay, strong very coarse prismatic breaks to angular blocky, extremely hard, s. firm, sticky, plastic, few to common fine roots, distinct very few medium white carbonate concretions, clay and oxide coatings (not prominent), vertical pressure face of about 70 cm^2. diffuse boundary.
B22	90-130cm.	Reddish brown (5YR4/4), clay, strong very coarse prismatic breaks to angular blocky, extremely hard, s. firm; sticky, plastic, few to common fine roots, distinct few to common coarse white carbonate concretions, clay and oxide coatings (not prominent), gradual boundary.
B23Ca	130-165cm.	Yellowish red (5YR4/6), clay, strong very coarse prismatic breaks to angular blocky, v. hard, s. firm, sticky, plastic, few fine roots, many coarse white carbonate concretions (prominent secondary carbonate accumulation), prominent clay and oxide coatings, faint organic matter coatings.

3.4.1.4 Profile No. 4

General information

Classification : Fine, Mixed, Thermic, Typic Palexeralfs. Or, Fine, Mixed, Thermic, Typic Xerochrepts.

Location : This profile is located on the right side of Ramtha - Damascus road east of Ramtha town.

Present land use : Summer, Winter crops.

Time of sampling : July, 1981.

Relief : Level-gentle sloping. 2-4% slope.

Parent material : Limestone derived colluvium material.

Climatic data : The annual precipitation is about 200-300 mm. The average air temperature in January is 10°c., and in June is 24°c. The potential evapotranspiration is 1600 mm/year.

Remarks : Moist colors. Very prominent wind activity during Summer.

Profile description

AP 0-34 cm. Dark reddish brown (5YR3/4), clay, a hard plow pan that seems to be massive to weak prismatic breaking to coarse subangular blocky, hard, friable, sticky, plastic, many fine roots, some limestone gravels and cherts, cracks (1.5 cm wide) were extended vertically till 67 cm., gradual boundary.

B21	34-67 cm.	Dark reddish brown (5YR3/4) clay, moderate coarse prismatic breaks to angular blocky, extremely hard, s. firm, sticky, plastic, many fine roots, few fine to medium white distinct carbonate concretions, some limestone gravels and cherts, clay coatings (less distinguished than below horizon), diffuse boundary.
B22	67-120cm.	Dark reddish brown (5YR3/4), clay, strong coarse prismatic breaks to angular blocky, extremely hard, s. firm, sticky, plastic, few to common fine roots, some limestone gravels 5 mm in diameter, organic matter coatings are less prominent than clay coatings, few charcoal and shell pieces, few to common medium white distinct carbonate concretions, well distinguished clay and organic matter coatings, clear boundary.
B23	120-148cm.	Yellowish red (5YR5/6), clay, moderate medium subangular blocky, v. hard, friable, sticky, plastic, few fine roots, few to common medium white distinct carbonate concretions, clay and oxide coatings,

few limestone gravels (5 mm in diameter), many carbonate films, and weak clay coatings, abrupt boundary.

IIB3Ca 148-165+cm. Strong brown (7.5YR5/6), clay, moderate medium subangular blocky, s. hard, friable, sticky, plastic, few fine roots, many distinct coarse white carbonate concretions, many carbonate films.

3.4.1.5 Profile No. 5

General information

Classification : Fine, Mixed, Thermic, Petrocalcic Paleargids. Or, Fine, Mixed, Thermic, Xeric Paleorthids.

Location : It is located between Ramtha cross roads and Huwwara.

Present land use : Summer, Winter crops.

Time of sampling : July, 1981.

Relief : Level-slightly convex. 1-3% slope.

Parent material : Colluvium material derived from limestone.

Climatic data : The average annual precipitation is about 250 mm. The average air temperature in January is about 10°c. and in June is about 24-26°c. The evapotranspiration is 1600 mm/year. Mean annual air temperature is 17-18°c.

Remarks : Moist colors.

Profile description

AP	0-24 cm.	Dark brown (7.5YR4/4), clay, moderate very coarse prismatic, extremely hard, friable to s. firm, sticky, plastic, common fine roots, few fine white carbonate concretions, clear boundary.
B21	24-60 cm.	Dark brown (7.5YR4/4), clay, weak medium subangular blocky that breaks to granular, hard, friable, sticky, plastic, common fine roots, some (1.5 mm. in diameter) limestone gravels and few (4 cm. in diameter) flint gravels, few to common fine carbonate concretions, gradual boundary.
B22Ca	60-79 cm.	Strong brown (7.5YR5/6), clay, very weak medium subangular blocky, hard, friable, sticky, plastic, few fine roots, the top 10cm is partially cemented that can be broken by hand in some part, many limestone gravels cemented by carbonate, many medium to coarse carbonate concretions, clear boundary.
B23Ca	79-115cm.	Strong brown (7.5YR5/6), clay, moderate medium subangular blocky, s. hard, s. friable, sticky, plastic, few fine roots, few to common medium white carbonate concretions, few flint gravels, filament of carbonate,

broken petrocalcic horizon about 5 cm. thick, gravels were surrounded by carbonate deposit, abrupt boundary.

IIB_3Ca	115+cm.	Reddish brown (5YR4/4), clay, moderate medium subangular blocky, hard, s. firm, sticky, plastic, few fine roots, common medium white carbonate concretions, thin filament of carbonate, hard limestone gravels.

3.4.1.6 Profile No. 6

General information

Classification : Fine, Smectitic, Thermic, Typic Chromoxererts.

Location : It is located on the left side of the road between Huwwara and Irbid opposite the Wheat Mill of Huwwara.

Present land use : Summer, Winter crops.

Time of sampling : July, 1981.

Relief : Extensive flat plain. 1-2% slope

Parent material : Colluvium material derived from limestone associated with basalt.

Climatic data : The average annual precipitation is about 300-400 mm. The average of air temperature during January is about 10^{o}c., and during June is about 24^{o}c. Potential evapotranspiration is 1600 mm/year and mean annual air temperature is 17-18^{o}c.

Remarks : Moist colors.

Profile description

AP	0-10 cm.	Dark reddish brown (5YR3/4), clay, moderate medium subangular blocky, extremely hard, friable, sticky, plastic, few fine black concretions, oxide and organic matter coatings, clear boundary.
B21	10-50 cm.	Dark reddish brown (5YR3/4), clay, very strong very coarse angular blocky, extremely hard, friable, sticky, plastic, few fine black concretions, oxide and organic matter coatings, diffuse boundary.
B22	50-80 cm.	Dark reddish brown (5YR3/4), clay, very strong very coarse angular blocky, extremely hard, friable, sticky, plastic, few fine black concretions, oxide and organic matter coatings, many 10 mm. in diameter hard limestone gravels, diffuse boundary.
B23	80-155cm.	Dark reddish brown (5YR3/4), clay, very strong very coarse angular blocky, extremely hard, friable, sticky, plastic, few coarse white carbonate concretions, few fine black concretions, oxide and organic matter coatings, a lot of limestone and flint gravels, slickensides and pressure faces, abrupt boundary.

B24Ca 155+cm. Dark reddish brown (5YR3/4), clay, strong medium angular blocky, extremely hard, s. firm, sticky, plastic, common medium to coarse white carbonate concretions, few fine black concretions, oxide and organic matter coatings, some flint gravels, many slickensides.

3.4.1.7 Profile No. 7

General information

Classification : Fine, Smectitic, Thermic, Typic Chromoxererts.

Location : This profile is located on the left side of the road between Turra and El-Shajara.

Present land use : Summer, Winter crops.

Time of sampling : July, 1981.

Relief : Level-undulating with hilly surrounding. 1-2% slope.

Parent material : Colluvium material derived from hard limestone.

Climatic data : The average annual precipitation is about 300-400 mm. Potential evapotranspiration is 1600 mm/year and mean annual air temperature is 17-18^{o}c. The average of air temperature during January is about 10^{o}c., and during June is about 24-26^{o}c.

Remarks : Moist colors.

Profile description

AP 0-21 cm. Yellowish red (5YR4/6), clay, moderate medium subanglar blocky breaks to granular, hard to v. hard, friable to firm, sticky, plastic, common to many fine to medium roots, depth of slickensides is 115cm., 40 cm^2 oblique on both sides of the ped, pressure faces, clear boundary.

B21 21-85 cm. Dark reddish brown (5YR3/4), clay, very strong very coarse prismatic breaks to angular blocky, extremely hard, v. firm, sticky, plastic, common fine roots, very few fine white carbonate concretions, thin carbonate filaments, chert and limestone round-edged gravels, oxide and organic matter coatings, gradual to diffuse boundary.

B22 85-133cm. Dark reddish brown (5YR3/4), clay, very strong very coarse angular blocky, extremely hard, very firm, sticky, plastic, common fine roots, few coarse white corbonate concretions, few coarse black concretions, many small fragments of chert, limestone and shell, oxide and organic matter coatings, diffuse boundary.

B23 133-175cm. Dark reddish brown (5YR3/4), clay, very strong very coarse angular blocky, extremely hard, v. firm, sticky plastic, common fine roots, common coarse white carbonate concretions, common coarse black concretions, clay, oxide and organic matter coatings.

3.4.1.8 Profile No. 8

General information

Classification : Fine, Smectitic, Thermic, Typic Chromoxererts.

Location : It is located northwest the industrial city of Irbid.

Present land use : Summer, Winter crops.

Time of sampling : July, 1981.

Relief : Flat-gentle sloping. 1-3% slope.

Parent material : Colluvium material derived from limestone associated with basalt.

Climatic data : The average annual precipitation is about 300-400 mm. The average of air temperature during January is about 10^{o}c., and during June is 24^{o}c. Evapotranspiration is 1600 mm/year. Mean annual air temperature is $18-20^{o}$c.

Remarks : Cracks 7 cm. wide and 80 cm. deep. Moist colors.

Profile description

AP 0-10 cm. Dark reddish brown (5YR3/4), clay, moderate medium subangular blocky breaks to granular, v. hard, firm, sticky, plastic, few to common fine to medium roots, clear boundary.

B21	10-70 cm.	Dark reddish brown (5YR3/4), clay, strong very coarse prismatic breaks to subangular blocky, extremely hard, v. firm, sticky, plastic, some chert and limestone gravels, diffuse boundary.
B22	70-130cm.	Dark reddish brown (5YR3/4), clay, very strong very coarse prismatic breaks to angular blocky, extremely hard, v. firm, sticky, plastic, few fine roots, few fine white carbonate concretions, few fine black concretions, organic matter coatings, gradual boundary.
B23	130-180cm.	Dark reddish brown (5YR3/4), clay, very strong very coarse angular blocky, extremely hard, v. firm, sticky, plastic, few fine roots, common coarse white and black concretions, carbonate concretions are prominently distinct, slickensides are oblique covering both sides of the ped, oxide and organic matter coatings, abrupt boundary.
IIB24	180+cm.	Dark reddish brown (2.5YR3/4), clay, strong coarse angular blocky, v. hard, v. firm, sticky, plastic, few fine roots, many coarse white and black concretions, oxides and organic matter coatings, oblique 40 cm^2 slickensides on both faces of the ped, flint and limestone gravels, basalt boulders are present.

3.5 Laboratory procedures

3.5.1 Sample preparation

Soil samples were air-dried and passed through a 2.0 mm. sieve. Natural unground samples were saved for particle size distribution. Natural clods were collected and saved for bulk-density determination.

3.5.2 Physical measurements

3.5.2.1 Particle-size distribution

Natural unground samples were soaked in 0.5 N sodium acetate pH5 to remove the carbonates as suggested by Jackson et al. (32).

Organic matter was then removed by heating the soil sample with 31% H_2O_2. Sodium hexametaphosphate 6%. and overnight shaking followed by sonic vibration were used to maintain maximum dispersion. Clay was measured by the pipette method (20). Sand fractions were separated by standard sieves.

3.5.2.2. Bulk-density

Bulk density was determined on natural clods by paraffin method (6).

3.5.3 Chemical determinations

3.5.3.1 Organic carbon

Organic carbon was determined by the potassium dichromate method (48).

3.5.3.2 Cation exchange capacity

Cation exchange capacity for soil and clay was according to Bower (9).

3.5.3.3 Extractable cations

Ca, Mg, K, and Na were obtained by extracting soil with 1N NH_4 AOC at pH7. Extractable sodium and potassium were measured by flame photometer. Extractable calcium and magnesium were determined by the versenate titration method (16).

3.5.3.4 Soil - pH

Soil pH was determined in 1:1 soil to water ratio (7).

3.5.3.5 Free iron oxides

Free iron oxides for total soil and clay was extracted using Mehra and Jackson procedure (37). The extracted iron was measured by the orthophenanthroline colorimetric method (34).

3.5.3.6 Carbonates

Carbonates in sand, silt, and clay fractions were determined by acid neutralization method (45).

3.5.3.7 Soluble salts

Soluble salts were determined by measuring the electrical conductivity in 1:2.5 soil to water extract (7).

3.5.4 Mineralogical examination - X - ray diffraction

Clay fraction was saved after the particle-size analysis and separated from silt by sedimentation. Iron oxide was removed before preparing slides for X-ray test. The X-ray diffraction curves were obtained for the following treatments;

1- Mg.,

2- Mg+ Ethyleneglycol.,

3- K., and

4- K+ heating for 4 hours at 550°c.

The treatments for silt included magnesium and glycolation only. Philips X-ray diffraction apparatus, model PW1130/90 was used in the X-ray analysis (34).

CHAPTER IV

RESULTS AND DISCUSSION

4.1.1 Soil pH

Tables 1 and 2, show the pH-depth distribution. pH values were above 8.0 for all studied soils. These values indicate the calcareous nature of these soils. pH values vary within a range of 7.9 to 8.4 for profiles 1,2,4,5,6 and 8; and 8.2-8.7 for profiles 3 and 7 due to the high amounts of extractable sodium and magnesium.

4.1.2 Soil organic-matter

The organic matter content for all studied pedons decreases gradually with depth (Tables 3,4,5,6). The average organic matter content of the upper 50 cm of all studied pedons is less than one pecent which is required for mollic epipedon. None of these soils was qualified to have the mollic epipedon (55).

4.1.3 Extractable cations (Ca, Mg, K, and Na)

Data of the extractable cations (Tables 3,4,5 and 6), indicated that calcium is the dominant cation in all studied profiles followed by magnesium, sodium, and potassium, respectively. The highest amount of extractable calcium was found in profiles 6 and 8, followed by profile No. 7. In all studied profiles the distribution of the extractable calcium did not indicate movement of this cation from the surface to the subsoil, on the contrary it shows an accumulation of this cation on the top soil.

Profiles 3,6,7 and 8 contain the highest amounts of magnesium. Further, the data of extractable magnesium offer two types of variation with depth; the first indicates Mg downward movement within profiles 1,2,3,4,7 and 8. The second indicates that, the surface has the maximum Mg content in profiles 5 and 6.

Sodium content increases with depth in all studied soils indicating leaching pattern within these soils. This could refer to an ancient humid climate. Whereas, potassium decreases with depth, reflecting the dominated aridic conditions.

4.1.4 Electrical conductivity (EC)

Results indicated that 0.9 mmhos/cm is the highest value in these studied soils (Tables 3,4,5,6). This suggests that, these soils are not saline. In all studied pedons, except No. 8 which exhibited an irregular vertical variation, the electrical conductivity increases gradually with depth.

4.2 Profile No. 1

4.2.1 Particle size distribution

Particle size distribution, carbonate free (Table 7, Figure 4), indicates that clay increases from 43.3% at the surface to 58% at 100 cm, then changes significantly to 63% below the depth of 100 cm. Difference of 15% in clay content between surface and subsurface (0 - 100 cm) suggests possible clay illuviation within this solum. According to Soil Taxonomy, this subsurface could be considered as an argillic horizon (55). Brewer, (10) suggested, however, that differential weathering could be a possible reason for the increase in clay content in the subsoil. Moreover, horizons of clay accumulation are considered to be argillic horizons although clay skins on ped surfaces and inside pores' walls are usually absent (12). Although the clay content of an argillic horizon must exceed that of the overlying horison by a specified amounts, a higher content of clay in B horizon is not sufficient evidence of clay translocation (36). Clay with carbonate suggests that the depth of 100 cm to be the zone of maximum clay accumulation with 8% difference between surface and subsurface (0 - 100 cm). Below the 100 cm depth, clay with carbonate declines to 49.5%. Particle size distribution on clay free basis indicates lithological discontinuity below the depth of 100 cm. Thus, clay illuviation and

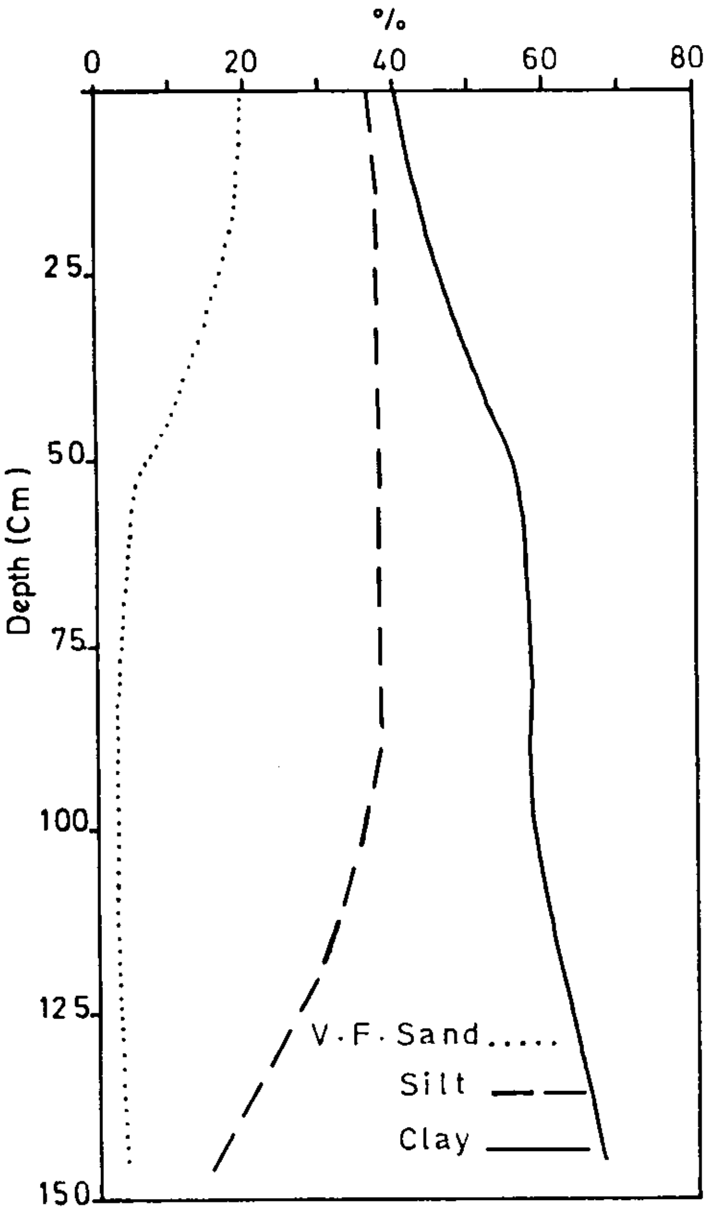

Fig.4 _ Particle size _ depth distribution without carbonate for profile No.1

carbonate leaching had occurred within the 100 cm zone. Silt without carbonate is distributed uniformly from surface till the depth of 100 cm then decreases suddenly from 38% above 100 cm line to 29% below. This substantiates the occurrence of lithological discontinuity at 100 cm depth as indicated previously.

Silt with carbonate increases with depth, especially to 100 cm, which coincides with the clay distribution suggesting carbonate leaching.

Very fine sand without carbonate decreases sharply from 18.6% at the surface to 5.7% at B21 horizon indicating a very recent accumulation of this fraction. Evidence for the sharp accumulation of very fine sand is also provided from the distribution of the same fraction with carbonate and from particle size distribution on clay free basis.

More than 0.1 mm fraction, with carbonate, (Table 7) indicates a significant difference in its ratios (from 3.7% to 12.5%) above and below the 100 cm depth, respectively. This may suggest that, when soil forming factors had changed, possibly climate, profile was truncated, followed by deposition of new material 100 cm thick. Evidence for this sequence in climatic changes could be found in the maximum carbonate-free clay content (63%) below the depth of 100 cm which implies strong chemical weathering suggesting different types of climate.

4.2.2 Carbonate

Total carbonate increases from the surface till depth of 100 cm suggesting carbonate leaching (Table 1). Below the depth of 100 cm, total carbonate maintains the maximum value which suggests two different parent materials.

Results of the total carbonate and the carbonate associated with coarse sand indicate that significant portion of the carbonate had occurred in this fraction. This strongly suggest that significant leaching had been active in this profile since carbonate occurred in carbonate concretions as revealed by the profile description.

Carbonate associated with silt and clay increases with depth from 3.4%, 7.9% at the surface to 13.6%, 10.7% at the 100 cm depth, respectiv ely. Similar pattern was exhibited by silt and clay with carbonate (Table 1, Figure 5).

Carbonate associated with very fine sand indicates accumulation of carbonate towards the surface. The distribution of very fine sand and the associated carbonate accumulation clearly indicate the accumulation at the surface. Aeolian sediments are of paramount significans to soil development during the Quaternary as reported by many workers (56).

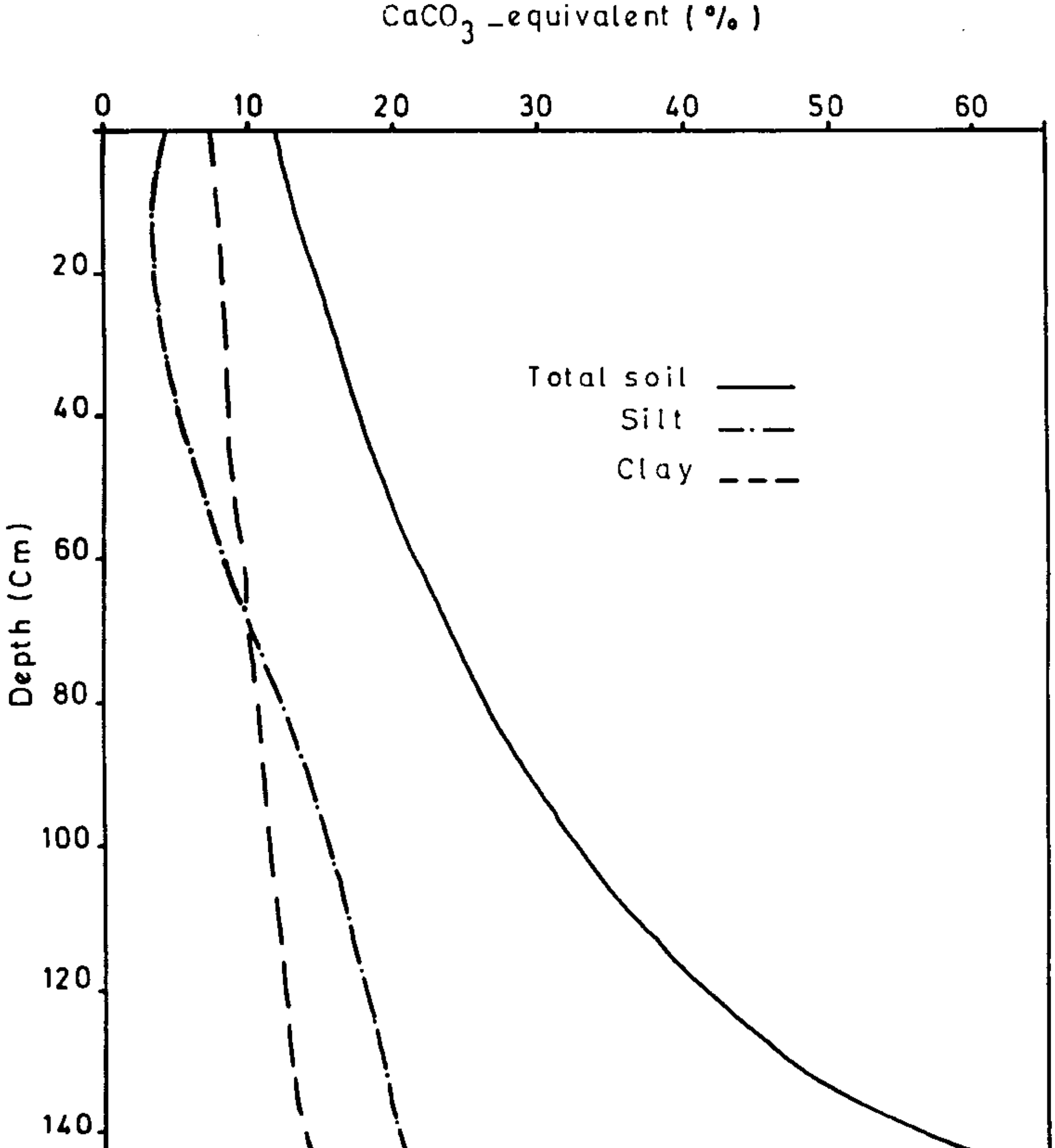

Fig.5 _Calcium carbonate_equivalent distribution in different soil fractions_depth for soil_profile 1

4.2.3 Free iron oxides

The free iron oxides for total soil and clay increase slightly towards the surface (Table 3).
This could be due to the fact that present weathering is restricted to the surface due to low precipitation.
Although clay fraction maintains higher amounts of free iron oxides than soil, the variation of free iron oxides with depth does not indicate noticeable translocation within this profile.

4.2.4 Cation exchange capacity(CEC)

The CEC for total soil decreases slightly with depth from 32.1 meq/100g (in AP) to 26.1 meq/100g (in IIB23Ca) horizon (Table 3). This may be due to the effect of organic matter.
Cation exchange capacity for clay indicates significant differences between horizons. Clay of AP horizon has the minimum CEC value (65.9 meq/100g), and B22 the maximum (114.4 meq/100g).
The variation of clay CEC suggests different dominant clay minerals due to the type of weathering, or due to the increase in clay content by illuviation. Fine clay possesses higher CEC due to its higher charge.

4.2.5 Mineralogy of Silt and Clay fractions

Figures 6 and 7 display the X-ray diffraction patterns for clay and silt. Clay fraction throughout contains the following minerals; vermiculite/smectite/illite interlayered mineral, illite and kaolinite. Illite of

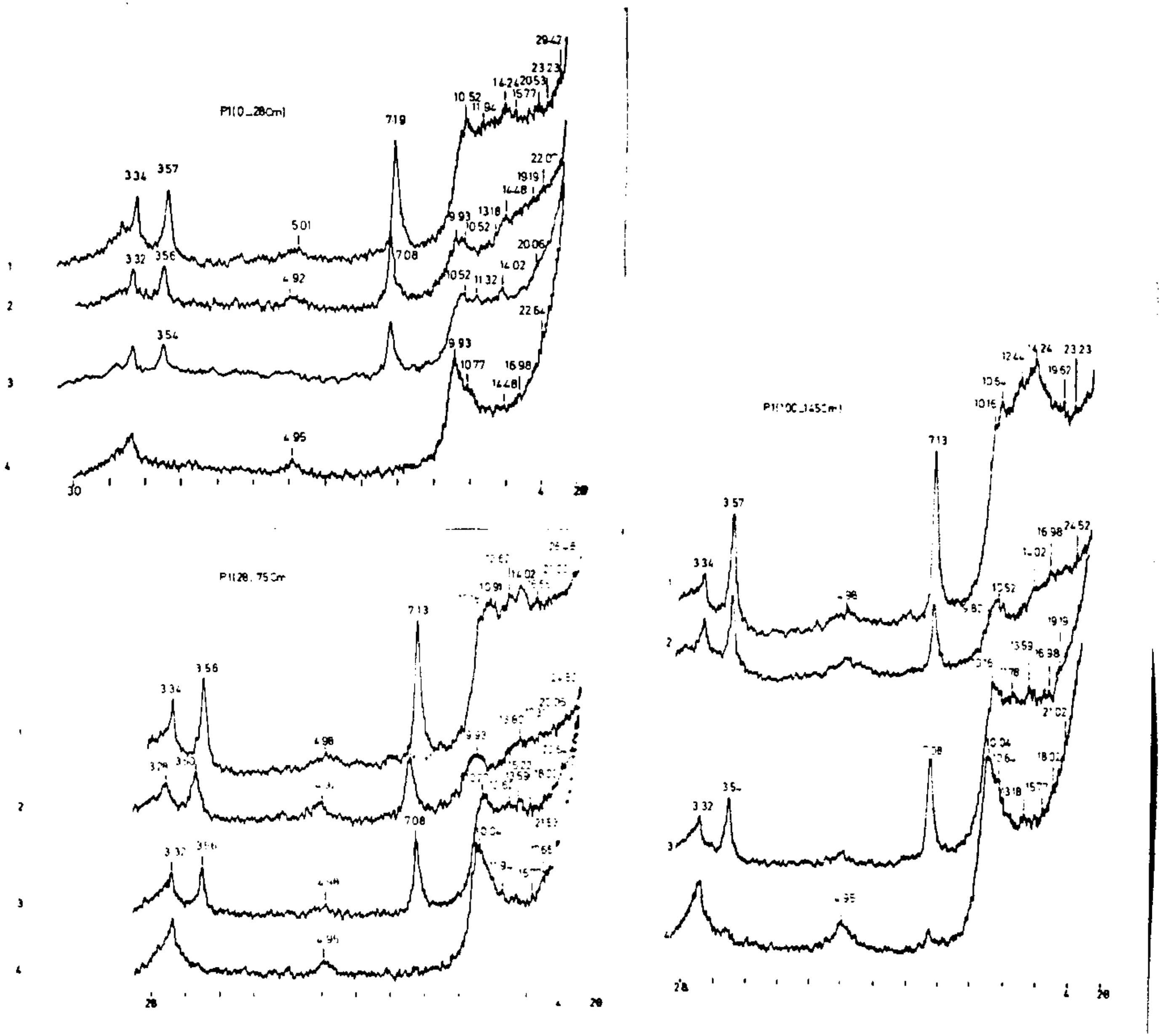

Fig.5_X_Ray diffraction patterns for clay_profile No.1

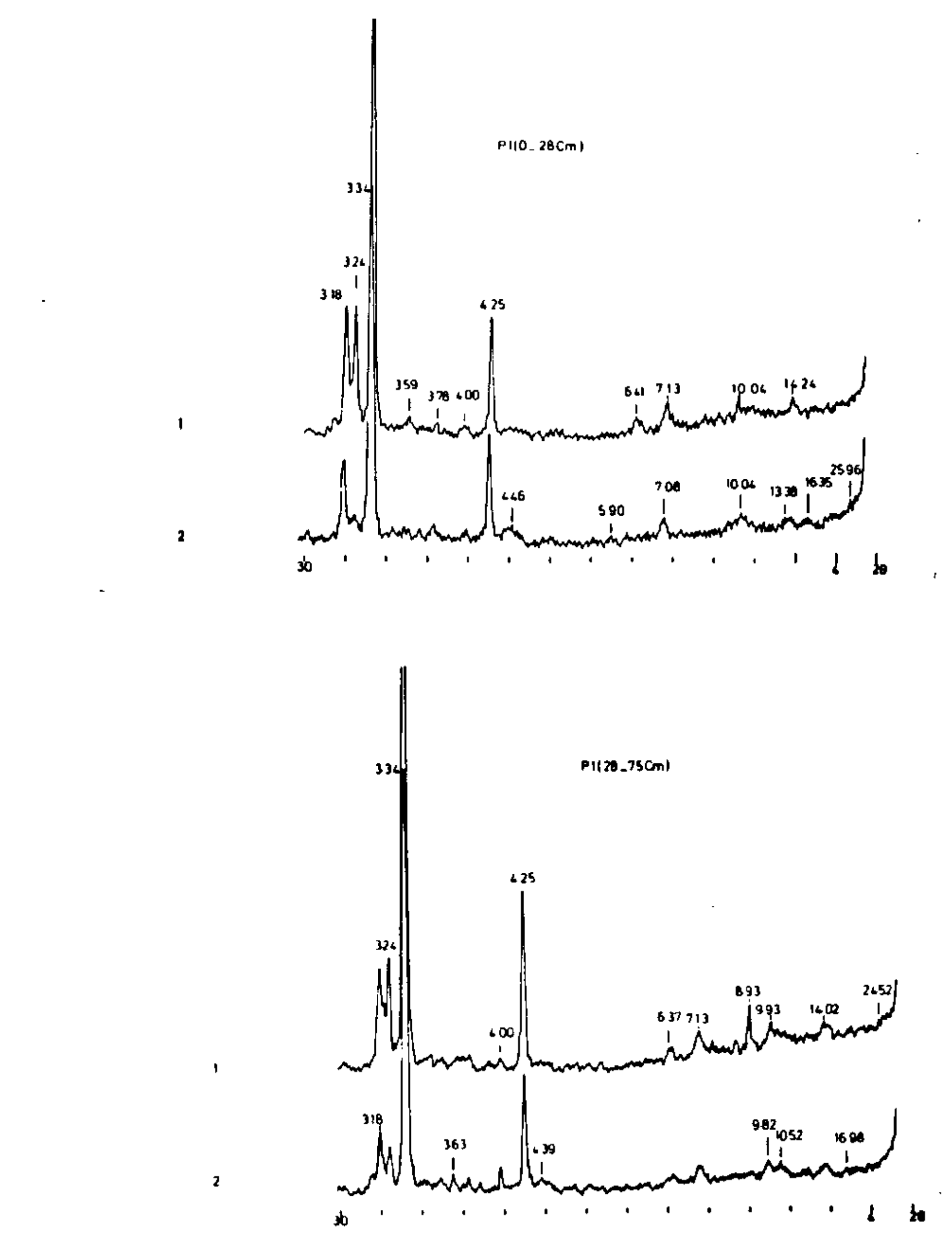

Fig.7_X_Ray diffraction patterns for silt_profile No.1

this fraction decreases vertically, while koalinite increases with depth. Further, the degree of interlayering increases with depth. The illite accumulation on the surface can be explained by examining the very fine sand fraction which indicates recent addition to the surface.

The mineralogy of the acid-insoluble residue of limestone from different climatic zones of Jordan was not found to be dominated by mica and contains kaolinite, although most of the previous investigations reported the dominance of mica and the absence of kaolinite (57). The increase in kaolinite content and degree of interlayering suggests intensive chemical weathering. Moreover, the kaolinite variation indicates that the lower solum had experienced the most intensive chemical weathering evidenced by the maxiumum carbonate-free clay content (Table 7). Further, cation exchange capacity for clay supports such conclusion. Shamali studied some limestone soils of Kufranjeh in Jordan and reported montmorillonite to be the dominant clay mineral; while illite, kaolinite and metahalloysite occurred in appreciable amounts (57). Muir (39) described some limestone soils from the desert of Syria, and showed that the dominant mineral was attapulgite associated with some of what he called kaolinoids micaceous materials. Kaolinite is supposed to be the end degradation product of feldspars and micas. Removal of K^+ by circulating water is essential to form kaolinite (35).

Others had indicated, however, that mixed layer illite/smectite could be the intermediate stage before the formation of kaolinite (35,43).

Mineralogical composition for silt is characterized by the presence of quartz, plagioclase, illite, interlayered vermiculite/smectite/illite mineral, kaolinite and a little amount of palygorskite. The distribution of silt with and without carbonate does not indicate noticeable accumulation of this fraction by winds, but there is an accretion of very fine sand. The occurrence of plagioclase, illite; and palygorskite at the surface is another evidence for the aeolian activity that implies an arid condition. This was indicated by Singer (54), who ascribed the occurrence of quartz and illite at the surface of soils at Golan Heights to the aeolian activity.

4.3 Profile No. 2

4.3.1 Particle size distribution

Clay content without carbonate increases from the surface till the depth of 130 cm suggesting possible clay illuviation (Table 8, Figure 8). The difference in clay content without carbonate between surface and subsurface (0 - 130 cm) is 7%. This difference does not meet the requirement of the argillic horizon (55), but strongly suggests the occurrence of illuviation.

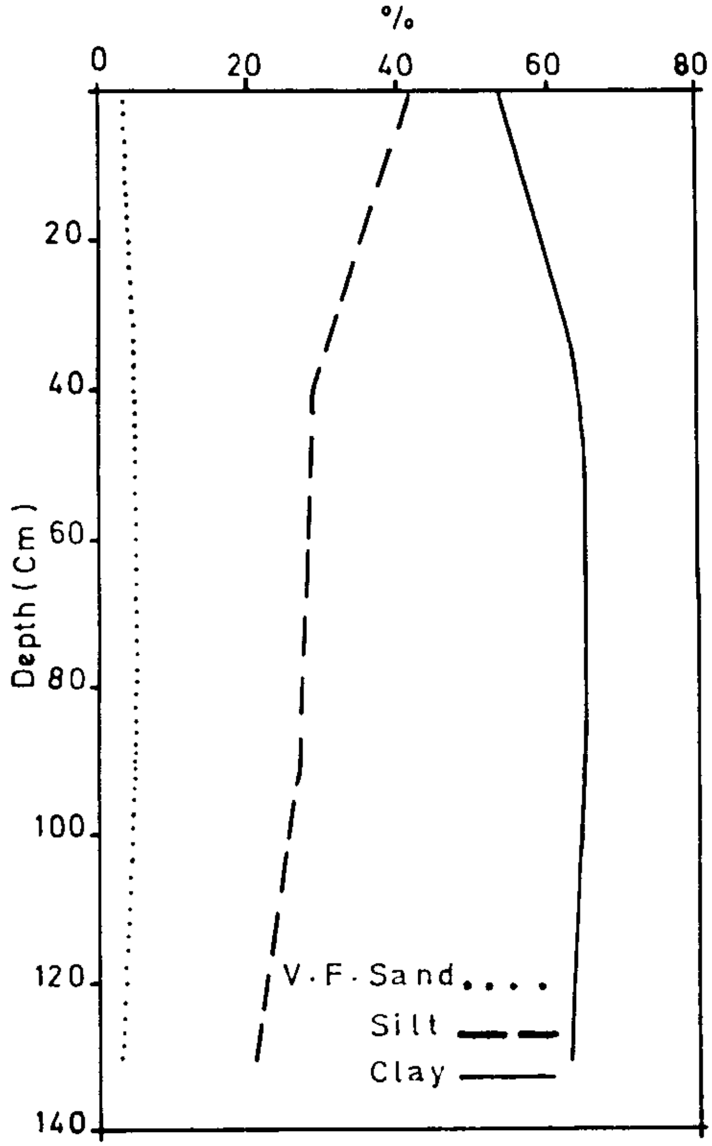

Fig.8_Particle size_depth distribution without carbonate for profile No.2

Clay content with carbonate follows the same pattern indicating carbonate leaching within this solum.
Silt without carbonate increases towards the surface indicating the accumulation of silt from the top by the aeolian activity. Moreover, silt with carbonate follows the same pattern as silt without carbonate, This provides an evidence to the nature of the deposit which occurred in the near past and still prevailing.
Medium sand (0.6 - 0.2 mm in diameter) without carbonate varied from less than 1% above 130 cm depth to 7% below this depth, while coarse sand fraction (>0.1 mm in diameter) with carbonate varied from 5% to 25%, respectively.
The particle size distribution recalculated on clay free basis exhibits a difference of >5% between above and below the depth of 130 cm for silt, very fine, medium, and very coarse sand fractions. This variation suggests possible lithological discontinuity at the 130 cm depth.

4.3.2 Carbonate

Total carbonate, and the carbonate associated with silt (Table 1, Figure 9) increases gradually with depth from the surface till the depth of 130 cm indicating carbonate leaching within the upper solum.
Carbonate associated with clay is distributed uniformly in the upper solum with a very slight increase towards

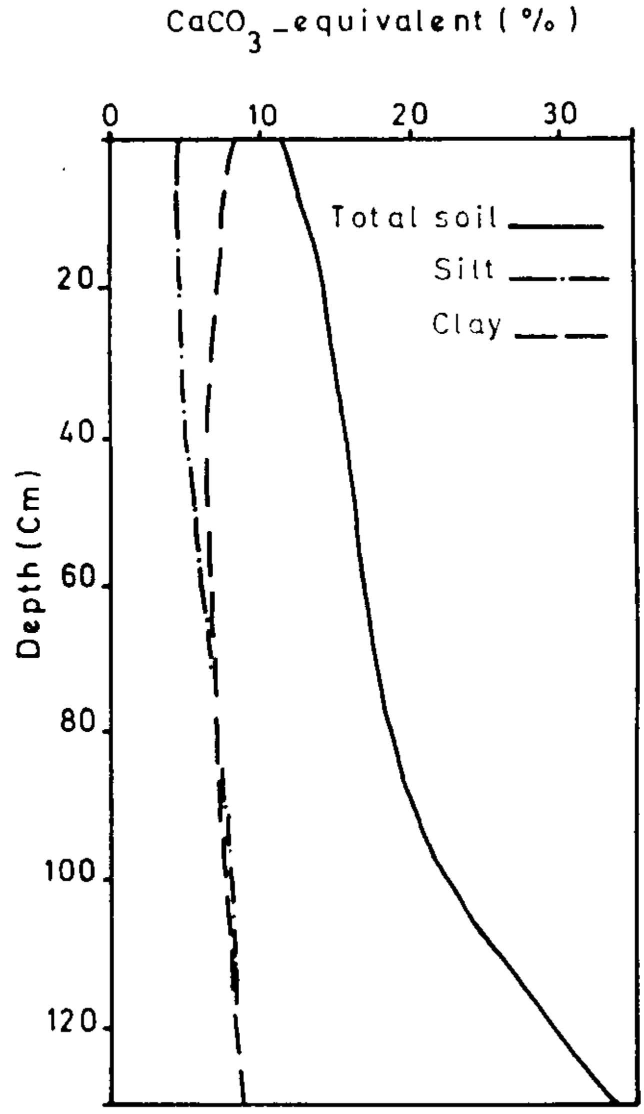

Fig. 9 _Calcium carbonate_equivalent distribution in different soil fractions_depth for soil profile 2.

the surface. The slight increase is reversed with depth below the surface which provides an evidence that leaching had commenced sometimes ago.

The carbonate associated with very fine sand increases very slightly towards the surface suggesting a weak accretion of carbonate.

The carbonate associated with >0.1 mm fraction, increased with depth which is explained by the occurrence of carbonate concretions (See profile description) indicating the depth of water movement and consequently the depth of carbonate leaching.

4.3.3 Free iron oxides

Free iron oxides for total soil (Table 3) is distributed uniformly throughout the profile with no noticeable difference between the two solum. On the other hand, the slight increase in free iron oxides in clay fraction might be associated with the illuviated clay as indicated by the particle size distribution.

The concentration of large portion of the iron oxides in the clay fraction coupled with the high carbonate free clay content show that this profile was subjected to intensive chemical weathering.

The absence of strong clay illuviation in such case could be attributed to the followings: 1) the high clay content will hinder the clay movement. 2) interruption in soil forming factor which had occurred when clay illuviation had started.

The accumulation of silt associated with carbonate could have occurred after the commencement of clay illuviation which apparently prevailed for sometimes. Consequently, a new cycle of soil fomring factors had evolved.

4.3.4 Cation exchange capacity (CEC)

CEC for soil increases gradually towards the surface above the 130 cm depth (Table 3). The cation exchange capacity for clay is 81.8 meq/100g for AP and B22Ca horizons, while it is 99.5 meq/100g for B21 horizon. At IIB23Ca horizon, CEC for clay is 90.9 meq/100g. The highest CEC of clay fraction of B21 horizon could be attributed to the 7% increase in clay content compared with AP horizon. So, B21 horizon may have more fine clay as a result of clay illuviation. This fine clay is more weathered and has higher charge i.e. higher CEC.

4.3.5 Mineralogy of silt and clay fractions

Results of X-ray analysis indicated (Figures 10,11) that this soil maintains a mixture of minerals in its both fractions; the silt and clay.

Comparing the mineralogical composition for AP and B22Ca horizons (clay fraction); it could be indicated that vermiculite/smectite/illite interlayered mineral increased with depth, while kaolinite is uniformly distributed with depth. The illite follows the same

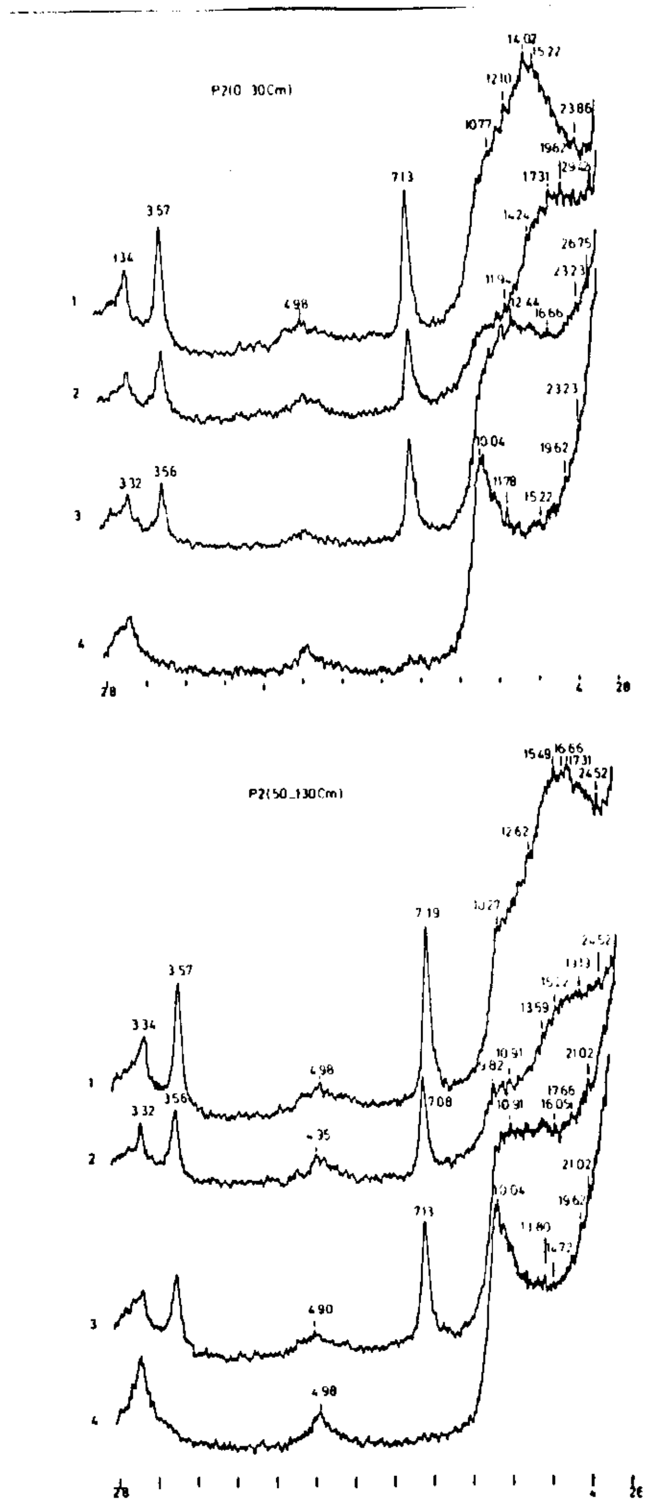

Fig.10_X_Ray diffraction patterns for clay_profile No.2

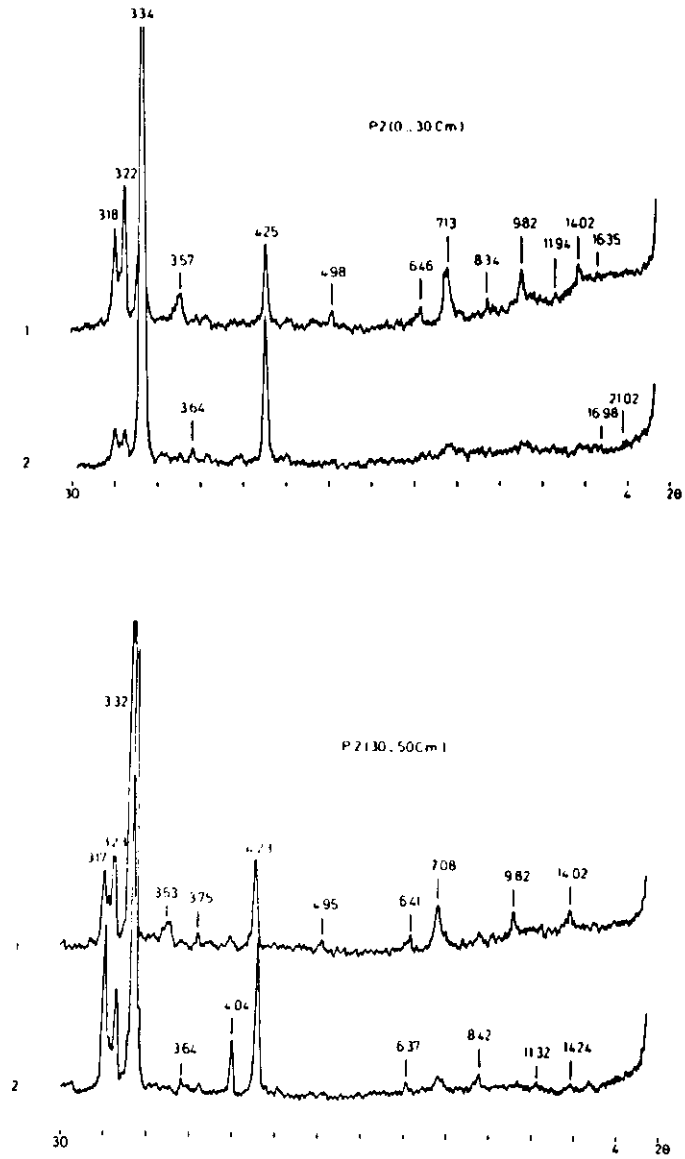

Fig.11_X_Ray diffraction patterns for silt_profile No.2

pattern as kaolinite. This provides an evidence that this soil had experienced a strong chemical weathering which involves high amounts of water passing through profile. Other workers had found that as clay content increased contrary smectite and interlayered mineral had also increased (50).

Occurrence of plagioclase feldspar, illite and palygorskite at the surface in silt fraction provides an evidence of concurrent aridity which is characterized by the addition of silt and carbonate to the surface. The presence of illite and quartz in the upper soil horizons of Golan Heights was explained by aeolian accretion (54). Moreover, it was found that the aeorosolic dusts contain micaceous vermiculite (56), which may explain the occurrence of interstratified vermiculite/illite mineral in silt fraction of this pedon.

4.3.6 Bulk density and coefficient of linear extensibility(COLE)

Bulk density was minimum at the surface (Table 9) and increased slightly with depth. Lower bulk density at the surface may be due to higher organic matter effect. The slight increase in bulk density from 30 to 130 cm depth reflects the limited clay invrease within this solum or due to the compaction.

COLE is 0.05 as an average value (Table 9). This value is less than 0.09 value necessary to place this soil as in the Vertisols order (55), but suggests appreciable shrinking and swelling potential.

4.4 Profile No. 3

4.4.1 Particle size distribution

Clay content without carbonate increases from 58.1% at the surface to 61% at B22 horizon (Table 10). Below this horizon, clay without carbonate increases to 72.4%. The difference in clay content between surface and subsurface (0 - 130 cm) is 4% and does not meet the requirement of the argillic horizon (55). The big difference in clay content above and below the depth of 130 cm indicates a change in soil forming factors. The uniform distribution of clay content without carbonate from the surface till 130 cm depth supports the suggestion that the A horizon might have been truncated by the geologic erosion accelerated after the Rift Valley formation (14). Though variation of clay without carbonate does not offer a very strong evidence for clay illuviation, it should not however, be ignored for two reasons; First: the high clay content does not allow a high rate of illuviation. Second: since it is suggested that A horizon might have been truncated, then it will be difficult to exclude the occurrence of illuviation.

Clay content with carbonate follows the same pattern as clay without carbonate, but offers some possibility to carbonate leaching.

Silt with and without carbonate increases towards the surface from the depth of 130 cm. Below this depth, there is a big difference in silt content with and without carbonate(Figure 12).

The higher silt (with carbonate) content at the surface suggests an accretion of this fraction, and indicates changes in soil forming factors, possibly in climate after an episode of intensive chemical weathering or illuviation active in the upper 130 cm had been interrupted by a new episode.

Very fine sand with and without carbonate decreases with depth indicating accretion of very fine sand and carbonate at the surface.

Fractions coarser than the very fine sand with and without carbonate are uniformly distributed. This pattern suggests that parent material is homogeneous throughout profile and the break at the depth of 130 cm may refer to a change in the pattern of weathering possibly due to a change in climate not a change in parent material.

Vertical distribution of silt and very fine sand (on clay free basis) indicates that the 130 cm depth serves as a line which separates two solum reflecting different weathering patterns, while the coarser fractions show a uniform distribution indicating one type of parent material.

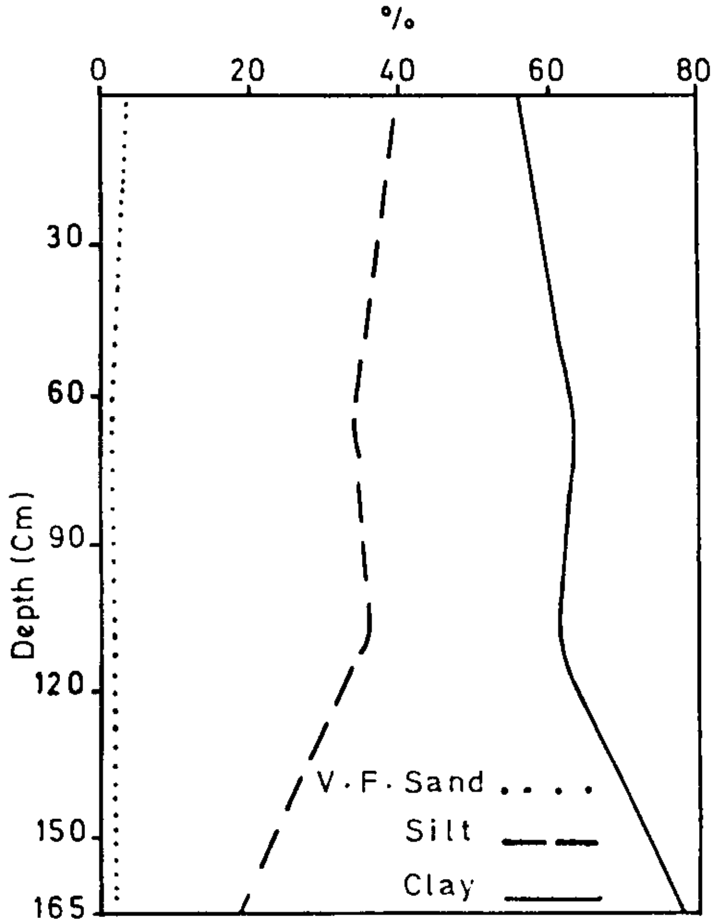

Fig.12_Particle size_depth distribution without carbonate for profile No.3

Particle size distribution data indicated a uniform distribution of soil separates throughout the subsurface horizons (from 40 to 130 cm). Also, this might be attributed to the fact that vertic property had developed in recent time after the evolution of basic conditions in the profile which arises with the enrichment of carbonate.

The absence of gligai topography in such soil indicates clearly that churning process has not been active for long time.

4.4.2 Carbonate

Total carbonate is distributed uniformly from the surface to the depth of 130 cm. Below this depth, total carbonate increased significantly. This substantiates the earlier suggestion that 130 cm line divides two different solums.

Carbonate associated with clay increases from 5.7% (at AP) to 10.4% (at B22 horizon), then increases sharply to 20.8% (at B23Ca horizon). This clearly indicates that leaching had occurred in the upper 130 cm zone coupled with downward clay increase in the same zone, which should strongly support the commencement of illuviation which had been interrupted afterwards.

Carbonate associated with silt and very fine sand increases towards the surface suggesting carbonate accretion due to aeolian activity (Table 1, Figure 13).

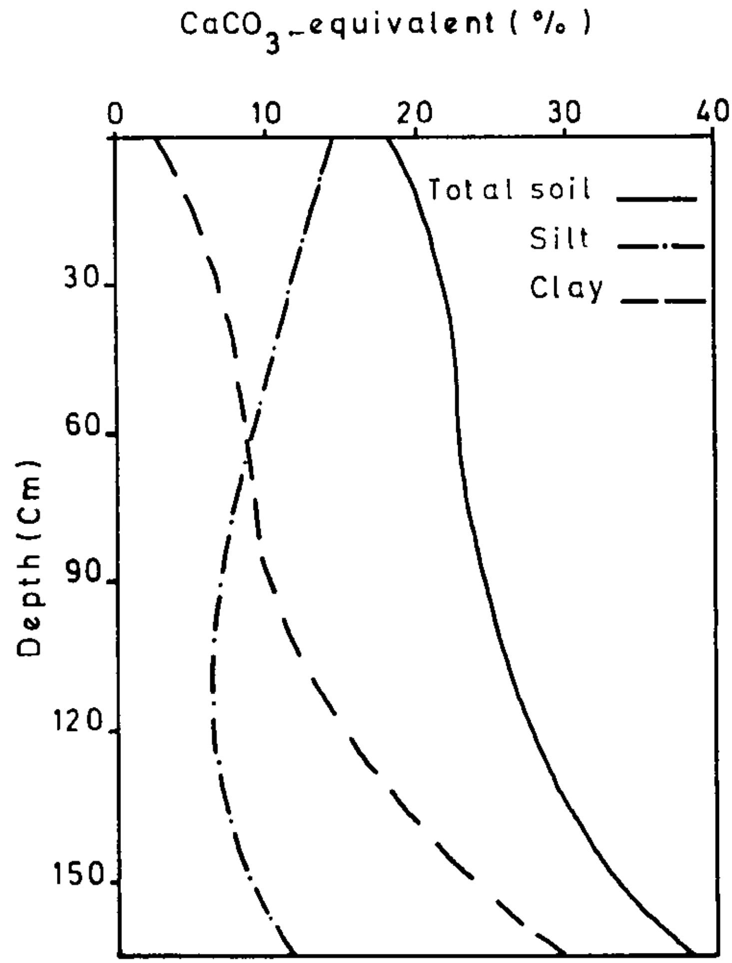

Fig. 13_Calcium carbonate_equivalent distribution in different soil fractions_depth for soil_profile 3.

The carbonate associated with >0.1 mm fraction increases with depth which coincided with the distribution of carbonate concretions. Moreover, profile description revealed that maximum carbonate concretions occur below the 130 cm depth suggesting that this portion of the profile was subjected to different type of weathering.

4.4.3 Free iron oxides

Free iron oxides for soil is distributed appoximately uniform throughout the profile (Table 4), while free iron oxides for clay decreases gradually from the surface till the depth of 130 cm. Below this depth it increases again. This suggests two different weathering patterns separated at the 130 cm depth. Free iron oxides data, however, suggest no noticeable translocation of this material in the upper 130 cm zone.

4.4.4 Cation exchange capacity (CEC)

Cation exchange capacity for soil (Table 4) decreases gradually with depth possibly due to the effect of the organic matter.

The cation exchange capacity for clay decreases significantly with depth, suggesting different dominating clay minerals in different horizons.

4.4.5 Mineralogy of Silt and Clay fractions

The interpretation of X-ray diffraction patterns (Figure 14) indicates the presence of the following minerals in clay fraction; smectite/vermiculite/illite inter-

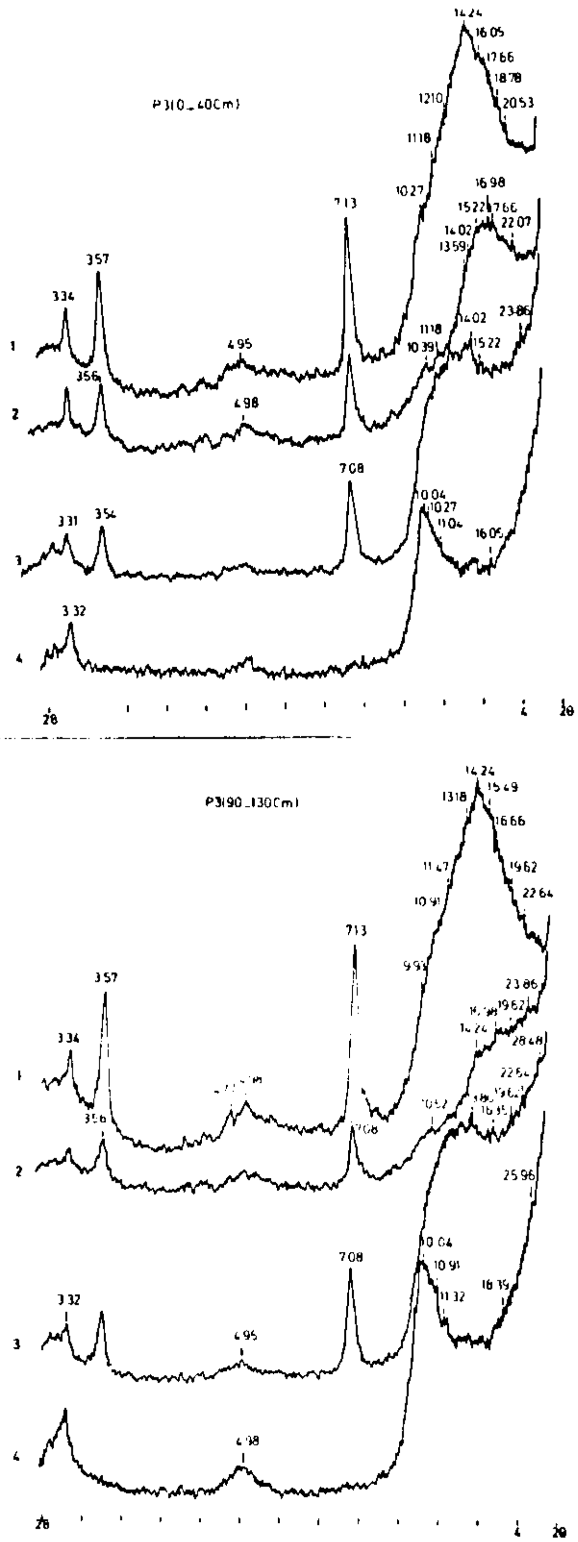

Fig.14_X_Ray diffraction patterns for clay_profile No.3

layered mineral, illite and kaolinite. Comparing surface and subsurface horizons, it could be noticed that kaolinite was uniformly distributed, whereas, illite decreased slightly with depth. The interlayered mineral increases vertically with smectite dominating. This indicates that this pedon experienced intensive chemical weathering evidenced by high clay content throughout the profile. Singer (52), in his study in the Galilee soils concluded that kaolinite dominated soils of high rainfall while montmorillonite dominated soils of low rainfall regions. Hosking (30) has done an extensive study on the mineralogy of different basaltic soils. He reported high montmorillonite type with appreciable amounts of kaolinite and illite in the red brown earth, and montmorillonite type in the black earth. Tuffahah (57) studied two basaltic soils in northeast Jordan and reported the following mine - rals in clay fraction; mica was found abundantly in the surface and the subsoil with medium amounts of montmorillonite and attapulgite, and smaller amounts of vermiculite and kaolinite.

X-ray diffraction patterns for silt of this profile (Figure 15), revealed that illite increases towards the surface. The accumulation of illite at the surface could be explained by the short period of time since it had been added to the surface and due to limited precipitation in present time. Quartz and illite

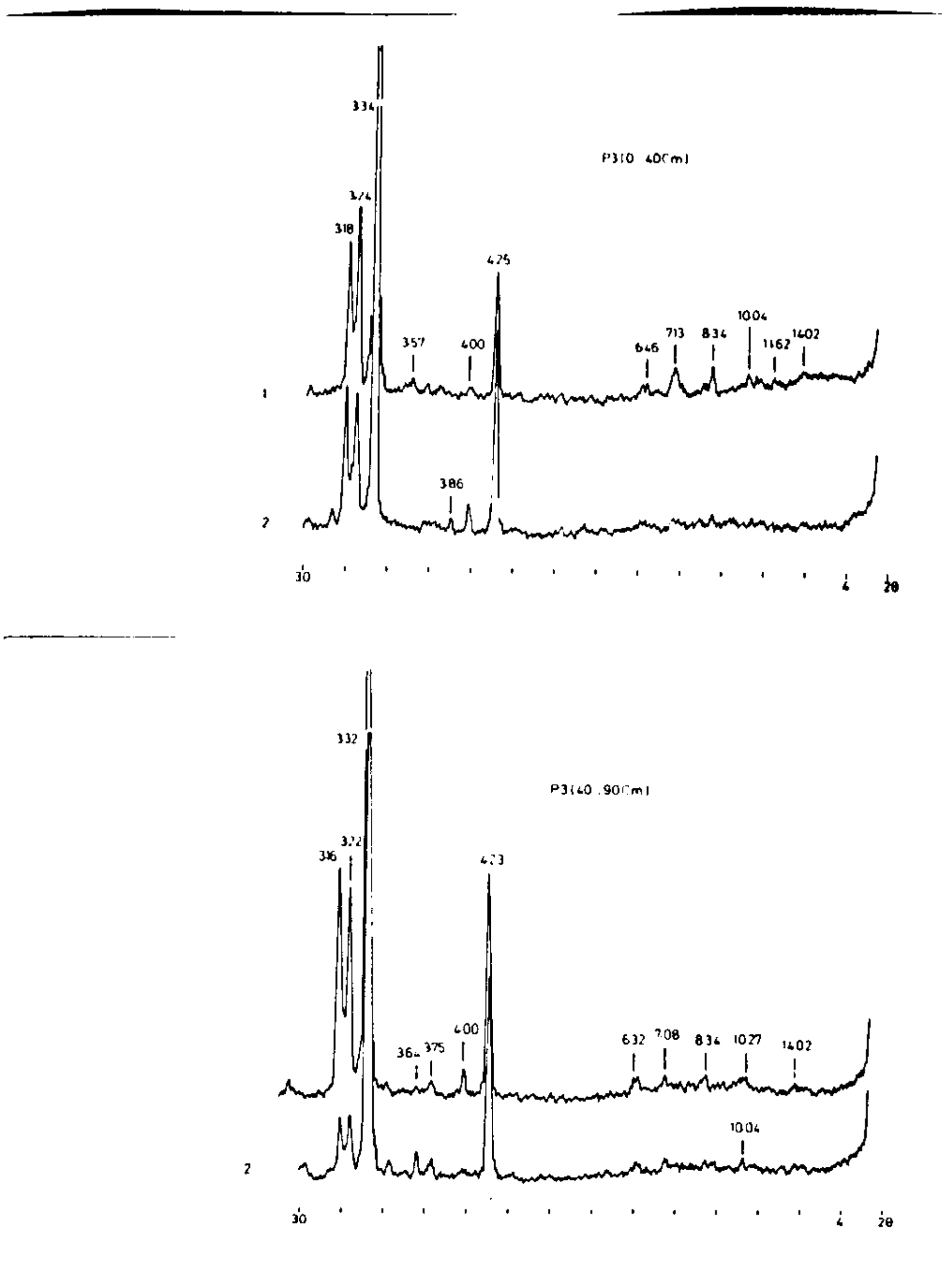

Fig.15_X_Ray diffraction patterns for silt_profile No.3

accumulation at this surface refers to aeolian activity (54). Moreover, the occurrence of palygorskite and plagioclase at the surface is an evidence for aridity.

4.4.6 Bulk density and coefficient of linear extensibility(COLE)

Bulk density on dry and moist basis is minimum at the surface (Table 9) and increases with depth. Below the depth of 130 cm, bulk density differs significantly. Coefficient of linear extensibility for B21 and B22 horizons is more than 0.09 which meets the requirement of Vertisols (55).

4.5 Profile No. 4

4.5.1 Particle size distribution

Carbonate free clay content varies from 42% to 64% (Table 11). This suggests strong chemical weathering, the availability of large amounts of water, and the occurrence of clay illuviation. Clay content with and without carbonate increases from the surface to the depth of 148 cm. The clay variation with depth suggests possible clay illuviation preceded by carbonate leaching within this zone (0 - 148 cm), (Figure 16). According to Soil Taxonomy (55), this soil is qualified to have an argillic horizon. Field investigation indicated the occurrence of clay coatings in this solum (See profile description), especially in B23t horizon.

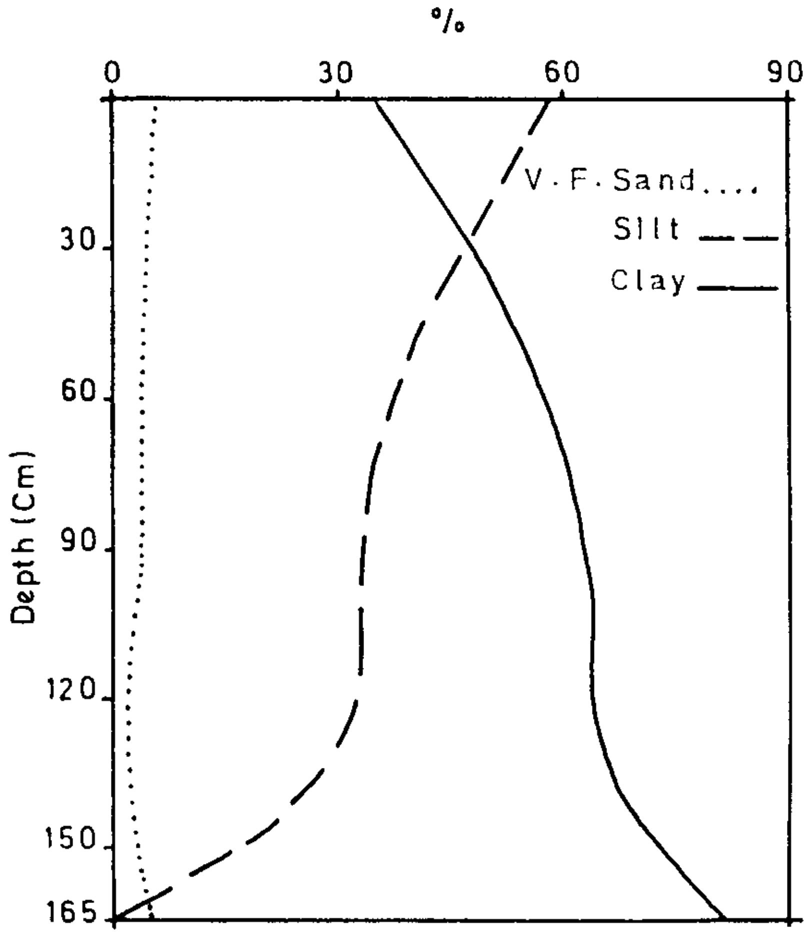

Fig.16_Particle size_depth distribution without carbonate for profile No.4

Silt content with and without carbonate increases towards the surface above the 148 cm (Table 11, Figure 16). Silt variation with depth indicates an accretion of silt and carbonate associated with it. The accretion of the silt implies the occurrence of aeolian activity during an arid episode.

Very fine sand with and without carbonate follow the same pattern as silt, supporting the forementioned suggestion of arid environment.

The recalculated particle size distribution on clay free basis, strongly suggests two different solum separated at the 148 cm line.

4.5.2 Carbonate

Total carbonate and carbonate associated with clay (Table 1) increased vertically to the depth of 148 cm (Figure 17). The carbonate variation with depth suggests two leaching patterns under different climatic conditions. Total carbonate and carbonate associated with >0.1 mm fraction increase sharply from 16.1%, 1.3% above 148 cm depth to 43.5% and 17.9% below it, respectively. Accordingly, it could be postulated that a significant difference occurred in carbonate content between above and below this depth. This difference provides another evidence for change of parent material possibly after climatic change. Field investigation revealed the increase in carbonates as concretions with

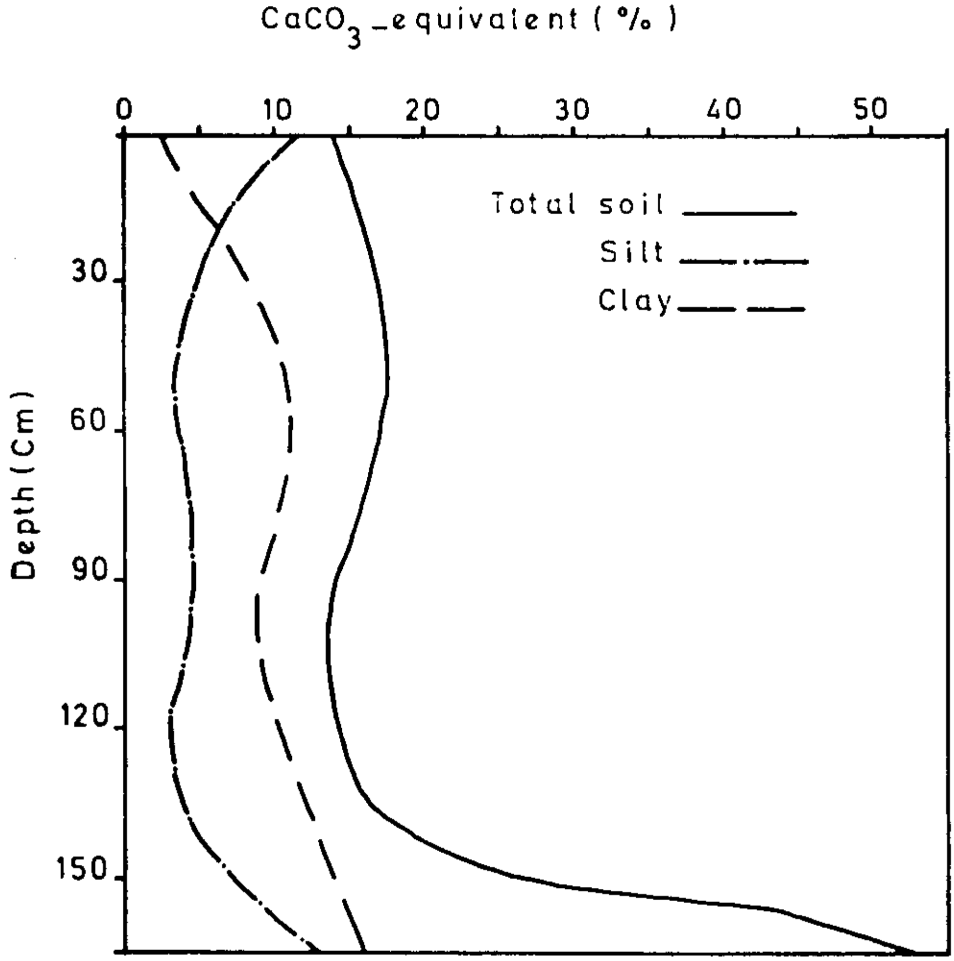

Fig.17_Calcium carbonate_equivalent distribution in different soil fractions_depth for soil _profile 4.

depth (See profile description).
The carbonate associated with silt and very fine sand indicated that carbonate associated with these fractions increased towards the surface above the 148 cm depth. This provides another evidence for carbonate accretion towards the surface due to the aeolian activity, which could have prevailed in the past and in recent times.

4.5.3 Free iron oxides

Free iron oxides for total soil decreases slightly with depth (Table 4). This type of variation may indicate that weathering intensity decreases towards the surface, which could be possible if climate shifted from humid towards aridiness.
Free iron oxides for clay follow the same pattern as free iron oxides for total soil. The highest value is reached in the AP horizon. IIB3Ca horizon maintains the minimum.

4.5.4 Cation exchange capacity (CEC)

Cation exchange capacity values for soil increase with depth from surface to 148 cm depth (Table 4). IIB3Ca horizon has the minimum CEC value. This pattern indicates that the upper solum was subjected to intensive weathering. Also, the vertical increase in CEC coincided with clay increase with depth which may be due to clay illuviation, especially of fine clay which has higher charge.

Data for CEC for clay of this soil indicate that AP and B21 horizons had the highest values of CEC, whereas, IIB3Ca horizon maintains the lowest value. This variation in clay CEC in the different horizons of this soil suggests some mineralogical variation. The original surface horizon in this soil is suggested to be lost by erosion. So, the present AP horizon originally was a part of B21 horizon. These two horizons (AP and B21) might have received higher amounts of illuviated fine clay. Thus, the higher values of CEC for these horizons could be referred to higher fine clay in these horizons. Because AP has lower clay content than B21 (Table 11), AP horizon has to have lower amounts of amorphous materials which contribute to decrease its CEC. Yaalon (59), concerning the small amounts of amorphous materials he indnetified in Jerusalem, Stated: " ... that the amorphous constituents, although occurring in considerably smaller quantities than the crystalline material, determine to a considerable degree the essential properties of the resulting soil CEC". The presence and importance of amorphous materials in terra rossas were also, reported by Muir (39).

4.5.5 Mineralogy of silt and clay fractions

The X-ray diffraction patterns for clay and silt fractions are shown in Figures 18 and 19.

The main minerals in the clay fraction of this pedon were; smectite/vermiculite/illite interlayered mineral,

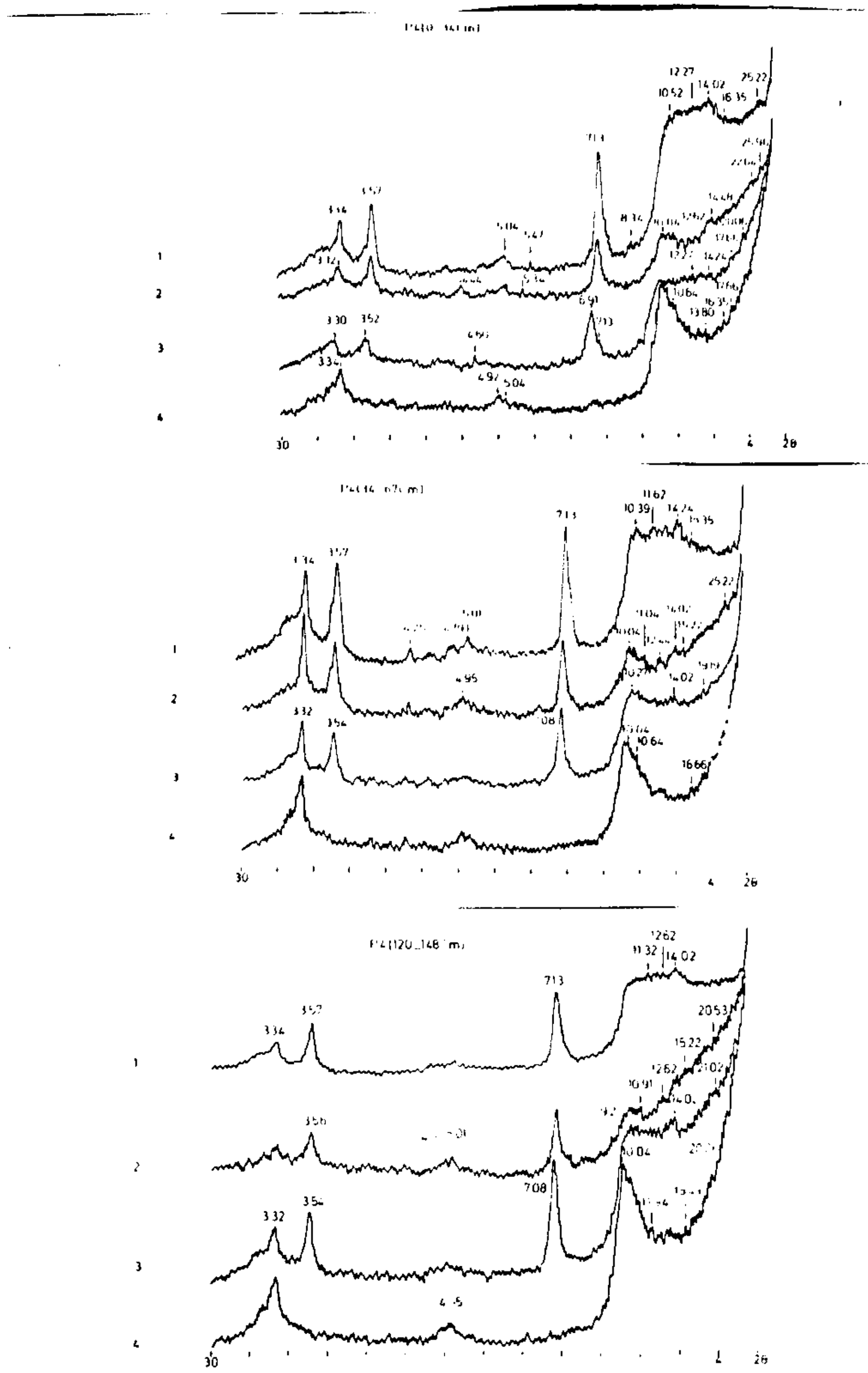

Fig.18_X_Ray diffraction patterns for clay_Profile No.4

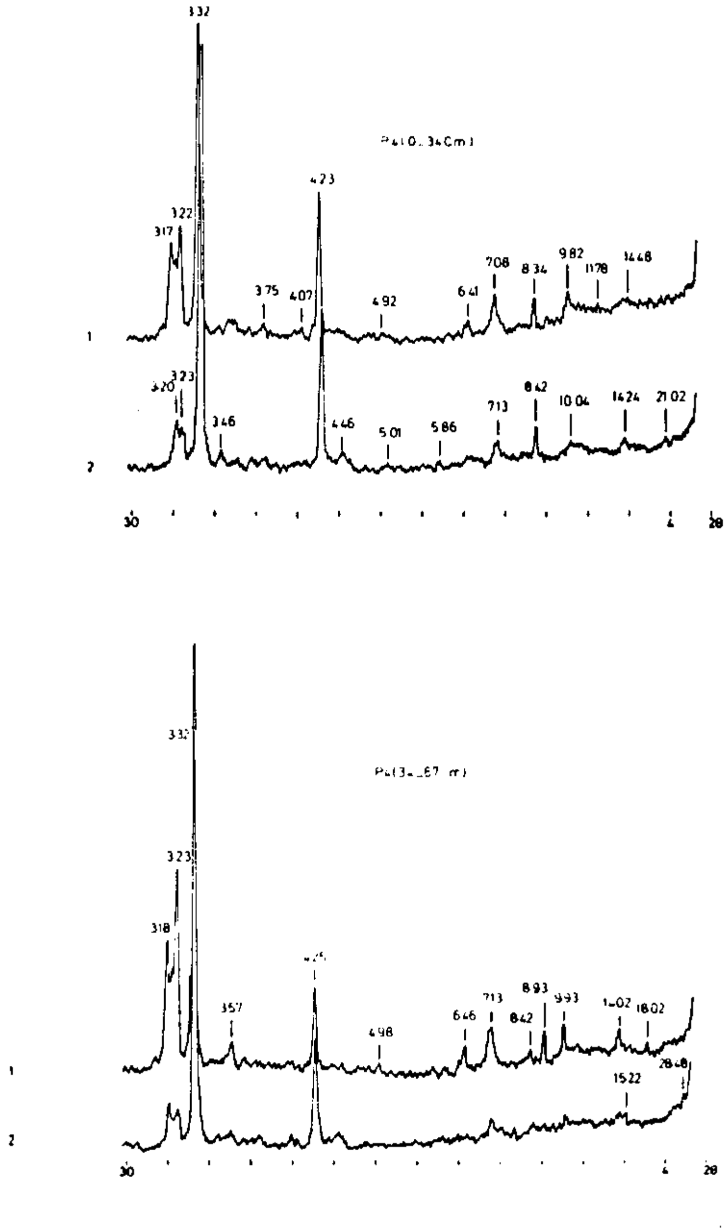

Fig.19_X_Ray diffraction patterns for silt_Profile No.4

kaolinite and illite. There is no noticeable variation in kaolinite throughout profile.

The degree of interlayering increases vertically providing another evidence that this solum had experienced intensive chemical weathering as suggested previously. Mixed layers also, reveal changes in environmental conditions since they are formed readily by only minor changes in the environment whereas most of other mineral alterations occur very slowly (47).

Illite decreases with depth. However, the occurrence of the illite at the surface could be explained by examining the distribution and mineralogy of silt fraction which shows clearly that illite had been added to the surface by wind activity as concluded earlier.

Silt fraction of this profile contains the following minerals in decreasing sequence; quartz, plagioclase feldspar, kaolinite, illite and smectite/vermiculite/illite interlayered mineral, and low amounts of palygorskite.

Quartz and illite accumulated by wind activity (54) at the surface evidenced by silt accretion (See particle size distribution, Table 11).

Occurrence of plagioclase and palygorskite at the surface in silt fraction indicates the weakness of chemical weathering under present climatic conditions, or the short time since their deposition had commenced.

4.5.6 Bulk density and coefficient of linear extensibility (COLE)

The analysis (Table 9) indicates that bulk density increases with depth. This is natural, since clay content coupled with fine clay illuviation increased with depth. Bulk density on moist basis follows the same pattern as bulk density on dry basis.

The COLE value for different horizons were less than 0.09. Accordingly, this soil does not possess very high shrink and swell potential.

4.6 Profile No. 5

4.6.1 Particle size distribution

According to particle size distribution (Table 12, Figure 20) carbonate free clay content increases with depth from 52.1% (in AP) to 77% (in B23Ca horizon). The clay variation offers an evidence for intensive weathering and possible clay illuviation. The change in clay content qualifies this soil to have an argillic horizon (55).

Clay with carbonate followed the same pattern as clay without carbonate suggesting strong carbonate leaching, which appeared to be interrupted more than one time.

The silt without carbonate increases sharply towards the surface. This type of variation indicates that large silt accumulation had occurred.

The variation of silt with carbonate indicates that carbonate associated with silt fraction had been added

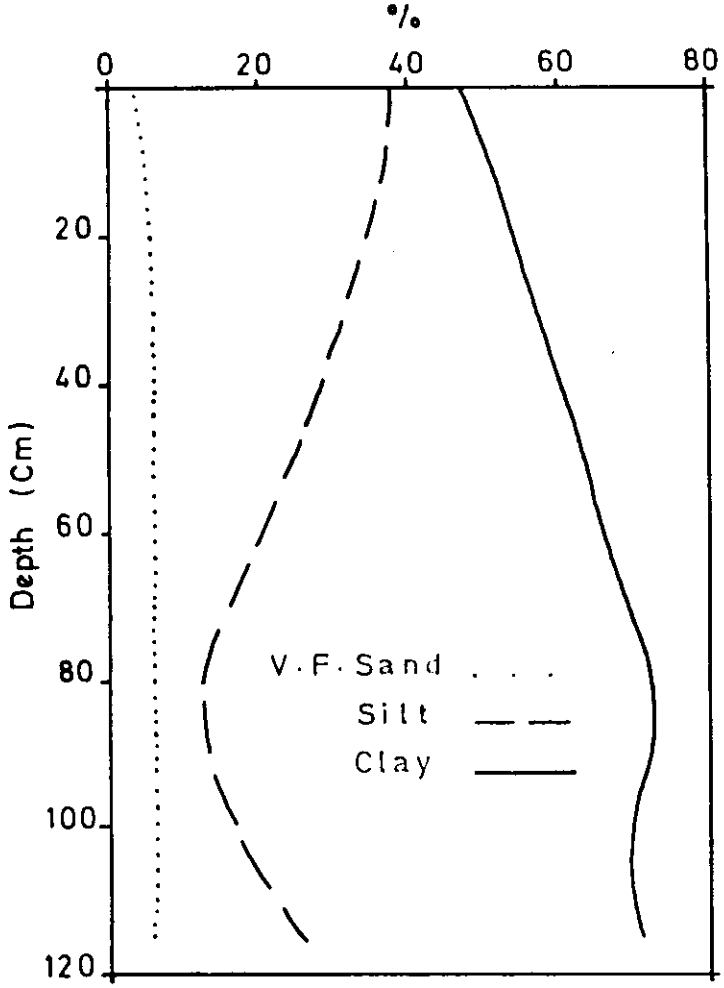

Fig.20_Particle size_depth distribution without carbonate for profile No.5

to this soil by wind activity during the dominance of an arid episode. This arid episode had possibly been preceded by an episode characterized by very intensive chemical weathering.

The coarser fractions were distributed uniformly in this soil (Table 12).

Particle size distribution recalculated on clay free basis indicates a major change in the solum possibly in the parent material at the depth of 115 cm. However, the same data, also suggest another breaks at the 60, 79, and 90 cm. These breaks might be attributed to different cycles of weathering. For silt fraction, it clearly suggests silt accumulation above the 79 cm depth, but also suggests leaching or weathering from 79-115 cm. This increase might be correlated with high clay content found in this zone (60-115 cm) which clearly suggests that intensive chemical weathering had occurred, which possibly preceded by another intensive weathering episode, as indicated by the high clay content. The clay illuviation had taken palce during the second episode which occurred after truncation. Then followed by silt accumulation episode which might have been interrupted more than one time.

4.6.2 Carbonate-equivalent distribution

Total carbonate increases from the surface till the depth of 90 cm (Table 2) providing a good evidence that leaching had been very active in this soil (Figure 21).

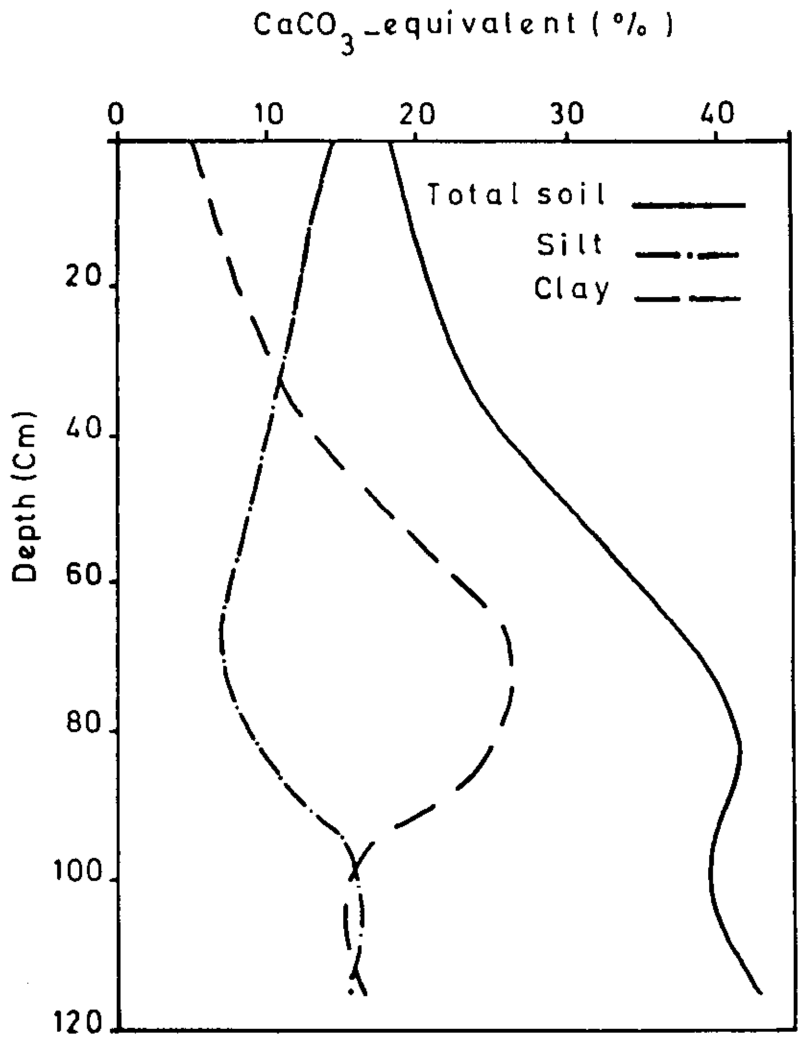

Fig.21 _ Calcium carbonate_equivalent distribution in different soil fractions_depth for soil_ profile 5

Moreover, the carbonate associated with clay fraction increases from 6.8% at the surface to 28.1% at the depth of 90 cm.

Carbonate associated with silt fraction exhibited two different patterns; leaching pattern shown below 60 cm and accretion pattern above that depth. The two patterns can be associated with stronger profile of leaching which had occurred:

The first one led to the accumulation and illuviation of clay and leaching of the carbonate associated with the clay fraction.

The second one led to the accumulation of carbonate above the 60 cm depth as it is clear from the silt distribution. Apparently, the carbonate accumulation in the upper 60 cm had occurred after the leaching episode, since present prevailing climate favors such accumulation.

The carbonate associated with more than 0.1 mm fraction, also increases with depth in this profile reflecting the concentration of carbonate as concretions (See profile description), which indicate the depth of leaching and water penetration in this profile.

4.6.3 Free iron oxides

Free iron oxides of this soil decreases slightly from (Table 5) the surface till the depth of 79 cm (from 3% to 2.3%). Below this depth, the free iron is uniformly distributed. The concentration of free iron oxides at the surface may be due to the higher intensity of weathering at the surface which suggests that, at the present time, soil weathering is restricted to the surface. On the other hand, the free iron oxides associated with clay fraction increases slightly with depth from 4% at the surface to 4.4 % at the depth of 79 cm.

This slight increase with depth may indicate a very weak iron translocation within this solum possibly associated with the clay illuviation (See particle size distribution). Below the depth of 79 cm, the variation pattern of iron is irregular.

4.6.4 Cation exchange capacity (CEC)

Cation exchange capcity for this soil increases gradually towards the surface (Table 5) from 22.6 meq/100g at the depth of 90 cm to 33.7 meq/100g at the surface. Below the depth of 90 cm, CEC of this soil is distributed rather uniformly. The high CEC at the surface can be due to the effect of organic matter and the higher effect of weathering at the surface. Clay of AP,B21 and IIB3Ca horizons had an average CEC of 84 meq/100g, while clay of other horizons had an average CEC of 75 meq/100g. This reflects different sets of weathering had commenced in this soil.

4.6.5 Mineralogy of silt and clay fractions

Figures 22 and 23, give the X-ray diffraction patterns for clay and silt.

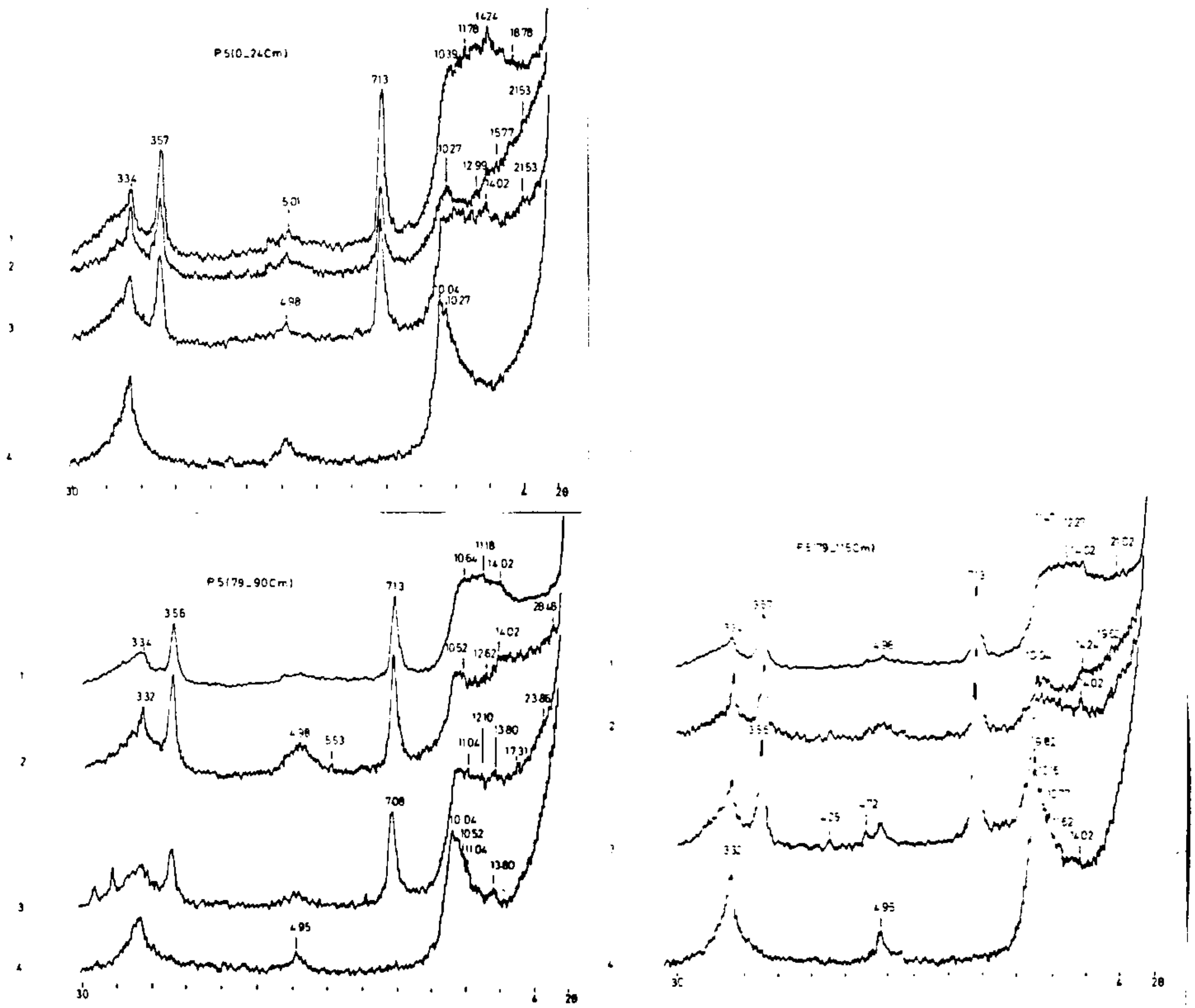

Fig.22_X_Ray diffraction patterns for clay_profile No.5

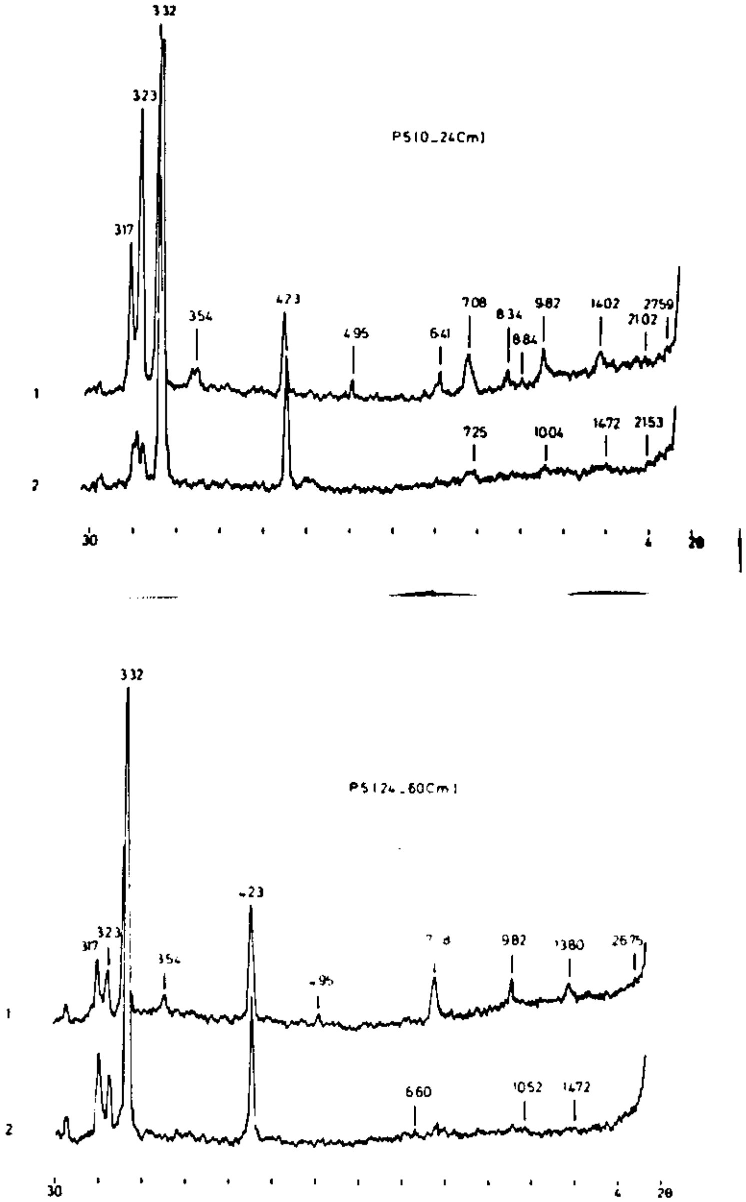

Fig.23_X_Ray diffraction patterns for silt_profile No.5

The X-ray diffraction patterns for clay indicated that, illite increases towards the surface, but the interstratification increases with depth due to the intensive weathering. This might also, explain the increase in CEC for clay as indicated before. By comparison, it was found that while illite decreases vertically, vermiculite/smectite/illite interlayered mineral increases with depth. The kaolinite distributed uniformly. The X-ray diffraction patterns of silt of this profile, revealed that, this fraction contains the following minerals; quartz, plagioclase feldspar, kaolinite, illite and palygorskite. By comparing the minerals in the two horizons (AP and B21), the plagioclase and palygorskite decrease with depth indicating weak chemical weathering.

4.7 Profile No. 6

4.7.1 Particle size distribution

Table 13, shows the particle size distribution. Clay content without carbonate increases with depth from 66% in AP to 76.9% in B24Ca horizon (Figure 24). Clay variation with depth provides an evidence for clay illuviation within this profile. Furthermore, the high clay content throughout this pedon indicates an intensive chemical weathering had occurred in this soil. The amount of clay increase in the subsurface meets the requirement

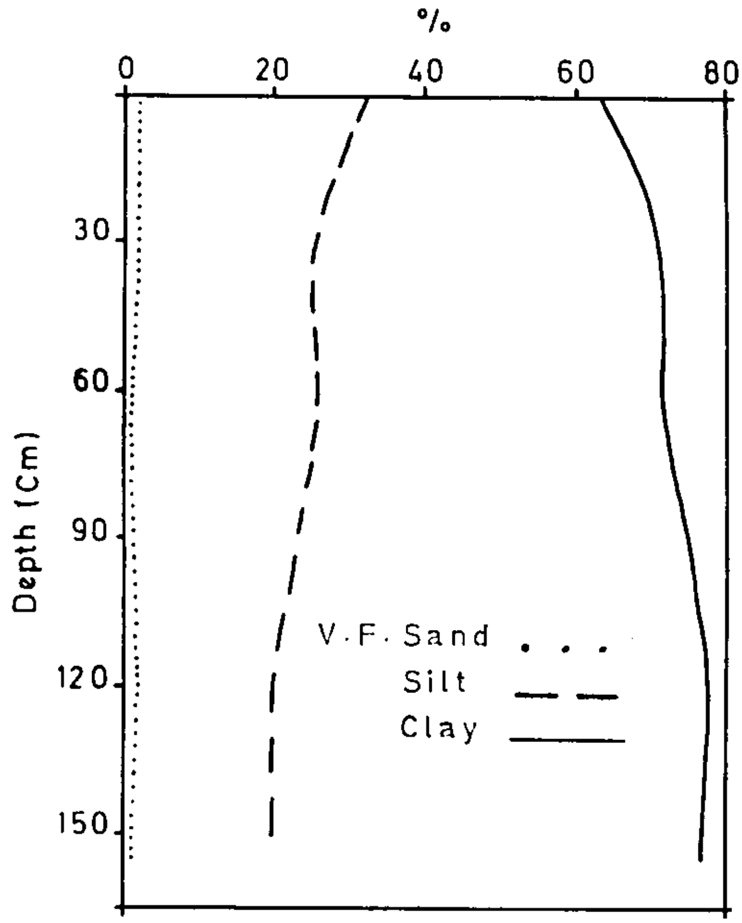

Fig.24_Particle size_depth distribution without carbonate for profile No.6

of the argillic horizon (55). Field investigation did not reveal occurrence of clay coatings in this solum which might have been masked by other processes like shrinking and swelling or dissection (41), (See profile description).

Clay content with carbonate follows the same pattern as clay without carbonate.

Silt content without carbonate increases towards the surface from 19.9% in B24Ca to 31.2% in AP horizon. The vertical variation of silt indicates that silt had accumulated at the surface possibly by the aeolian activity which has been active in recent time (56). The silt with carbonate follows the same pattern.

Sand fractions with and without carbonate are distributed uniformly with depth. This uniformity in distribution of sand fractions could be inherited from the soil parent material.

The particle size distribution recalculated on clay free basis does not indicate any lithological discontinuity.

4.7.2 Carbonate

Total carbonate (Table 2) increases with depth from an average of 8.7% in AP to 14.8% in B24Ca horizon (Figure 25). This slight variation of total carbonate with depth indicates that leaching process was weak or due to the low infiltration rate of this soil due to the high clay content.

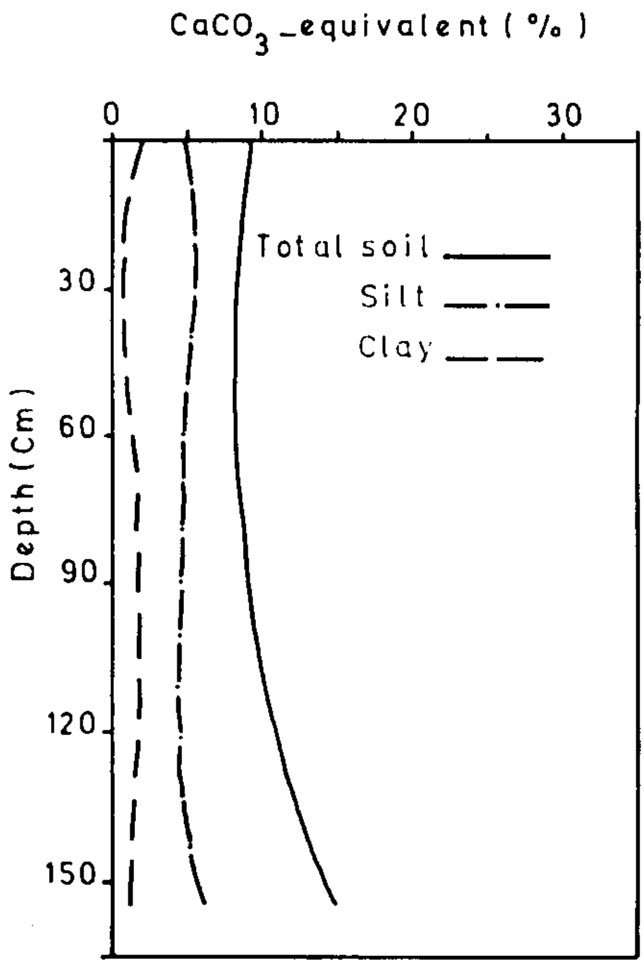

Fig.25–Calcium carbonate–equivalent distribution in different soil fractions–depth for soil profile 6.

Carbonate associated with clay fraction (Table 2) is, however, uniformly distributed throughout this solum. Carbonate associated with silt fraction slightly increases towards the surface from 4.5% at the depth of 155 cm to 5.3% at the surface which coincides with silt fraction accumulation towards the surface (See particle size distribution, Table 13).

The carbonate associated with very fine sand fraction follows the same pattern as carbonate associated with clay fraction. The uniformity can be attributed to the churning processes recently developed in this pedon. Carbonate associated with >0.1 mm fraction follows the same pattern as total carbonate. Field investigation, however, (See profile description) revealed that carbonate concretions increase with depth signaling the occurrence of leaching in this profile which indicates the depth of the water penetration.

4.7.3 Free iron oxides

Table 5, shows the distribution of the free iron oxides for total soil and clay fraction. Free iron oxide for total soil and clay fraction is distributed uniformly throughout the profile. This uniformity in iron distribution within this profile may be due to the churning processes.

4.7.4 Cation exchange capacity (CEC)

Cation exchange capacity of this soil is relatively uniform from the surface till the depth of 80 cm (Table 5), after which the CEC for the total soil decreases slightly. Cation exchange capacity of clay fraction follows the same pattern, except for the B21 which indicates higher CEC. The uniformity of the CEC in the whole profile might suggests that, the whole profile had experienced same weathering intensity, while the maximum CEC/clay exhibited in the B21 horizon suggests that subsequent weathering episode had occurred during which weathering was restricted at this depth. This recent change in weathering had resulted in a new type of minerals with high CEC.

4.7.5 Mineralogy of silt and clay fractions

Figures 26 and 27, illustrate the X-ray diffraction patterns for clay and silt of this profile.

The X-ray diffraction patterns for clay revealed that, smectite/vermiculite interlayered mineral was the abundant, followed by kaolinite and illite. Illite and kaolinite were higher at the surface. The absence of a definite maxima indicates clearly the interstratification of the smectite, which is also, clear in the heated samples. The dominance of swelling smectite is clear from the strong churning process observed in the profile.

The interpretation of X-ray diffraction patterns for silt indicated that, quartz, plagioclase feldspar, and

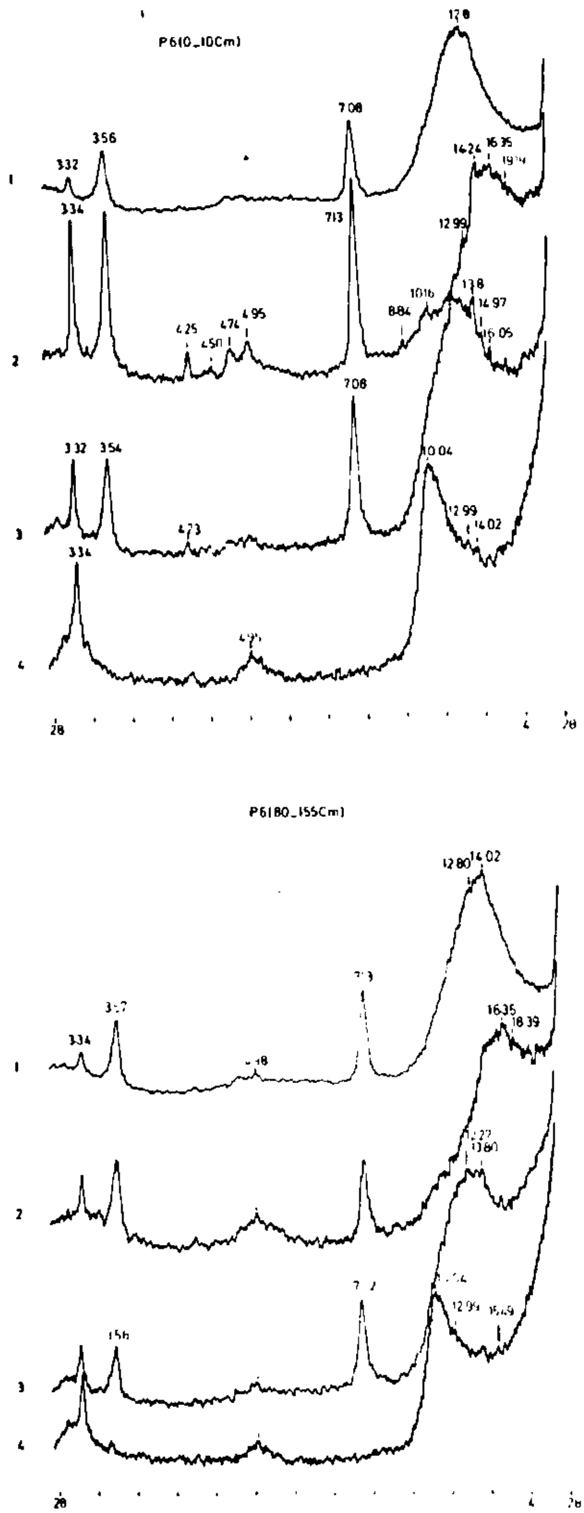

Fig.26_X_Ray diffraction patterns for clay_profile No.6

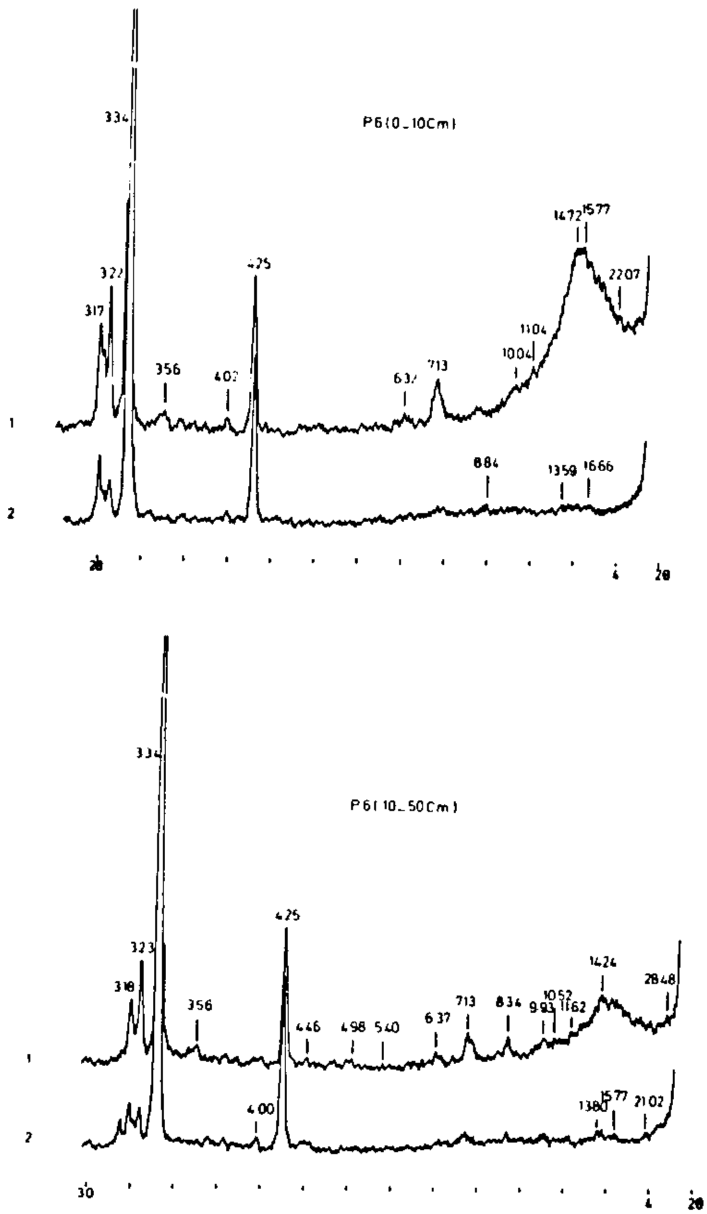

Fig.27_X_Ray diffraction patterns for silt_profile No.6

kaolinite were unifromly distributed in the first 50 cm of this solum. Illite and interlayered smectite/or vermiculite were concentrated in the surfacial layer. Palygorskite occurred in very small amount in surface and the subsurface horizons.

Occurrence of higher amounts of illite at the surface could provide an evidence of the aeolian activity. Whereas, the occurrence of plagioclase feldspar and palygorskite indicates the weakness of the chemical weathering in this pedon which characterize the arid conditions.

4.7.6 Bulk density and coefficient of linear extensibility (COLE)

Horizons from 10 - 155 cm have similar bulk density (Table 9). Whereas, COLE value is higher than 0.09 throughout this profile.COLE values for various horizons qualify this soil to be placed in the Vertisols order (55).

4.8 Profile No. 7

4.8.1 Particle size distribution

Carbonate free clay content throughout this solum reflects that intensive chemical weathering had operated in this soil and yielded high clay content. Clay increases vertically from 67.1% in AP to 73% in B21 and B22 horizons (Figure 28) then increases sharply to 81% in B23

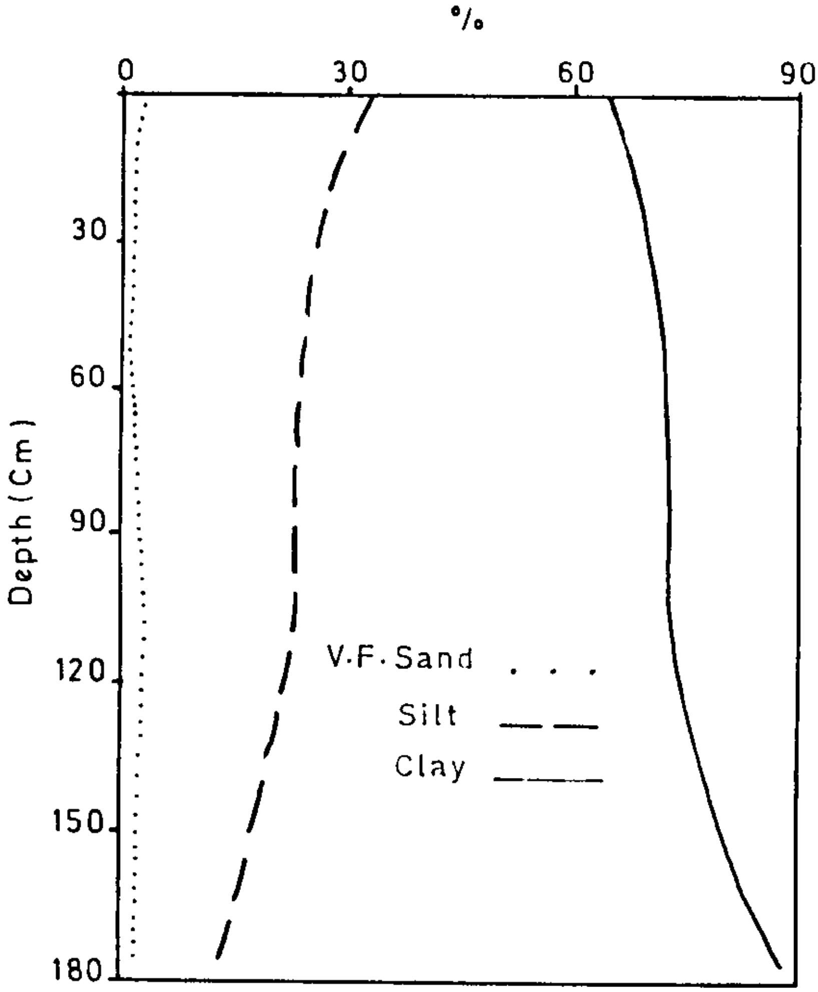

Fig.28_Particle size_depth distribution without carbonate for profile No.7

horizon (Table 14). This variation could indicate that clay illuviation had occurred in this solum suggesting rather wet conditions. Subsurface horizon contains 6% greater clay than the surface. This clay difference does not meet the requirement of the argillic horizon (55). The original surfacial horizon could be absent due to truncation by the erosion evidenced by high clay content of the AP horizon, and its closure to the subsurface horizon. The extensive high clay content below the depth of 133 cm provides a good evidence for a major change in one of the soil forming factors, possibly climate.

Clay content with carbonate increases with depth from 57.8% at the surface to 71.2% at the bottom. This suggests carbonate leaching coupled with clay illuviation within this solum.

Silt without carbonate increases towards the surface from 16.5% at the bottom to 29.8% at the surface. This offers an evidence to silt accumulation by the aeolian activity.

Silt with carbonate follows the same pattern as silt without carbonate indicating the nature of the deposits. The particle size distribution with carbonate suggests that most of the carbonate in this soil is asso ciated with the clay and silt fractions.

The recalculated silt on clay free basis also, increases

towards the surface from 87% at the bottom to 90% at the surface. The calcareous silt addition to the surface could enhance the dissection process or obliterate any illuviation process which could also be terminated (25). Sand fractions with and without carbonate exhibit a fairly unifrom distribution with depth.
The particle size distribution recalculated on clay-free basis indicates a highly uniform distribution of the different particle sizes. This uniformity may be due to the churning processes or inherited from the soil parent material. The absence of gilgai topography (See profile description) indicates that churning process has operated in this solum for a short period of time when basic conditions were redeveloped after carbonate accretion from the top.
Overall, the extremely high clay content below 133 cm depth and the change in silt content could indicate that a major change in soil forming factors possibly climate had occurred. The change in parent material by truncation at this depth (133 cm) is not highly probable due to the highly uniform distribution of the different particle sizes on clay-free basis and the fairly uniform distribution of sand with and without carbonate. The suggested change in climate is postulated to include a major shift from very wet climate towards arid and then humid again, but less

than the first episode, and finally towards arid which prevails now.

4.8.2 Carbonate

The total carbonate is distributed uniformly from the surface till the depth of 133 cm (Table 2), then increases slightly form 27% to 30% at the bottom (Figure 29). Carbonate associated with clay fraction increases with depth from 9.3% at the surface to 16.6% at the depth of 133 cm. This pattern of variation provides another evidence for carbonate leaching within this solum, whereas the carbonate associated with silt fraction increases towards the surface from 5.9% at the depth of 133 cm to 13.6% at the surface. Carbonate associated with very fine sand was fairly uniform with depth.

The carbonate associated with $>$ 0.1 mm fraction follows the same pattern as total carbonate. Field investigation, however, revealed that carbonate concretions increased below the depth of 133 cm (See profile description). The uniform distribution of total carbonate with depth could be due to the increase of carbonate associated with clay with depth and the reverse distribution of carbonate associated with silt. This suggests a leaching pattern (clay) associated with addition pattern (silt). The leaching pattern, especially, below 133 cm depth is supported by the occurrence of the

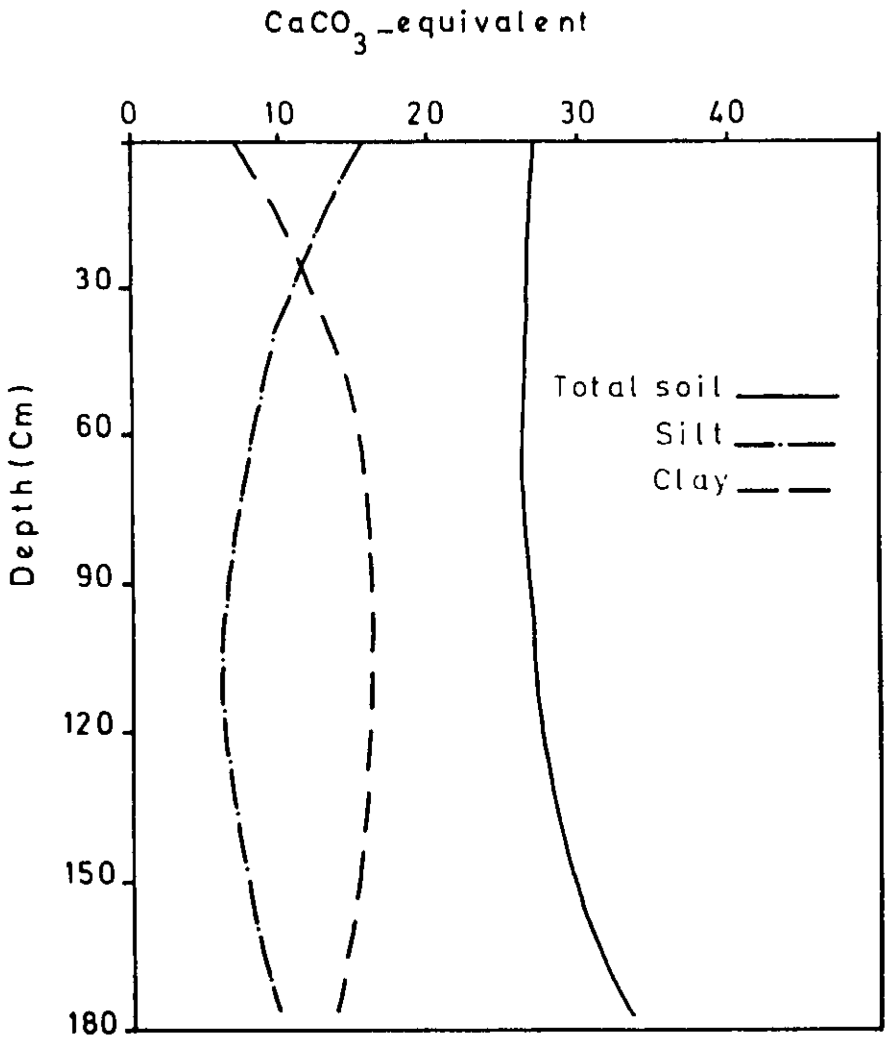

Fig.29_Calcium carbonate_equivalent distribution in different soil fractions_depth for soil_ profile 7 .

carbonate concretions.

4.8.3 Free iron oxides

The free iron oxide of the total soil and clay is distributed unifromly with depth (Table 6). This might be attributed to the effect of churning process in this solum which could have masked any translocation of iron associated with clay.

4.8.4 Cation exchange capacity (CEC)

Maximum cation exchange capacity for total soil is 49.7 meq/100 g at the surface (Table 6). CEC for soil is uniformly distributed from B21 to B23 horizon with a value of 46 meq/100 g. The higher value of CEC at the surface could be due to the effect of soil organic matter and the higher intensity of weathering at the surface of this soil.

The cation exchange capacity for clay decreases vertically from 136.3 meq/100 g at the surface to 85.6 meq/100 g at the bottom of this profile. This could be due to fact that chemical weathering is restricted to the surface due to the limited precisitation.

4.8.5 Mineralogy of clay and silt fractions

Figures 30 and 31 indicate the X-ray diffraction patterns for clay and silt of this profile, respectively. Smectite dominates the clay minerals, followed by vermiculite, kaolinite and illite (For clay fraction). Smectite is interstratified with vermiculite. Further,

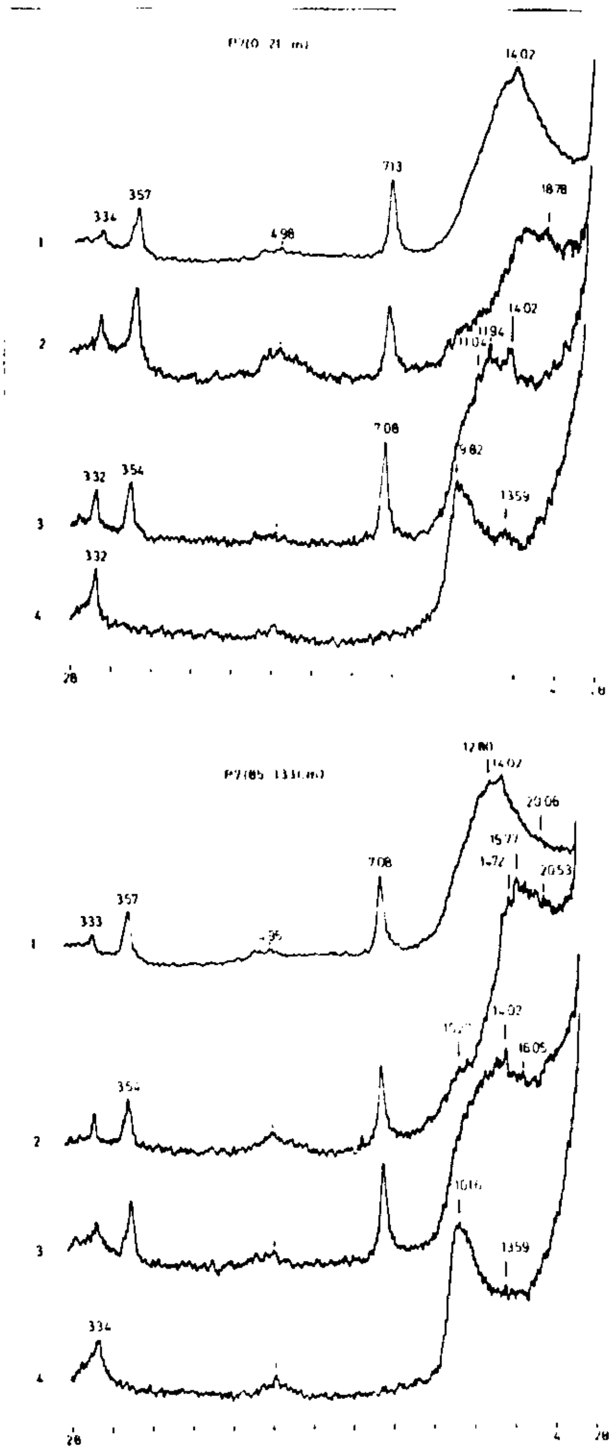

Fig. 30_X_Ray diffraction patterns for clay_profile No.7

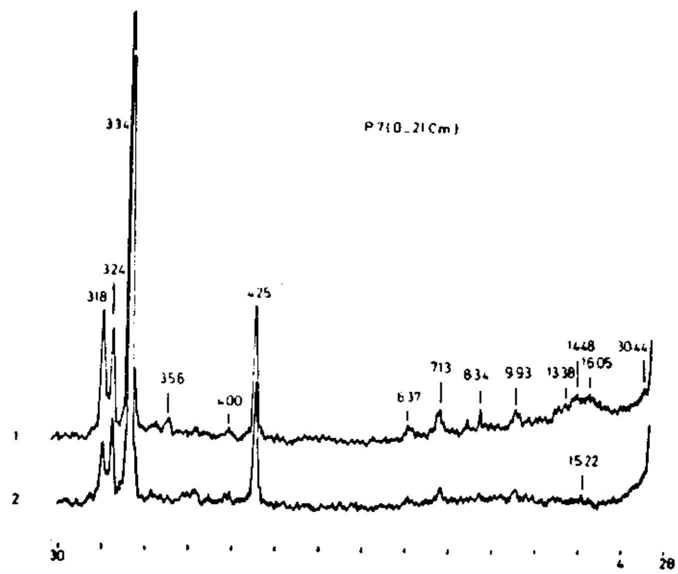

Fig. 31 _ X_Ray diffraction patterns for silt_profile No.7

degree of interlayering in these minerals increases with depth reflecting the level of the chemical weathering which had operated in this profile. Kaolinite is rather uniformly distributed in this profile, while illite or illite/vermiculite interlayered mineral is slightly higher at the surface.

Silt fraction of the top soil contains the following minerals; quartz, plagioclase feldspar, kaolinite, illite, interlayered smectite/vermiculite mineral, and to a less degree palygorskite. The occurrence of illite and palygorskite on the surface offers an evidence to the aeolian activity, whereas plagioclase indicates the weakness of chemical weathering which reflects the present aridity.

4.8.6 Bulk density and coefficient of linear extensibility (COLE)

Bulk density on dry basis is the minimum at the surface. B21 and B22 horizons possess the maximum values of bulk density on dry basis, whereas B23 horizon maintains a bulk density of 1.85 g/cm^3 (Table 15).

On the other hand, bulk density on moist basis is the minimum at the surface, whereas it is uniform (1.48 g/cm^3) from 21 to 175 cm depth.

COLE value is higher than 0.09 throughout this profile, except B23 horizon which maintains a lower COLE value. Accordingly, this soil has a high shrink-swell potential, and qualifies to have placed in Vertisols order

(55). Field investigation indicated that the depth of slickensides was 115 cm; 40 cm^2 oblique on both sides of the ped (See profile description).

4.9 Profile No. 8

4.9.1 Particle size distribution

Particle size distribution (Table 16, Figure 32) indicates that, carbonate free clay content is distributed uniformly from the surface till the depth of 180 cm, then increases suddenly to 77.6%. The high clay content throughout the profile has been subjected to an intensive chemical weathering. The close similarity of clay content between surface and subsurface suggests truncation of the original soil surface by erosion during an arid episode, which had been accelerated after Rift Valley formation or due to the churning processes. Silt content without carbonate indicates a relatively uniform distribution above 180 cm with increasing pattern towards the surface. Same pattern is exhibited by silt with carbonate. The carbonate accretion could have masked the real change in the upper zone. Particle size distribution recalculated on clay free basis also confirms the change in parent material below 180 cm depth. Field investigation had indicated, however, that the upper 180 cm had developed from basalt parent material, while solum below had developed

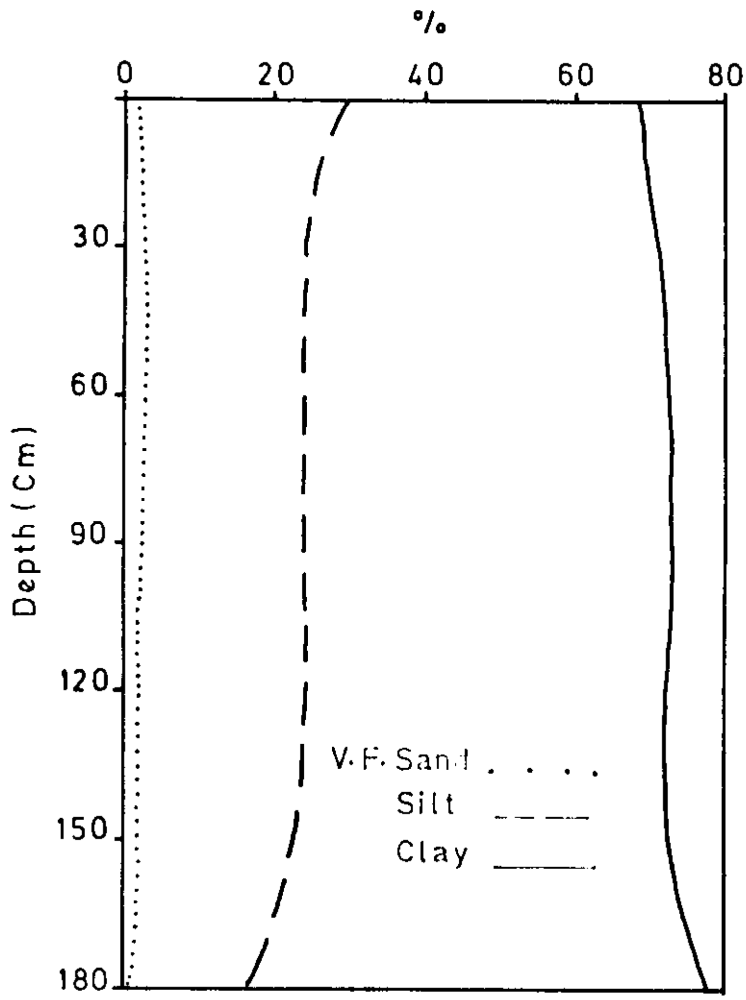

Fig. 32_Particle size_depth distribution without carbonate for profile No.8

from hard limestone.

The other soil separates are distributed uniformly with and without carbonate.

Field investigation indicated that this soil is a cracking one and maintains oblique slickensides covering both sides of the ped (See profile description).

4.9.2 Carbonate

Total carbonate reflects big difference between the two parent materials. Total carbonate does indicate (Figure 33) however, a leaching pattern if surface and last horizon were compared (0 - 180 cm). This leaching pattern might have been masked again by the carbonate accumulation at the surface and the subsequent movement of the carbonate. Moreover, the higher carbonate content of the sand fraction suggests that the leached carbonate was concentrated in the form of carbonate concretions below 70 cm (See profile description).

Carbonate associated with clay fraction (Table 2) indicates a uniform distribution throughout the profile.

The carbonate associated with silt indicates, however, relatively uniform distribution from surface to depth of 180 cm, and a sudden increase below that depth.

Carbonate associated with very fine sand, and coarser fractions follows similar pattern (Table 2).

4.9.3 Free iron oxides

Free iron oxides for total soil and clay is uniformly distributed throughout profile (Table 6). Although,

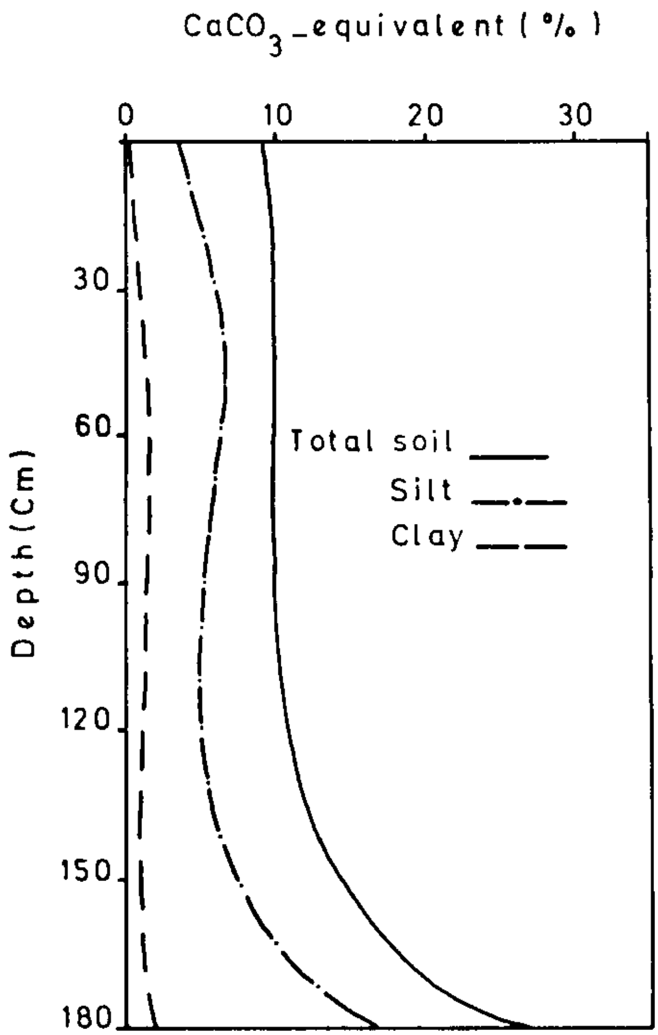

Fig.33_Calcium carbonate_equivalent distribution in different soil fractions_depth for soil profile 8.

iron in clay fraction is lower than it is in total soil, it does not reflect any translocation within this pedon which might be due to the churning processes.

4.9.4 Cation exchange capacity (CEC)

Various horizons from the surface up to 130 cm depth have similar CEC values then decreases afterwards (Table 6).

Maximum CEC of clay is 133 meq/100 g at the surface, followed by 112.8 meq/100 g at the depth of 70 cm. Clay of B22 and B23 horizons maintain the same CEC, but below, CEC of clay is 97.4 meq/100 g.

Cation exhange capacity of clay indicates the dominance of different clay minerals due to different weathering intensities. The most intensive chemical weathering affecting clay is restricted to the first 70 cm which resulted in clay minerls with higher CEC.

4.9.5 Mineralogy of Silt and Clay fractions

Figures 34 and 35 illustrate the X-ray diffraction patterns for clay and silt fractions of this profile, respectively.

Clay fraction throughout profile contains smectite/vermiculite/illite interlayered mineral, illite, and kaolinite.

Whereas, quartz, plagioclase, palygorskite, kaolinite, illite and smectite/vermiculite/illite interlayered mineral were the principal minerals in silt fraction.

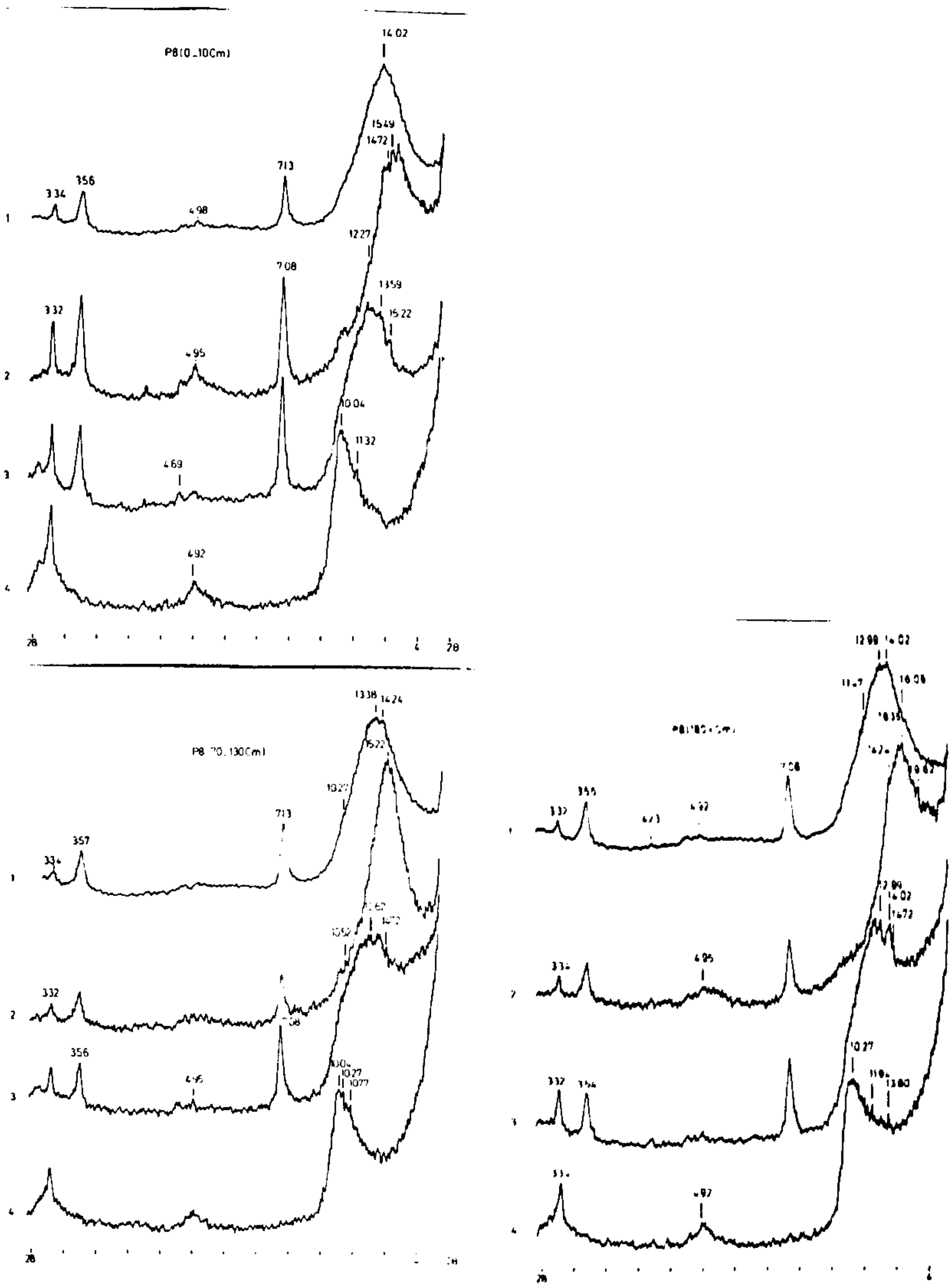

Fig.34_X_Ray diffraction patterns for clay_Profile No.8

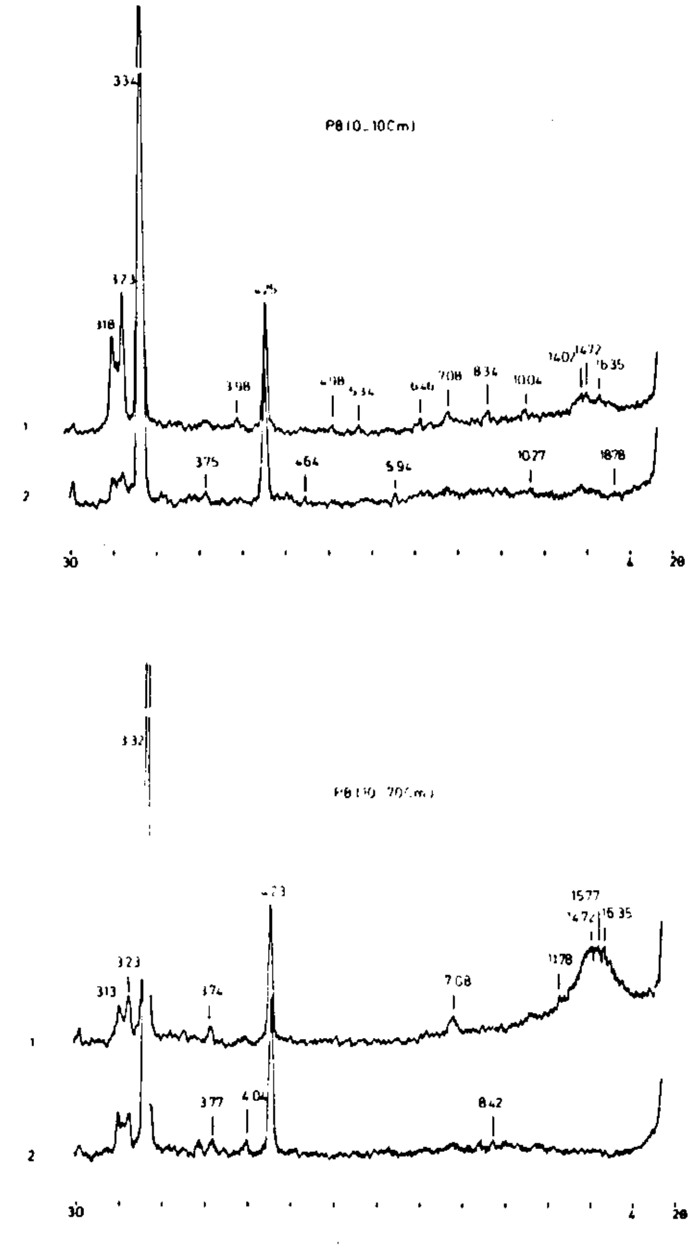

Fig. 35_ X_Ray diffraction patterns for silt_Profile No.8

Kaolinite in both fractions increases vertically suggesting an intensive chemical weathering associated with strong leaching. Pleistocene had pluvial periods which enhanced formation of kaolinite (12). While, illite mineral in silt and clay decreases vertically due to accumulation from the top by aeolian activity (54). Smectite interlayered mineral in the two separates increases with depth indicating weathering of parent materials under low rainfall and limited leaching for released magnesium (18, 27, 28).

Palygorskite, Ca-feldspar and quartz minerals are concentrated in the silt fraction of the top soil. This provided another evidence to aeolian activity. The presence of illite and quartz in the upper soil horizons is explained by aeolian accretion (54). The source of palygorskite mineral might be basaltic areas (57).

4.9.6 Bulk density and coefficient of linear extensibility (COLE)

The values of bulk density (oven dry basis)were equal throughout profile, especially below the depth of 70 cm (Table 15).

The bulk density (on moist basis) follows the same pattern. Whereas, COLE value maintains more than 0.09 indicating that this soil has a high shrink-swell potential supported by the dominance of shrink-swell smectite mineral.

According to the modern system of soil classification (55). This soil is qualified to be placed in the Vertisols order. However, the absence of gilgai topography indicates that churning process had not been active in the profile for a long period of time.

CHAPTER V

SOIL GENESIS

5.1 Profile No. 1

Soils of Irbid area are a part of the landscape and -zero time- of soil development begins with the formation of the landscape (46). Limestone of the upper Cretaceous age (Figure 3) is the parent rock of this soil. Soil development could be hypothesized in the following sequence through four stages:

Stage I

This stage started when the parent rock exposed to effect of soil forming factors. The lower solum (below 100 cm depth) represents the soil of this stage (See the results and discussion). It is apparent that leaching of carbonates and clay formation and accumulation were the principal processes in this stage. The 63% carbonate-free clay content is an evidence for the intensive chemical weathering which characterized this stage. Limestone is a sedimentary rock composed of calcite mainly, beside some impurities such as oxides and clay minerals. Upon weathering, the $CaCo_3$ is dissolved and the residue is a strongly calcareous clay or silty clay, which is an important soil forming material in East Jordan. In the wet areas this clay has a typical reddish brown color (13, 38). Clay mineral components, and thus perhaps the chief silicate components present in calcareous sediments are illites and smectites. In the weathering of calcareous sediments, there is substantially no alteration of silicates until the carbonate is completely broken and the calcium removed from the environment (18,27, 28). Accordingly, the brown color, the 63% clay content, and the occurrence of kaolinite in the lower solum (below 100 cm depth) are strong evidences for prevailing of wet climate in this stage.

Stage II

The major event affected this pedon in this transitional episode was the truncation of the lower portion (lower 100 cm depth) by the geologic erosion which was effective, especially after the formation of Rift Valley (14). A new soil forming material from the surroundings was deposited. These deposits had been transported by water from higher places coupled with wind activity when climate changed from wet to dry. Fluviatile sediments were deposited in basins and depressions during the Pleistocene. Fluviatile gravels covered extensive areas of the eastern slopes of the Mountain Ridge Province (8).

Stage III

When the landscape became stable, a new cycle of soil evolution started (15). Leaching of carbonate and clay illuviation were the most effective pedogenic processes in this stage. Clay alteration, also took place during this stage. One of the most striking feature in arid and semiarid soils is the carbonate - enriched layer that tends to develop at the bottom of the illuvial horizon, when these soils were derived from parent materials containing carbonate (12,23,24). It is postulated that in more moist portion of the arid and semi-arid regions tend to prefer a theory calling for translocation from the upper to the lower part of the profile (12). The obtained results revealed that carbonate associated with clay had been leached downward and accumulated as concretions. Apparently, clay illuvation followed the carbonate leaching in the upper solum (above 100 cm depth). A 15% difference in carbonate free clay content between surface and subsurface is a good evidence for clay illuviation in this solum (See particle size distribution, Table 7). Clay formation in situ is not the only process responsible for the development of an argillic horizon in the arid and semiarid soils; more likely, both clay formation in situ and enrichment by illuviation of fine clay are responsible for the development of argillic horizon in such soils (10,22,36).

However, the prevailing climate during this stage was less wet than climate of stage I or, this episode was shorter in time, evidenced by less amounts of carbonate free clay content in the upper solum. Soils of Pleistocene age can have distinct argillic horizons and strong horizons of carbonate accumulation (12).

Stage IV

This is the very recent one which is characterized by dominance of processes usually operating under arid conditions. Results showed that this soil receives appreciable amounts of aeolian materials such as very fine sand and carbonates associated with it (See particle size distribution and carbonate distribution). Aeolian sediments are of paramount significance to soil development during the Quaternary, because the aeolian materials can add to soil parent material by accretion from the top (56).

5.2 Profile No. 2

This soil is a part of Irbid landscape, and zero time of soil development had begun with the formation of the land surface.

The genetic hypothesis suggests that this pedon which consists two solum has passed through the following stages of development from the hard limestone (Figure 3).

Stage I

This stage represents the initial steps in soil development that formed the lower solum (below 130 cm). The 63% clay content without carbonate, and the reddish brown color of this layer provides an evidence to strong chemical weathering which had altered the parent rock of the upper Cretaceous limestone. Carbonate leaching and clay formation and accumulation were, however, the principal processes which indicate the availability of large amounts of water in this stage. This substantiates the prevalence of humid climate. This stage had been ended when the lower solum of this pedon (below 130 cm depth) truncated by geologic erosion when climate shifted towards aridiness and the landscape become unstable.

Stage II

A climatic shifting from humid to arid was hypothesized to occur evidenced by the occurrence of the lithological discontinuity at 130 cm depth. Thus, arid conditions dominated this stage. A new colluvium material was deposited over the 130 cm line from higher places by running water (8) evidenced by occurrence of limestone gravels in the solum (See profile description). Aeolian activity also added some from the surroundings. Apparently, this stage was ended when a stable surface was formed when climate shifted towards humid again.

Stage III

This stage of soil development, apparently, was dominated by humid climate and stable landscape. Results showed that clay illuviation coincided with carbonate leaching were the most important pedogenic processes within this stage. Clay illuviation, apparently, was interrupted due to fast climatic changes, or due to low rate of water movement within the solum due to high clay content throughout the pedon. Thus, the environmental conditions discouraged the formation of argillic horizon in the subsoil. The formation of the interlayering mineral in this pedon indicates intensive chemical weathering (47). A cambic horizon was formed in the upper solum just before this stage was ended, apparently, when climate shifted gradually towards aridiness.

Stage IV

This stage represents the most newly cycle of soil development. Results showed that this soil had received silt and carbonate associated with it by aeolian activity characterized the Quaternary (56). This process, usually, predominates under arid climatic conditions. The addition process could be preceded by truncation of the A horizon due to accelerated erosion occurred in late Pleistocene (14,44). Thus, the overall pronounced process is the desertification which affects all the studied area.

5.3 Profile No. 3

The evolution of this pedon could be divided into three stages as follows:

Stage I

This stage of soil development represents the primitive step in soil development which aided in the deposition of the parent material. The homogeniety of the parent material throughout pedon was evidenced by absence of any lithological discontinuity within profile and the uniform distribution of fractions coarser than very fine sand with and without carbonate. This substantiates the belief that colluviation process and aeolian activity were very active during this stage. These activities led to deposition of a thick layer of colluvial material derived from limestone associated with basalt. Apparently, the arid conditions which favoured such process dominated this stage, which is in harmony with the climatic condition prevaled stage II in profiles 1 and 2.

Stage II

Stage I ended and this stage started when previous arid climate shifted towards humid. Parent material had experienced intensive chemical weathering. The 72.4% carbonate free clay content below 130 cm depth offers a strong evidence for intensive chemical weathering which dominated this stage. The concentration of total carbonate below the depth of 130 cm, the vertical increase of carbonate associated with $>$0.1 mm fraction coincided with distribution of carbonate concretions is a strong evidence for commencement of carbonate leaching in this stage. Carbonate associated with clay gives another evidence for leaching pattern by its increase with depth from 5.7% to 10.4% (from 0-130 cm) which coupled with clay increase which supports the occurrence of clay illuviation within this stage. The 4% clay difference between surface and subsurface suggests possible clay illuviation without yielding an argillic horizon (55), which implies water to pass through the soil and preceded by carbonate leaching. Dominance of smectite interlayered mineral in this pedon offers another evidence to intensive chemical weathering dominated this humid stage of soil development. This stage, however, was ended when climate shifted again towards aridiness. Apparently, this stage of soil development correlated with stage III in profiles 1 and 4.

Stage III

This represents the very recent and present soil development which started after the gradual climatic change to arid. Such climatic change from humid to arid was evidenced by the significant decrease in clay content, total carbonate, and the reverse pattern of distribution of free iron oxides associated with clay fraction below the depth of 130 cm. Since, parent material is homogeneous throughout, the break in weathering pattern at the depth of 130 cm could refer to a change in one of soil forming factors, possibly due to a change in climate.

The uniform distribution of clay content without carbonate from the surface till 130 cm depth supports the suggestion that A horizon might have been truncated by the geologic erosion accelerated after the Rift Valley formation (14). The fact that vertic property had developed in recent time after the evolution of basic conditions in the profile which arose with the enrichment of carbonate is evidenced by the uniform distribution of soil separates throughout the subsurface horizons (from 40 to 130 cm). COLE value of B21 and B22 horizon which is $>$ 0.09 is another evidence for dominating swell-shrink mineral. Thus, this soil could be placed in Vertisols order (55). Whereas, the absence of gilgai topography in such soil indicates clearly that churning process has not been active for a long time.

The higher silt content (with carbonate) at the surface indicates the accretion of this fraction by aeolian activity evidenced by the vertical decrease of carbonate associated with silt and very fine sand. Aeolian activity is very well documented in Quaternary (33, 40). The illite accumulation at the surface supports the aridiness of present climate and the aeolian activity (54). This stage correlates with stage IV in profiles 1 and 4.

5.4 Profile No. 4

The parent rock of this soil is hard limestone of the upper Cretaceous age (Figure 3). The profile of this soil consists two solum separated at the depth of 148 cm evidenced by the recalculated particle size distribution on clay free basis (Table 11), and the total carbonate content (Table 1).

The variation of soil properties in both solum indicates that many cycles of soil formation had operated on this soil, possibly due to changes of set of soil forming factors. The changes that took place in this profile could be divided into the following stages:

Stage I

This stage of soil development ended with the soil truncation at the depth of 148 cm. The truncation at this depth, apparently had occurred due to the prevalence of arid climate which accelerated the erosion or probably accelerated after the Rift Valley formation (14), and resulted in the loss of the surface horizon.

Apparently, the arid climate followed a very humid climate which resulted in the formation and accumulation of high clay content (64%) and the depletion of calcium carbonate. Upon weathering of limestone in the wet areas, the $CaCO_3$ is dissolved and the residue is a strongly calcareous clay with a typical reddish brown color (13,38).

Stage II

This stage of soil development had commenced after the prevalence of an arid climate.

This episode was characterized by high colluvial and aeolian activity which led to the deposition of the upper solum. The period of the deposition could be well correlated with the deposition of basalt flow in the nearby location. The presence of gravels in the profile substantiates the hypothesis that colluvial activity was responsible for the formation of the upper solum. In the meantime, aeolian activity should not be under estimated.

Stage III

The shift in climate from arid to humid characterized this stage and had operated after the deposition of the upper solum. The humid climate was apparently either less in humidity or operated for shorter time than the first humid climate episode. Evidences to such change in climate include the high clay content, carbonate leaching (carbonate associated with clay), and the depth of carbonate movement, clay illuviation and the presence of clay coatings at the lower portion of this solum. The occurrence of interlayered minerals and the increase of interlayering with depth, also suggest humid weathering. Clay formation in situ is not the only process responsible for the development of an argillic horizon in such soil. More likely, both clay formation in situ and enrichment by illuviation of fine clay are responsible for the development of the argillic horizon in this soil (22). The presence of clay coatings at the lower part of this profile indicates clay movement subsequent to parent material deposition (3,21,36).

Stage IV

This stage of soil development had commenced at the end of the third stage when the humid climate had shifted gradually to more aridic climate before 5,000-10,000 years. Arid and semiarid lands, widespread during the Xerothermic Interval of 6,000-4,000 years before present (2). The main features that characterize the soil development at this stage is the truncation of the original A horizon and enrichment with calcareous silt and very fine sand at the surface, which aided in the obliteration of features that could characterize the previous humid climate such as upward increase in carbonate, the absence of clay coatings in the upper portion of this profile. Furthermore, the presence of illite and plagioclase at the top soil clearly reflects the effect of prevailing aridity. The slightly higher iron oxides at the surface suggests that present weathering is restricted at the surface, which is in harmony with the precipitation pattern in the area.

5.5 Profile No. 5

Limestone of the upper Cretaceous age (Figure 3) forms the parent rock for this pedon. By refering to results and discussion, this profile has a lithological discontinuity at 115 cm depth (See particle size distribution, Table 12).

According to obtained results, the evolution of this pedon could be hypothesized as following:

Stage I

The upper Cretaceous limestone which is the parent rock had been exposed to highly intensive chemical weathering in this primitive stage. Most of its carbonate was leached, and a high clay content (71%) carbonate free was accumulated as a residue in the lower solum (below 115 cm). The reddish brown color, clay texture in addition to high clay content of the lower solum substantiate that parent rock was altered under humid climate (13,38). This stage ended by truncation of the lower portion (below 115 cm) of this pedon, probably when climate shifted towards aridiness.

Stage II

When the base level of the erosion was lowered in the Rift Province, the westward drainage had been rejuvenated. During Pleistocene, periods of higher rainfall than today were assumed to have taken place, thus erosion by water predominated (14). This could explain the occurrence of the lithological discontinuity at 115 cm depth wich separates the two solum. A new colluvium material, however, derived from surroundings was deposited by water, evidenced by common limestone gravels in the upper solum.
Winds also, added calcareous materials from the top when climate shifted to arid. However, this stage ended when arid climate shifted again towards humid.

Stage III

Apparently, when a stable surface had been formed and climate become wetter than the former, the materials deposited during the previous stage had been leached followed by clay illuviation. Carbonate concretions in the lower solum supports the occurrence of strong carbonate leaching. The early stage of the petrocalcic horizon formation (79-90 cm) had been commenced in this stage of soil formation. Along the Rio Grande Valley, petrocalcic horizons were found to occur in soils of late Pleistocene age in very gravelly parent materials, but were restricted to mid-Pleistocene or older soils in non gravelly parent materials (26). Thus, this stage of soil development could correlate to mid to late Pleistocence. This soil and similars are Paleargids or Paleorthids in the new classification system (55). Clay illuviation process, however, led to form an argillic horizon in the upper solum evidenced by the change in clay content between surface and subsurface (55). Although the clay content of an argillic horizon must exceed that of the overlying horizon by a specified amount, a higher content of clay in a B-horizon is not sufficient evidence of clay translocation (36). Other workers see that, horizons of clay accumulation are considered to be argillic horizons, although clay skins on ped surfaces and pore walls are usually absent (12).

It appears that turbation, probably by wetting and drying, destroys such clay skins (36). Results also, showed that very slight iron translocation had been occurred coincided with clay illuviation.

Stage IV

This stage of soil development started when the previous climate shifted towards aridiness which extended to present. Repetitive events characterized the Quaternary , whether in the glaciated or nonglaciated regions (46). Erosional and depositional processes were to have taken place during this stage. Carbonate accumulation above the 60 cm depth had occurred in this stage, probably, after the former leaching episode Weathering processes had been retricted to the surface due to limited precipitation. Obtained results showed that, accretion of silt and carbonate associated with it is pronounced. Addition of illite and quartz by winds was substantiated by other workers (54).

5.6 Profile No. 6

The original rock surface of Irbid landscape was hard limestone of the upper Cretaceous age (Figure 3). Whereas, this pedon had developed in colluvium materials derived from limestone associated with basalt. The basaltic lava flows in East-Jordan are a continuation to those of the Jebel Druze (19). The lava fields in northeast Jordan are classified as Pleistocene - Recent basalt. Picard (44) placed the basalts of the Yarmuk River Valley in the midle Pleistocene. The fifth basaltic flow covers older flows and Paleogene and Miocene sediments which can be correlated with the basalts on the limestone plateau of the Yarmuk River area and has undergone late Pleistocene erosion. According to the obtained results and properties this soil had passed the following hypothetical stages of development.

Stage I

This stage of soil development started under aridic conditions which dominated stage II in profiles 1, 2 and 4 that characterized by colluviation and aeolian activity. A series of basalt flows occurred and covered the Pleistocene fluviatile gravels and fossil landslides. Erosional and depositional agencies were accelerated, and new colluvial and aeolian sediments derived from the surroundings (limestone and basalt) were thickly deposited by water and wind action evidenced by field investigation and occurrence of limestone and flint gravels in the solum. However, this stage of soil development ended when one of the soil forming factors had changed, possibly climate which shifted from arid to humid.

Stage II

Apparently, the landscape had become more stable in this stage and climate was more humid. These environmental conditions encouraged soil forming processes to operate within the pedon. Occurrence and dominance of smectite interlayered mineral in pedon is a strong evidence to commencement of intensive chemical weathering (47). Clay illuviation, probably, preceded by carbonate leaching evidenced by the vertical increase of clay content with carbonate (Table 13), were active in this stage, and argillic horizon was formed (55).

Stage III

Again, climate shifted gradually towards aridiness and a new cycle of soil development had started. Among the properties which indicate such climatic change is the accumulation of calcareous silt at the surface by aeolian activity as a pronounced process in the arid regions. The enrichment of carbonate and the dominance of swell-shrink mineral, beside the high clay content throughout pedon enhanced the newly developed churning process, evidenced by field investigation (See profile description), and COLE value which is more than 0.09. The absence of gilgai topography offers another evidence to the short period of time since churning process had commenced. Apparently, pedoturbation processes such as shrink-swell action and dissection masked the earlier formed argillic horizon (36). However, soil properties meet the requirement of Vertisols in the new soil classification (55).

5.7 Profile No. 7

This pedon consists one solum had been originated in a thick colluvium material derived from the limestone of the upper Cretaceous age (Figure 3), which formed the old landscape of Irbid plateau.

According to obtained results and soil properties, soil development could be hypothesized in the following manner:

Stage I

This stage of soil development was characterized by active colluviation and aeolian sedimentation evidenced by a thick colluvium material deposited in this site. Probably, this stage of soil development correlates with stage I in profiles 3 and 6 or stage II in profiles 1, 2, 4, 5 and 8.

Apparently, the arid climate predominated this stage enhanced the erosional and depositional agencies which created unstable landscape. This stage was ended by climatic shift towards humid and a new cycle of soil development began.

Stage II

Existence of this well developed soil at ground surface offers a strong evidence that landscape had been stable for a reasonable period of time without active surfacial processes such as erosion or deposition. Humid climate which favours such environmental conditions, probably, dominated this stage of soil development. It is apparent that, intensive chemical weathering had occurred within this stage evidenced by the extremely high clay content (carbonate free) accumulated below the depth of 130 cm and the occurrence of smectite interlayered mineral. Clay accumulation and clay alteration had to have preceded by carbonate leaching. Leaching of carbonate associated with clay is supported by the occurrence of the carbonate concretions below 133 cm depth. The change in parent material is not probable in this case due to the highly uniform distribution of different particle sizes with and without carbonate (See particle size distribution, Table 14). However, clay illuviation process failed to form an argillic horizon in this solum (55). This could be explained by interruption of the process due to minor climatic changes and/or due to low rate of water movement due to high clay content.

This stage of soil development ended when the dominated humid climate shifted gradually towards aridiness.

Stage III

Gradually aridic climatic conditions had prevailed this stage. The aeolian activity predominated and calcareous silt had been added to surface evidenced by variation of silt and associated carbonate (See Tables 14 and 2). The original A horizon had been truncated by the accelerated geologic erosion (14) evidenced by the high clay content of the AP horizon and its similarity to subsurface horizon. Variation of cation exchange capacity of clay agreed with the fact that, chemical weathering is restricted to the surface due to the limited precipitation in this stage which is in harmony with the present. The addition of calcareous silt to the surface in this stage enhanced the dissection process or obliterate any illuviation which could be occurred earlier (25). Apparently, churning process is dominated in this solum after the redevelopment of basic conditions by carbonate accretion and the dominance of swell-shrink clay mineral, beside the high clay content throughout profile (55). Churning process could have masked any translocation of iron associated with clay. This process might have been operated since a short period of time, evidenced by the absence of gilgai topography (29,55). Thus, this soil is qualified to be placed in Vertisols order.

5.8 Profile No. 8

This soil is a part of Irbid landscape that developed from colluvium material derived from limestone associated with basalt. Results showed that 180 cm depth separates two different solum which developed from different parent materials (See profile description). The lower solum had been originated from the upper Cretaceous limestone, and the upper one originated from Quaternary basalt and aeolian sediments (mainly calcareous silt). The following stages of soil development hypothesize the formation sequence of this soil:

Stage I

The upper Cretaceous limestone plateau (Figure 3) had been exposed to intensive chemical weathering which resulted in the formation of a high content of clay (free of carbonate) preceding by carbonate leaching. The lower solum (below 180 cm) represents the soil that formed in this stage. Its color (reddish brown , clay content (78%), and clay mineralogy indicate that parent material (limestone) had been weathered under humid or very humid conditions (13,38). This stage, however, had been ended when climate had shifted from humid to arid.

Stage II

When previous climate shifted towards aridiness, the erosional and depositional agencies activated, and a new basaltic material beside aeolian sediments were added to cover the lower solum. Six different phases of major emissions can be distinguished (5). The fifth flow of basalt covers older flows and Paleogene and Miocene sediments, which could be correlated with the basalts on the limestone plateau of the Yarmuk River area and has undergone late Pleistocene erosion. The main tuff eruptions started after the extrusion of the fifth lava flow. The basalts of the sixth extrusive phase form north trending flows many kilometers long. They most probably correlate with the basalts that flowed down the Yarmuk River Valley to the west where they overlie Pleistocene fluviatile gravels and fossil landslides (5). This stage of soil development ended when climate shifted from arid to humid and a stable landscape was formed.

Stage III

This stage of soil development represents weathering of basaltic materials which formed the upper solum (above 180 cm). This basaltic and colluvium material had experienced intensive chemical weathering evidenced by high clay content and occurrence of smectite interlayered mineral (47). The illuviation and leaching processes could be operated in this stage of soil development and masked afterwards. When climate shifted towards aridiness, this stage ended and a new stage started.

Stage IV

This stage is the most recent, that started when the previous climate shifted towards aridiness which characterizes present stage.

A, horizon was probably, truncated by the effective erosion in the late Pleistocence (5). Carbonate accretion by aeolian activity has been the most effective process in this stage (56). Results showed that the most intensive chemical weathering was restricted in the first 70 cm due to limited precipitation and low rate of water movement within this soil due to high clay content. Obtained results also, showed that, this pedon is clayey throughout, COLE value is more than 0.09, smectite is the dominant mineral, and it is basic. Accordingly, churning process has operated in this stage of soil development evidenced by field investigation (See profile description). But, the absence of gilgai topography indicates that, this process has operated since a short time (29). The churning process masked any clay, carbonate, or iron translocation which could have resulted from the last stage. Apparently, this soil qualifies to be placed in the Vertisols order (55).

5.9 Classification of the soil

The studied soils were classified according to the Soil Taxonomy as follows:

Soil Profile No. 1 : Fine, Mixed, Thermic, Typic Palexeralfs Or,
Fine, Mixed, Thermic, Typic Xerochrepts.

Soil Profile No. 2 : Fine, Mixed, Thermic, Typic Xerochrepts.

Soil Profile No. 3 : Fine, Smectitic, Thermic, Typic Chromoxererts.

<u>Soil Profile No. 4</u> : Fine, Mixed, Thermic, Typic Palexeralfs Or,
Fine, Mixed, Thermic, Typic Xerochrepts.

<u>Soil Profile No. 5</u> : Fine, Mixed, Thermic, Petrocalcic Paleargids. Or,
Fine, Mixed, Thermic, Xeric Paleorthids.

<u>Soil Profile No. 6</u> : Fine, Smectitic, Thermic, Typic Chromoxererts.

<u>Soil Profile No. 7</u> : Fine, Smectitic, Thermic, Typic Chromoxererts.

<u>Soil Profile No. 8</u> : Fine, Smectitic, Thermic, Typic Chromoxererts.

CHAPTER VI

CONCLUSION

Eight profiles within Irbid Region were characterized chemically, physically, and mineralogically beside the field investigation to hypothesize their mode of formation.

Results showed that climate is the major effective soil forming factor, since it changes several times during the formation of these soils.

The general hypothesis for studied soils within Irbid Region could be summerized in the following sequence:

Stage I. A humid to very humid climate dominated this stage of soil development. The limestone of the Upper Createaceous age was covered the total area during this stage. Apparently, an intensive chemical weathering dominated this stage. Differences in clay content and carbonate concretions in the lower solum from site to another could reflect the effect of the micro relief which contributes to soil moisture differences and the consequent intensity of chemical weathering. All portions of studied 1, 2, 4, 5 and 8 pedons below 100 - 180 cm depth represent soils which reflect this weathering pattern. Whereas, pedons 3, 6 and 7 do not reflect this stage because of their unsufficient depth.

Stage II This stage of soil development dominated by arid climate and was characterized by unstable landscape due to active erosional and depositional surfacial processes and basaltic activity (Pleistocene - Recent).
Profiles 1, 2, 4, and 5 experienced truncation and deposition of new colluvium material derived from limestone due to effect of water and winds. Meanwhile, profile 8 had been covered by colluvium material derived from limestone and basalt. While a colluvium material derived from limestone was depositing in site of profile 7, a thick colluvium material of limestone associated with basalt was deposited in sites of profiles 3 and 6. Thickness of deposited material was uneven due to uneven relief of studied soils.

Stage III However, landscape in this stage of soil development was stable when climate had become humid again. Thus, the pedogenic processes were accelerated again. The geographical distribution, slopes and shape of surfaces created significant changes in soil water and the intensity of soil forming processes. However, results indicate that this stage of soil formation was, either shorter in period of time, or relatively less humid than climate dominated stage I.

Stage IV This stage of soil formation, probably started since a short time (4,000 - 6,000 years B.P) and still prevailing. The gradual climatic shifting from humid to arid had interrupted the processes such as leaching, translocation, and illuviation which had commenced earlier, or obliterated other pedogenic features.

One of the pronounced processes taking place in these soils, especially 3, 6, 7 and 8 is the churning process which leads to pedoturbation of soil properties and masking any illuviation process had been occurred earlier.

The most important process has been taking place in this stage is the enrichment of calcareous materials from the top by the aeolian activity. The aeolian activity within the studied area is active and shortly will desertify the area which will ultimately decreases their agricultural productivity. The Northeast and Eastern areas consist a favorable source of such materials which can be easily deflated by winds due to less vegetative cover and low precipitation. Moreover, water erosion is active there for several reasons; first: difference in elevation between the area and the Rift Valley, second: weakness of the vegetative cover which gives erosion by water stronger impact, third: bad land management which decreases the soil ability to resist erosion forces. Moreover, present available data* showed that soils of Jordan loose 1-10 ton/h annually by water erosion and 1-50 ton/h by wind erosion.

* Battikhi, A. (4, in press)

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Appendix - A: Chemical Analyses

Table 1 -Chemical Analyses For Profiles No.1, 2, 3 and 4

Hor.desig.	Depth	pH	$CaCO_3$-Equivalent				Total
			>.1	.1-.05	.05-.002	<.002	
	cm		%				
			Profile No.1				
AP	0 -28	8.2	0.3	1.8	3.4	7.9	13.5
B21	28 -75	8.4	3.7	0.5	6.2	9.0	19.3
B22	75 -100	8.2	3.0	0.3	13.6	10.7	27.6
IIB23Ca	100-145	8.4	9.7	0.8	18.2	12.5	41.2
			Profile No.2				
AP	0 -30	8.2	0.9	0.9	4.6	7.4	13.6
B21	30 -50	8.1	3.3	0.8	5.2	6.4	15.6
B22Ca	50 -130	8.2	2.6	0.6	7.6	7.4	18.2
IIB23Ca	130+	8.3	15.8	0.1	8.8	8.8	33.5
			Profile No.3				
AP	0 -40	8.2	1.6	0.9	12.7	5.7	20.9
B21	40 -90	8.7	3.8	0.6	8.6	9.6	22.6
B22	90 -130	8.6	5.0	0.5	6.3	10.4	22.2
B23Ca	130-165	8.4	4.3	0.3	6.9	20.8	32.4
			Profile No.4				
AP	0 -34	8.1	2.2	0.9	7.0	5.5	15.6
B21	34 -67	8.4	2.3	0.6	3.1	12.8	18.8
B22	67 -120	8.1	0.7	0.4	4.4	8.9	14.4
B23	120-148	8.2	1.3	0.1	2.2	12.5	16.1
IIB23Ca	148-165+	8.4	17.9	0.8	9.7	15.1	43.5

Table 2 -Chemical Analyses For Profiles No. 5, 6, 7 and 8.

Hor.desig.	Depth	pH	$CaCO_3$-Equivalent				Total
			>.1	.1-.05	.05-.002	<.002	
	cm		%				
			Profile No.5				
AP	0 -24	8.0	0.6	1.0	12.9	6.8	21.3
B21	24 -60	8.4	0.6	1.4	10.8	14.1	27.0
B22Ca	60 -79	8.2	4.1	0.9	6.3	27.3	38.6
IIB23Cam	79 -90	8.3	6.5	1.4	8.8	28.1	44.8
IIB23Ca	79 -115	8.4	6.1	1.2	17.1	13.9	38.2
IIB3Ca	115+	8.2	8.7	1.1	15.5	16.4	41.8
			Profile No.6				
AP	0 -10	7.9	2.1	0.1	5.3	1.6	9.1
B21	10 -50	8.0	2.0	0.1	5.7	1.0	8.7
B22	50 -80	8.1	1.5	0.1	4.8	1.8	8.2
B23	80 -155	8.4	3.5	0.1	4.5	1.9	10.0
B24Ca	155+	8.3	7.3	0.1	6.1	1.3	14.8
			Profile No.7				
AP	0 -21	8.2	3.3	0.7	13.6	9.3	27.0
B21	21 -85	8.2	2.4	0.6	7.7	15.4	26.1
B22	85 -133	8.7	3.5	1.0	5.9	16.6	27.0
B23	133-175	8.5	6.5	0.4	8.2	15.2	30.3
			Profile No.8				
AP	0 -10	7.9	3.7	0.2	4.1	1.6	9.6
B21	10 -70	8.1	1.6	0.1	7.2	1.1	10.0
B22	70 -130	8.3	3.6	0.2	4.5	1.3	9.6
IIB23	130-180	8.3	5.6	0.1	5.2	1.4	12.2
IIB24	180+	8.2	6.6	0.1	16.7	1.8	25.2

Table 3 - Chemical Analyses For Profiles No. 1 and 2

Hor.desig.	Depth	Organic matter	Free Fe_2O_3		Electrical conductivity	Cation exchange		Extractable			
			Soil	Clay		Soil	Clay	Ca	Mg	K	Na
	cm	%			mmhos/cm	meq/100g					
					Profile No.1						
AP	0 -28	1.0	3.7	6.0	0.26	32.1	65.9	51.2	13.8	1.8	1.6
B21	28 -75	0.6	3.1	5.1	0.42	31.0	82.8	46.3	15.8	0.8	3.9
B22	75 -100	0.4	2.8	4.7	0.60	29.6	114.4	47.2	11.8	0.7	4.0
IIB23Ca	100-145	0.2	2.2	5.0	0.64	26.1	91.5	39.4	16.7	0.5	4.0
					Profile No.2						
AP	0 -30	0.7	3.9	5.8	0.15	43.2	81.8	55.1	12.8	1.2	1.1
B21	30 -50	0.5	3.9	6.5	0.18	40.2	99.5	52.2	15.8	0.9	1.6
B22Ca	50 -130	0.3	3.8	6.1	0.22	37.5	81.5	50.2	15.8	0.9	2.3
IIB23Ca	130+	0.2	3.2	6.2	0.24	33.2	90.9	50.2	12.8	0.8	2.2

Table 4 - Chemical Analyses For Profiles No. 3 and 4

Hor. desig.	Depth	Organic matter	Free Fe_2O_3		Electrical conductivity	Cation exchange		Extractable			
			Soil	Clay		Soil	Clay	Ca	Mg	K	Na
	cm	%			mmhos/cm	meq/100g					
					Profile No.3						
AP	0 -40	0.6	4.0	7.0	0.21	42.9	127.1	54.1	15.8	1.7	1.4
B21	40 -90	0.4	4.6	6.7	0.35	39.7	116.6	44.3	19.7	1.0	3.9
B22	90 -130	0.4	3.9	5.4	0.68	39.1	83.0	43.3	19.7	0.9	4.4
B23Ca	130-165	0.1	3.6	6.1	0.90	37.0	72.3	42.3	20.7	0.9	4.2
					Profile No.4						
AP	0 -34	0.8	3.9	5.7	0.24	34.5	105.2	52.2	11.8	1.3	1.1
B21	34 -67	0.4	3.6	4.1	0.26	34.8	102.6	47.2	13.8	0.8	2.4
B22	67 -120	0.2	3.5	5.4	0.36	37.0	65.7	52.2	10.8	0.9	3.4
B23	120-148	0.1	3.8	5.6	0.40	37.0	89.9	49.2	13.8	0.9	3.8
B3Ca	148-165+	0.1	2.5	4.1	0.38	28.5	59.2	50.2	4.9	0.7	2.8

Table 5 - Chemical Analyses For Profiles No. 5 and 6

Hor.desig.	Depth	Organic matter	Free Fe_2O_3		Electrical conductivity	Cation exchange		Extractable			
			Soil	Clay		Soil	Clay	Ca	Mg	K	Na
	cm	%	%	%	mmhos/cm	meq/100g	meq/100g	meq/100g	meq/100g	meq/100g	meq/100g
					Profile No.5						
AP	0 -24	1.0	3.0	4.0	.22	33.7	83.9	49.2	12.8	1.2	0.9
B21	24 -60	0.5	2.8	4.2	.21	30.7	85.1	50.2	10.8	0.7	0.9
B22Ca	60 -79	0.3	2.3	4.4	.25	26.6	75.5	49.2	9.8	0.6	1.0
IIB23Cam	79 -90	0.4	2.1	2.4	.28	22.6	72.4	42.3	11.8	0.5	1.0
IIB23Ca	79 -115	0.2	2.0	3.7	.24	24.5	76.8	45.3	10.8	0.6	1.2
IIB3Ca	115+	0.2	2.0	3.5	.35	23.4	82.8	45.3	9.8	0.5	1.6
					Profile No.6						
AP	0 -10	0.8	3.7	4.5	.30	61.1	95.9	65.0	19.7	1.5	1.0
B21	10 -50	0.7	3.5	5.0	.25	61.7	143.5	65.0	17.7	1.1	1.3
B22	50 -80	0.6	3.8	4.8	.28	60.9	86.0	63.0	19.7	0.9	2.4
B23	80 -155	0.5	3.6	4.6	.30	57.1	83.9	60.0	21.6	0.7	4.1
B24Ca	155+	0.4	4.1	4.4	.39	55.4	98.8	54.1	19.7	0.8	3.9

Table 6 - Chemical Analyses For Profiles No. 7 and 8

Hor.desig.	Depth	Organic matter	Free Fe_2O_3		Electrical conductivity	Cation exchange		Extractable			
			Soil	Clay		Soil	Clay	Ca	Mg	K	Na
	cm	%			mmhos/cm	meq/100 g					
					Profile No.7						
AP	0 -21	0.7	4.6	5.0	.22	49.7	136.3	61.0	14.8	1.2	0.9
B21	21 -85	0.6	4.7	4.7	.30	46.2	126.7	52.2	17.7	0.9	4.1
B22	85 -133	0.5	4.2	4.5	.39	45.6	103.7	50.2	19.7	0.8	6.5
B23	133-175	0.4	4.5	4.6	.56	45.6	85.6	45.3	20.7	1.0	7.6
					Profile No.8						
AP	0 -10	1.0	5.7	5.0	.28	63.2	133.0	67.9	15.8	1.2	0.9
B21	10 -70	0.8	5.9	4.8	.20	62.8	112.8	65.9	16.7	0.9	1.2
B22	70 -130	0.6	5.6	4.8	.27	60.9	91.5	59.0	19.7	0.7	2.7
IIB23	130-180	0.4	5.2	3.5	.32	54.4	91.5	54.1	18.7	0.8	4.1
IIB24	180+	0.3	5.1	4.6	.50	47.8	97.4	54.1	17.7	0.6	4.6

Appendix - B: Physical Analyses

Table 7 -Particle Size Distribution for Profile No. 1

Hor.desig.	Depth cm	Gravel	Sand					Silt	Clay
		mm							
		>2.0	2-.8	.8-.6	.6-.2	.2-.1	.1-.05	.05-.002	<.002
					CO_3-Free				
AP	0 -28	.17	0.05	.03	0.22	.12	18.6	37.5	43.3
B21	28 -75	.08	0.06	.03	0.12	.06	5.7	38.2	55.8
B22	75 -100	.20	0.31	.11	0.24	.07	2.7	38.4	58.0
IIB23Ca	100-145	.55	1.02	.60	2.00	.64	3.2	29.0	63.0
					With CO_3				
AP	0 -28					* 0.8	17.9	35.9	45.4
B21	28 -75					4.0	5.1	37.0	54.0
B22	75 -100					3.7	2.3	41.3	52.7
IIB23Ca	100-145					12.5	2.7	35.2	49.5
	Particle Size Distribution-Calculated on Clay-free basis								
AP	0 -28	0.30	0.09	0.05	0.39	0.21	32.7	66.2	
B21	28 -75	0.18	0.14	0.07	0.27	0.14	12.9	86.3	
B22	75 -100	0.48	0.74	0.26	0.57	0.17	6.3	91.4	
IIB23Ca	100-145	1.48	2.75	1.62	[illegible].40	1.73	8.7	78.3	

* >.1mm.

Table 8 -Particle Size Distribution for Profile No. 2

Hor.desig.	Depth cm	Gravel	Sand					Silt	Clay
		mm							
		>2.0	2-.8	.8-.6	.6-.2	.2-.1	.1-.05	.05-.002	<.002
		%							
					CO_3-Free				
AP	0 -30	0.03	0.12	0.09	0.28	.10	4.1	36.8	58.5
B21	30 -50	0.07	0.28	0.18	0.31	.15	4.6	29.2	65.2
B22Ca	50 -130	2.45	0.20	0.08	0.32	.14	4.6	27.4	64.8
B23Ca	130 +	1.73	2.03	1.32	7.05	.68	2.9	21.2	63.1
					With CO_3				
AP	0 -30					1.4	4.4	36.3	57.8
B21	30 -50					4.1	4.7	29.9	61.4
B22Ca	50 -130					5.2	4.4	29.7	60.6
B23Ca	130 +					24.4	2.0	22.6	51.1
	Particle Size Distribution-Calculated on Caly-free basis								
AP	0 -30	0.07	0.29	0.22	0.7	0.24	10.0	88.6	
B21	30 -50	0.20	0.80	0.52	0.9	0.43	13.1	84.0	
B22Ca	50 -130	6.97	0.57	0.23	0.9	0.40	13.0	77.9	
B23Ca	130 +	4.69	5.51	3.58	19.1	1.84	7.8	57.6	

*>.1mm.

Table 9- Dry (D_{b_d}), Moist (D_{b_m}) Bulk Density And Coefficient Of Linear Extensibility (COLE).

Hor	Depth	D_{b_d}	D_{b_m}	COLE
	cm	g/cm^3		
		Profile No. 2		
AP	0 -30	1.48	1.29	0.05
B21	30 -50	1.65	1.40	0.06
B22Ca	50 -130	1.74	1.49	0.05
		Profile No. 3		
AP	0 -40	1.61	1.36	0.06
B21	40 -90	1.86	1.32	0.12
B22	90 -130	1.91	1.39	0.11
B23Ca	130-165	1.64	1.38	0.06
		Profile No. 4		
AP	0 -34	1.43	1.[illegible]2	0.05
B21	34 -67	1.71	1.42	0.06
B22	67 -120	1.75	1.47	0.06
B23	120-148	1.66	1.31	0.08
		Profile No. 6		
B21	10 -50	1.93	1.35	0.12
B22	50 -80	1.69	1.32	0.13
B23	80 -155	1.88	1.34	0.12

Table 10 – Particle Size Distribution for Profile No. 3

Hor.desig.	Depth cm	Gravel	Sand					Silt	Clay
		mm							
		>2.0	2-.8	.8-.6	.6-.2	.2-.1	.1-.05	.05-.002	$<.002$
		%							
					CO_3-Free				
AP	0 -40	.11	.22	.14	.35	.16	3.0	37.9	58.1
B21	40 -90	.11	.26	.14	.25	.16	2.2	33.6	63.3
B22	90 -130	.14	.11	.11	.21	.11	2.2	36.1	61.0
B23Ca	130-165	.78	.07	.06	.63	.09	2.1	23.9	72.4
					With CO_3				
AP	0 -40					*2.4	3.3	42.4	51.9
B21	40 -90					4.5	2.3	34.3	58.9
B22	90 -130					5.5	2.2	34.4	57.9
B23Ca	130-165					5.4	1.8	23.0	69.8
	Particle Size Distribution-Calculated on Clay-free basis								
AP	0 -40	0.26	.53	.33	0.84	.38	7.1	90.6	
B21	40 -90	0.30	.71	.38	0.68	.44	5.1	91.6	
B22	90 -130	0.36	.28	.28	0.54	.28	5.6	92.6	
B23Ca	130-165	2.83	.25	.22	2.28	.33	7.5	86.6	

*$>$0.1mm.

Table 11 - Particle Size Distribution for Profile No. 4

Hor.desig.	Depth cm	Gravel >2.0	Sand 2-.8	Sand .8-.6	Sand .6-.2	Sand .2-.1	Sand .1-.05	Silt .05-.002	Clay <.002
		%							
		CO_3-Free							
AP	0 -34	0.16	0.15	.04	0.16	.13	5.2	52.0	42.1
B21	34 -67	0.09	0.21	.02	0.22	.16	3.8	38.7	56.9
B22	67 -120	0.03	0.17	.12	0.18	.06	4.0	31.2	64.2
B23	120-148	0.04	0.04	.02	0.21	.06	0.5	34.7	64.4
IIB3Ca	148-165+	4.42	1.95	.44	1.50	.27	4.2	10.[illegible]	77.0
		With CO_3							
AP	0 -34					* 2.75	5.31	50.9	41.0
B21	34 -67					2.92	3.74	32.[illegible]	60.8
B22	67 -120					1.17	3.78	31.1	63.9
B23	120-148					1.60	0.46	31.1	66.8
IIB3Ca	148-165+					22.77	3.20	15.4	58.6

*> .1mm.

Table 11 - Particle Size Distribution for Profile No. 4 (Continued)

Hor.desig.	Depth	Gravel	Sand					Silt	Clay
	cm	mm							
		> 2.0	2-.8	.8-.6	.6-.2	.2-.1	.1-.05	.05-.002	< .002
		%							
	Particle Size Distribution Calculated on Clay-free basis								
AP	0 -34	0.28	0.26	0.07	0.28	0.22	9.1	89.8	
B21	34 -67	0.21	0.49	0.05	0.51	0.37	8.7	89.7	
B22	67 -120	0.03	0.48	[illegible]	[illegible]	[illegible]	11.2	87.7	
B23	120-148	0.11	0.11	0.06	0.59	0.17	1.4	97.5	
IIB3Ca	148-165+	19.18	8.46	1.91	6.51	1.17	18.4	44.3	

Table 12 _Particle Size Distribution for Profile No. 5

Hor.desig.	Depth	Gravel	Sand					Silt	Clay
	cm	mm							
		>2.0	2-.8	.8-.6	.6-.2	.2-.1	.1-.05	.05-.002	<.002
		%							
					CO_3-Free				
AP	0 -24	3.3	0.9	.43	0.6	0.6	5.4	36.7	52.1
B21	24 -60	1.9	1.0	.34	0.7	0.7	6.2	28.2	60.9
B22Ca	60 -79	5.0	1.0	.30	0.9	1.0	6.3	16.4	69.2
IIB23Cam	79 -90	3.2	1.3	.57	1.4	1.9	6.2	8.5	77.0
IIB23Ca	79 -115	5.4	1.0	.30	1.0	1.0	6.6	14.3	70.4
IIB3Ca	115 +	1.9	0.9	.41	1.0	0.8	5.7	26.3	71.2
					With CO_3				
AP	0 -24					* 5.2	5.3	42.3	47.3
B21	24 -60					4.1	5.9	31.6	58.4
B22Ca	60 -79					9.1	4.8	17.1	69.0
IIB23Cam	79 -90					11.2	4.8	13.7	70.3
IIB23Ca	79 -115					11.4	5.3	25.7	57.7
IIB3Ca	115 +					11.6	4.4	26.3	57.7

* >.1mm.

Table 12 -Particle Size Distribution for Profile No. 5 (Continued)

Hor.desig.	Depth	Gravel	Sand					Silt	Clay
		mm							
	cm	>2.0	2-.8	.8-.6	.6-.2	.2-.1	.1-.05	.05-.005	<.002
		%							
	Particle Size Distribution-Calculated on Clay-free basis								
AP	0 -24	7.0	1.9	0.90	1.2	1.2	11.3	76.7	
B21	24 -60	4.9	2.6	0.87	1.8	1.9	15.8	72.2	
B22Ca	60 -79	16.1	3.2	0.98	2.9	3.2	20.4	53.2	
IIB23Cam	79 -90	14.1	5.7	2.47	6.2	8.1	26.7	36.7	
IIB23Ca	79 -115	18.3	3.3	1.02	3.2	3.4	22.5	48.4	
IIB3Ca	115+	5.1	2.5	1.11	2.6	2.2	15.3	71.1	

Table 13 _ Particle Size Distribution for Profile No. 6

Hor.desig.	Depth	Gravel	Sand					Silt	Clay
		mm							
	cm	>2.0	2-.8	.8-.6	.6-.2	.2-.1	.1-.05	.05-.002	<.002
					CO_3-Free				
AP	0 -10	0.3	.21	.04	.29	.11	1.8	31.2	66.0
B21	10 -50	0.1	.14	.06	.23	.22	1.6	25.4	72.3
B22	50 -80	0.4	.03	.03	.11	.12	1.4	26.0	71.9
B23	80 -155	0.2	.15	.03	.17	.14	1.7	19.8	77.8
B24Ca	155 +	1.1	.15	.03	.22	.34	1.4	19.9	76.9
					With CO_3				
AP	0 -10					*3.01	1.8	32.9	62.4
B21	10 -50					2.66	1.5	27.4	68.5
B22	50 -80					2.12	1.3	29.7	67.8
B23	80 -155					4.12	1.6	23.4	70.9
B24Ca	155+					8.82	1.3	21.6	68.3

* >.1mm.

Table 13 - Particle Size Distribution for Profile No. 6 (Continued)

Hor.desg.	Depth	Gravel	Sand					Silt	Clay
		mm							
	cm	>2.0	2-.8	.8-.6	.6-.2	.2-.1	.1-.05	.05-.002	<.002
		%							
	Particle Size Distribution Calculated on Clay-free basis								
AP	0 -10	1.0	.52	.12	.85	0.32	5.4	91.7	
B21	10 -50	0.4	.50	.22	.83	0.79	5.6	91.6	
B22	50 -80	1.4	.11	.11	.39	[illegible]	5.1	92.6	
B23	80 -155	0.8	.68	.14	.76	[illegible]	7.7	89.2	
B24Ca	155+	4.6	.65	.13	.95	1.47	6.2	85.9	

Table 14 – Particle Size Distribution for Profile No. 7

Hor.desig.	Depth	Gravel	Sand					Silt	Clay
	cm	mm							
		>2.0	2-.8	.8-.6	.6-.2	.2-.1	.1-.05	.05-.002	<.002
		%							
		CO_3-Free							
AP	0 -21	.5	.19	.10	.4	.3	1.7	29.8	67.1
B21	21 -85	.7	.03	.08	.2	.3	1.5	24.0	73.1
B22	85 -133	.9	.12	.05	.2	.2	2.6	22.7	73.2
B23	133-175	.3	.07	.05	.1	.2	1.7	16.5	81.0
		With CO_3							
AP	0 -21					*4.4	1.9	35.9	57.8
B21	21 -85					3.4	1.7	27.5	67.4
B22	85 -133					4.6	2.9	22.2	70.3
B23	133-175					7.0	1.6	20.2	71.2
		Particle Size Distribution Calculated on Clay-free basis							
AP	0 -21	1.6	.58	.30	1.1	0.9	5.1	90.4	
B21	21 -85	2.5	.30	.30	0.9	1.2	5.4	89.3	
B22	85 -133	3.5	.45	.19	0.7	0.6	9.7	84.8	
B23	133-175	1.5	.37	.26	0.6	0.8	9.1	87.1	

*>.1mm.

Table 15- Dry (D_{b_d}), Moist (D_{b_m}) Bulk Density And Coefficient Of Linear Extensibility (COLE).

Hor	Depth	D_{b_d}	D_{b_m}	COLE
	cm	g/cm^3		
		Profile No. 7		
AP	0 -21	1.69	1.24	0.11
B21	21 -85	1.99	1.47	0.11
B22	85 -133	1.92	1.48	0.09
B23	133-175	1.85	1.48	0.08
		Profile No. 8		
B21	10 -70	1.78	1.29	0.11
B22	70 -130	1.94	1.47	0.10
B23	130-180	1.92	1.42	0.11
B24	180+	1.93	1.38	0.12

Table 16 - Particle Size Distribution for Profile No. 8

Hor.desig.	Depth	Gravel	Sand					Silt	Clay
		mm							
	cm	>2.0	2-.8	.8-.6	.6-.2	.2-.1	.1-.05	.05-.002	<.002
		%							
		CO3-Free							
AP	0 -10	0.6	.30	.06	.25	.15	2.0	28.0	68.6
B21	10 -70	0.4	.04	.05	.10	.26	2.8	24.1	72.2
B22	70 -130	0.4	.14	.07	.19	.29	1.7	24.2	73.0
B23	130-180	1.0	.28	.14	.31	.43	2.0	24.2	71.7
IIB24	180+	2.1	.44	.22	.35	.94	1.3	17.1	77.6
		With CO_3							
AP	0 -10					*4.93	2.0	30.7	62.4
B21	10 -70					2.43	2.6	30.2	65.6
B22	70 -130					4.58	1.7	26.9	66.8
B23	130-180					7.47	1.8	27.2	63.6
IIB24	180+					9.58	1.1	29.7	59.6
	Particle Size Distribution-Calculated on Clay-free basis								
AP	0 -10	1.8	0.95	.19	0.80	0.48	6.5	89.2	
B21	10 -70	1.6	0.14	.11	0.36	0.94	9.9	86.9	
B22	70 -130	1.6	0.52	.26	0.70	1.07	6.1	89.7	
B23	130-180	3.4	0.99	.50	1.10	1.52	6.9	85.5	
IIB24	180+	9.2	1.96	.98	1.56	4.19	6.0	76.2	

*>.1mm.

نشأة وتطور وتصنيف بعض الاراضي المختاره بمنطقة اربد

تعتبر أراضي اربد الزراعية من أهم الاراضي المطرية في الاردن . لذا كان اختيار منطقة اربد لهذه الدراسة .

درست ثمانية مقاطع رأسية للتربة بمواقع منتخبة بمنطقة اربد من النواحي الكيماوية والفيزياوية والمعدنية والمورفولوجية ، وذلك بغرض وضع فرضية تفسر نشأة هذه التربة ثم تصنيف هذه الاراضي حسب النظام العالمي الحديث.

اتبعت طريقة الفرضيات المتعددة لتفسير خواص الاراضي المحسوسة أو المقاسة كوسيلة للوصول الى الفرضية الاكثر ملائمة .

تبين من نتائج هذه الدراسة أن أراضي منطقة اربد قد تطورت تحت اربع مناخات على الاقل وهي : رطب أو رطب جدا ثم جاف ثم رطب ثم جاف وهو السائد حاليا . كما اظهرت النتائج أن هذه المنطقة معرضة للتصحر وللانجراف بفعل الماء والهواء .