PROPERTIES AND FORMATION OF VERTISOLS IN JORDAN AS AFFECTED BY PARENT MATERIAL AND PRECIPITATION

BY

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ABSTRACT

Vertisols can be found in various locations in Jordan. These soils possess many problems due to the cracking phenomena, compaction and poor permeability, but are very productive when managed properly

This study is concerned with the effect of parent material and precipitation on the formation and the properties of vertisols in various locations in Jordan. The objectives of the study are to;

1) Study the formation of these soils.
2) Compare between vertisols developed on basalt and on limestone under different amounts of rainfall.
3) Apply modern soil classification.

Eleven soil profiles representing the vertisols in Jordan were selected according to parent material and rainfall underwhich these soils occur. The soils were selected from three transects located in the northern part (Irbid region), middle part (Baq'a and Madaba region) and southern part (Karak region).

Soil development hypotheses were proposed in sequential mode to explain the occurence of some of their properties. The results showed that these soils as they are, were subjected to four different cycles of soil formation with some differences being injected due to the deposition of the basalt rock.

These soils were subjected to four episodes of climatic changes since the deposition of the parent material. The four episodes were; Humid, Arid, Subhumid to semiarid arranged in chronological order.

Gilgai microrelief was absent in all the studied soils. All the studied soils were classified as Vertisols except Ramtha soil which was classified as Inceptisol.

Clay and carbonate content were higher for the limestone derived soils than for basalt derived soils. Moreover, carbonates decreased with increasing rainfall. Extractable calcium was higher for limestone derived soils, while magnesium was higher for basalt derived soils. Free iron oxides and organic matter were directly proportional to amounts of precipitation regardless of the parent material type.

Smectite dominated the clay minerals for basalt derived soils, while smectite/vermiculite interstratified mineral dominated the clay minerals for limestone derived soils regardless of the precipitation. Cation exchange capacity was higher for basalt derived soils.

Below 300 mm rainfall, formation of Vertisols is not expected within the study area.

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DEDICATED

TO

MY PARENTS

SISTERS AND BROTHERS

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CHAPTER I

INTRODUCTION

Cracking soils or vertisols occupy a large and important part of the agricultural land in Jordan. These soils are present in various locations, under different climate and are formed from basalt and limestone.

Due to the properties of these soils, they pocess many agricultural and engineering problems. However, they are very productive when properly managed. Nevertheless, much is yet to be learned about the inherent characteristics of these soils. It seems that these soils allow only limited increase in yield under known methods of management.

The aim of this study is to understand the formation of these soils under the different environmental conditions in Jordan, as well as their chemical, physical, mineralogical properties and their classification.

The factors considered in this study were climate and parent material. The investigation sites were distributed over three transects; northern part,middle part,and southern part of Jordan.

The objectives of this study were to;

1. Study the formation of vertisols in arid and semiarid regions.
2. Compare between vertisols developed from different parent materials (limestone and basalt associated with limestone), and under different amounts of precipitation.
3. Apply modern soil classification.

CHAPTER II

LITERATURE REVIEW

Soil is defined as a collection of natural bodies covering the earth's surface, which is modified or even made by man of earthy materials in some places, and it contain living matter and it can support plants out-of-doors. It's upper limit is air or shallow water. At its margins, it grades to deep water or to barren rock or ice. It's lower limit to the not soil beneath perhaps is the most difficult to define. Soil includes the horizons near the surface that differ from the underlying material as a result of interactions, through time, of climate, living organisms, parent materials, and relief (43).

Vertisols

Vertisols are soils with high clay content which expand and contract markedly with changes in moisture content. They are characterized by minimal horizon differentiation which may be due to pedoturbation, and very plastic and sticky soil consistency when wet.

Concept of Vertisols

The concept behind the classification of these soils is the high clay content. The unstable nature of these soils is attributed primarily to the high content of swelling clay mineral, which in dry season causes the soil to develop deep,wide cracks(17).

A significant amount of material from the upper part of the profile may slough off into the cracks giving rise to a primary inversion of the soil. This accounts for the term invert which is used to characterize this order in a general way(9).

The movement of the soil is sufficent to cause vertical mixing of the soil profiles(3).

Climate

Vertisols occur under a wide range of climatic conditions. They are found in both very hot and cool climate. They exist in various areas where the average annual temperatures generally ranges between 15.5-26.5°C. In all cases,Vertisols are located in areas with high summer temperatures which is seldom lower than 20°C and may even reach as high as 35°C. The difference between the highest and the lowest mean monthly temperatures depends on the latitude at which these soils may occur. At the vicinity of equator zone the difference does not exceed 5°C but in the higher latitudes it may be as high as 15°C (18).

Vertisols occur under both arid and humid conditions, where annual rainfall ranges from 150 mm as in Sudan to 2,000 mm as in Indonesia (18). The duration of the dry period varies from 0 to 12 months, while the humid ranges from 0 to 9 months (18).

Vertisols occur only in climates with a pronunced dry season. A dry period of 4 to 8 months seems to be the most common climatic feature in vertisols. The wet season in these regions is very seldom longer than 7 months (18).

Topography

Vertisols occur in areas of elevation less than 1,000 meters surfaces. Proto-vertisols represent the mature soil type on noneroded level surfaces in all but the more humid parts of the eastern mediterranean (40).

Effect of time

Vertisols are considered as immature soil if assesed by the rate of profile development. Vertisols may develop on parent materials of recent age such as marine, lacustrine, alluvial deposits, and on volcanic materials. Something else lead to a youthful profile is pedoturbation which takes place laterally and vertically, limiting the development of natural soil horizons and in many cases absecing evidences of leaching, differential weathering and soil aggregates formation in different parts of the profile (11).

Clay distribution

Clay content in vertisols may reach as high as 80 percent or be as low as 30 percent. The clay remains high and uniform throughout the profile to a depth of at least 1 meter. However in some cases, there is a gradual increase of clay with increasing depth, while in others clay might decrease with depth. These differences are attributed to the variations in the parent material rather than in the soil formation (18).

Cracking pattern

Vertisols have at some time in most years unless cultivated, open cracks at a depth of 50 cm that are at least 1 cm wide and extend upward to the surface or the base of the plough layer or surface crust (43). Cracks are developed when the expanding type clay dries. The width and depth of cracking are associated with the degree of dessication and the amount of rainfall. The dessication is often related to the type and the density of vegetation. It is evident that grass develops shallow cracking and deep cracks underlies trees since they deplete soil moisture to a greater degree and from deeper layers (21). It appears that in a soil having vegetation, the pattern of cracking is basically a function of positioning of the plants rather than the soil itself. However, where there is no vegetation the pattern of cracking develops at the point of least resistance with highest soil water content (37).

It was found that the average depth of cracks is inversely related to the amount of precipitation or irrigation water. Also, that the cracks widths are affected by length of the drying period, history of the soil, and the clay content. In Gezira area (Sudan), it was found that irrigation reduces the volume of cracks to one forth of the volume under natural conditions (21).

Shrink-Swell

Most soil fabrics change in volume as the water content changes. The fractional linear dimension change in a ped or clod which result from soil movement had been described as the coefficent of linear extensibility (COLE). Vertisols have a coefficent of linear extensibility of 0.09 or more. Cracking and high COLE values indicate a shrink-swell potential affecting soil behaviour (17),

The relationship of the COLE in relation to soil parameters, such as fine clay percent, coarse clay, silt, organic matter, inorganic carbon, electrical conductivity and exchangeable sodium percentage,, was studied by Anderson et al. (3), and it was concluded that COLE was highly correlated with fine clay and ESP.

Shrinkage produces cracks, the high cohesion accounting for the large size of peds. In the dry season some of the loose material from the surface falls inside the cracks, or is washed down by rain. When the soil is moistened the peds expand and press against each other. The pressures resulting from the force excerted by expansion cause the sliding of one mass of soil past another which produces polished and grooved surfaces called slickensides (18,48).

Gilgai development

Gilgai microrelief is an alternating microdepressions and micro elevations in a horizontal or weakly inclined clay plain. It is limited to clayey soils with a high capacity for swelling and shrinkage. The usual explanation of the formation of gilgai is by soil heaving resulting from expansion upon wetting. When the soil is wetted, lateral pressure is developed and is released by expansion upwards initiating a mound. The formation of a mound gives a locally prefered site for further release of pressure, and hence a regular pattern tends to form (19).

If the blocks between the cracks are small, the width of the cracks are relatively small and no gilgai topography is formed. Thus, where the soil structure is favourable no gilgai is found (19). Recently it was suggested that it is not necessary to have gilgai microrelief or intersecting slickensides in vertisols (14).

Large areas of gilgai terrain and related specific kinds of vertisol profiles which have developed during the quaternary on every continent (25).

Vertisols bulk density is unusually high, typically 1.8 gm/ cm^3 (48).

Chemical properties

Calcium constitutes the dominant exchangeable cation in the calcareous soils and magnesium in the volcanic ash soils. The levels of exchangeable magnesium is higher for those soils developed in a drier climate. The cultivated soils have lower amounts of organic matter but the color gives no indication of the amount present (2).

Mineralogy

Montmorillonite and " Mixed layer" clays have been reported to form an important part of the clay fraction in most areas where vertisols have been studied (18). The dominant clay mineral group is the smectite group and the dominant mineral is the 2:1montmorillonite. These soils are in equilibrium with their environment and that 2:1 expanding lattice clays are stable and will presist climatic changes (10). Some vertisols of the semiarid regions have their primary minerals disintegrated and formed clays, whilst the soil may be calcareous throughout (40).

Vertisols from widely seperated sites in Texas developed on limestone and under 600-800 mm rainfall were studied (28). Mineralogy of the silt fraction showed quartz to be the most abundant mineral constituent in the surface horizons. The occurence of calcite, however, increases with depth and dominates in the lower horizons. Feldspars varies from trace to small amounts in all horizons. Clay fraction showed montmorillonite to be the predominating mineral constituent. Illite was found in small amounts in the lower horizons. Kaolinite occurs in all horizons. Quartz was found in all horizons (28).

Palygorskite was identified only in the calcareous soils formed from Neogene sedimentary rocks (38).

Vertisols developed on basalt under 300 mm rainfall in Arizona showed that montmorillonite was the dominant clay mineral associated with minor amounts of mica and Kaolinite(27).

Dioctahedral smectite accompanied by disordered kaolinite were found to be the predominant minerals in the basaltic vertisols under 500 mm precipitation. Sometimes the smectite is interstratified with small quantities of a swelling chlorite. The non clay fraction of these soils were composed of quartz and plagioclase (39,40).

Micaeous or illitic minerals are important in vertisols developed on basic igneous and metamorphic rocks. These are not abundant in soils developed on limestone(1). Montmorillonite of limestone soils are directly inherited from the parent rock and are not due to the product of soil genesis (2).

The dominant clay minerals where rainfall is in the range of 400-500 mm/year, are smectite and kaolinite coming second. It has been reported that increasing rainfall increases the kaolinite in the clay fraction at the expense of smectite.(27). Under subatmospheric conditions and good drainage basalt weathers into an assemblage of smectite and kaolinite and halloysite (27).

Soils with the vertic subgroup showed that the smectite/ kaolinite ratio decreases with soil depth. The clay mineral distribution pattern does not change significantly with soil depth. Also, the lower most horizon possibly contains a larger proportion of the 2:1 clay minerals. The studied soils were developed under 1200 mm precipitation and this consequently leads to low pH. This indicates that alkaline conditions that are particularly favourable for 2:1 clay mineral formation had not prevailed in these soils (39).

Usually in vertisols, high silica concentration is maintained by slow movement or stagnation of the soil water which is required for montmorillonites synthesis. Montmorillonites are unstable under conditions of high hydronium concentration and rapid leaching. However, it often occurs in dense clay layers in which rate of leaching is slow, and thus it persists under conditions of high weathering intensity when inherited from parent material (11).

Moormann studied the vertisols of east Jordan and found that they consisted of fine sized clay particles (32).

Jamous (26) also studied vertisols developed from basalt and limestone origin. He has found that churning processes which leads to pedoturbation of soil properties and masking any illuviation process that had occured earlier. The mineralogy of these soils indicates the pressence of smectite, vermiculite, illite, interlayered minerals, and kaolinite. Clay content was more than 50 percent. Free iron oxides and cation exchange capacity were uniformly distributed throughout the soil profile (26).

Nomenclature and classification

Vertisols have different names. Among these are Grumusol, Black cotton, Tropical black clays, Gray and Brown soils of heavy texture, and smonitiza. It also include some soils that have been called alluvial soils, particularly these with large amounts of expanding lattice clays in a hot dry climate of alternating seasons (42).

Vertisols were called Grumusols in the 1938 classification system (11). The term Vertisol was suggested (in the 7th approximation 1960) as a new order name. The term is derived from the latin "vertere" meaning to turn or invert indicating that the soils are self-mixing, thus limiting the development of classical soil horizons (42).

According to the 7th approximation, Vertisols may have a mollic or umbric epipedon (42). If one of these is present; the lower boundary is often very irregular, but the irregularity is not diagnostic for it can be the result of frost action. There may be a horizon meeting the requirments of an argillic horizon provided that the upper boundary lies within 5 cm of the surface. An albic horizon as much as 5 cm thick may overlie the argillic horizon. Calcic horizon and ca horizons are common (42).

Recently , the central concept of Vertisol was redefined according to the most recent classification (43). Vertisols are soils that do not have a lithic or a paralithic contact, petrocalcic horizon, or duripan within 50 cm of the surface, and after the soil to a depth of 18 cm has been mixed, as by plowing have 30% or more clay in all subhorizons to a a depth of 50 cm or more, and have at some time in most years, unless cultivated, open cracks at a depth of 50 cm that are at least 1 cm wide and extend upward to the surface or the base of the plough layer or surface crust; and have one or more of the following:

A. Gilgai;

B. At some depth betwwen 25 cm and 1 m, slickensides close enough to intersect; or

C. At some depth between 25 cm and 1 m wedge-shaped natural structural aggregates that have their long axis tilted 10° to 60° from the horizontal (43).

Vertisols occur under different moisture regimes, such a Xeric, Torric, Udic, and Ustic (43). Recently it has been reported under Aquic moisture regime, increasing the Vertisols suborders to five namely; Xerert, Torrert, Udert, Ustert, and Aquert (14).

According to the FAO classification system vertisols have two major soil units, Pellic and Chromic (11).

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soils This was found to be helpful for water penetration in the soil through the developed cracks and a benefical for fertility conservation (21). Some vertisols are under extensive non-irrigated cultivation, particularly for tobacco (48).

CHAPTER III

MATERIALS AND METHODS

3.1 Location of the study area

The selected soils are distributed over three transects, these transects are; Irbid region in the northern part of Jordan, Baq'a and Madaba in the middle part, and Karak region in the southern part of Jordan. Eleven sites were studied and one pit at each site was dug. Sampling was carried out during august and september, 1985.

3.2 Soil forming factors

3.21 Geology

The geological formations found through the study area are as follows; (5,12).

Baq'a	: Bedded limestone with clay partings ten to fifteen meters thick seperated from each other by marls of varying thickness, Cenozoic.
Madaba, Karak, Irbid	: Chalks, and marls with varying amounts of flint-chert, bitiminous cement, Cenozoic.
Karak, Irbid	: Alkali basalts and basalt tuffs (basalts flow), Neogene and Quaternary.

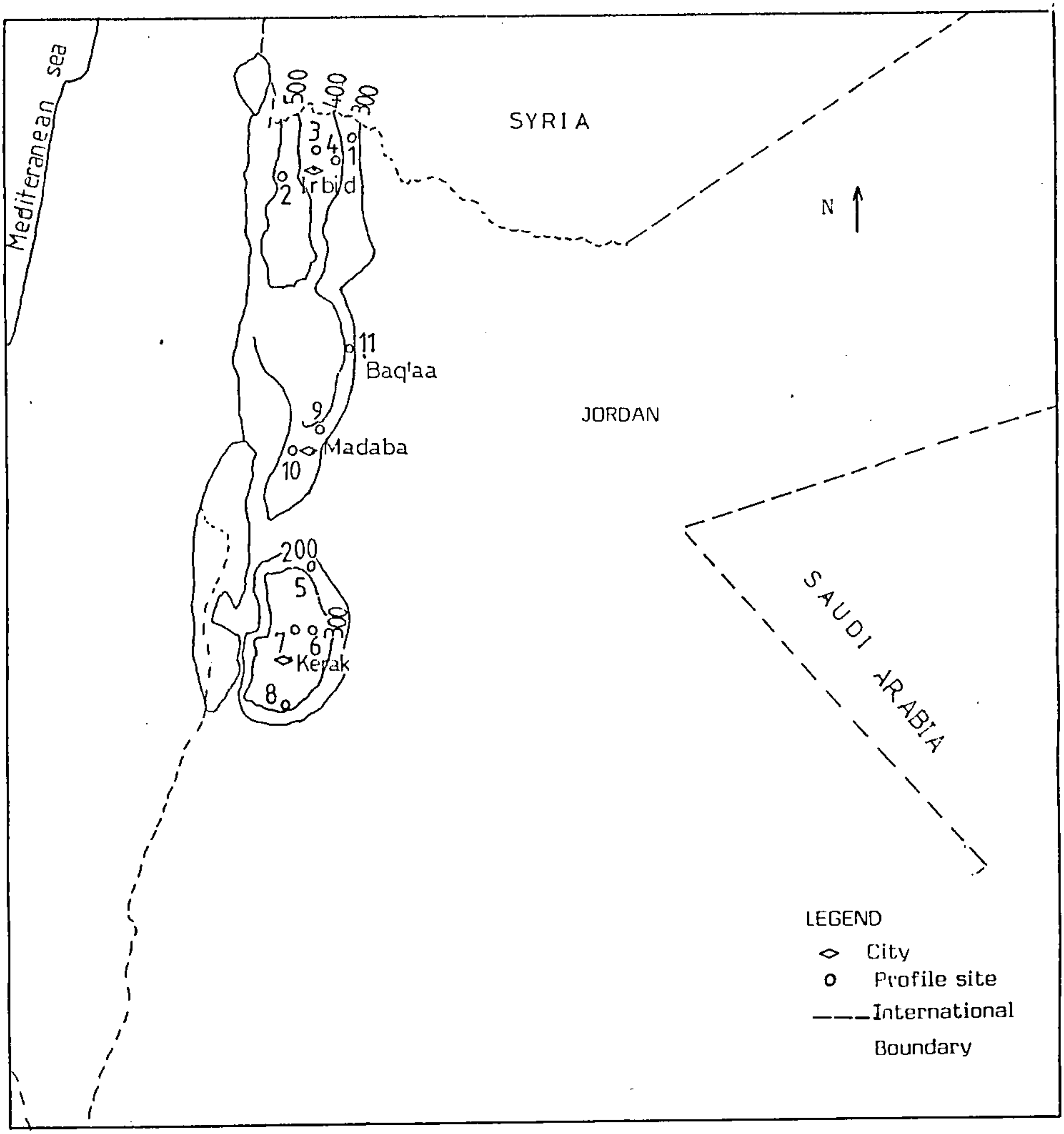


Fig. 1. Map of Jordan indicating site locations and their mean annual precipitaion

The geological maps constructed by Bender (1975) are illustrated by Fig. 2 and 3, indicating that most of the studied profiles are of the Quaternary (5).

3.22 Relief

All selected sites have slope gradient of 1-2%, linear to concave except Majra and Baq'aa where it was 2% convex. The selected sites were located on a level landscape. The elevations of the site locations were as Follows; Ramtha 590m, Jamha 570m, Kherja 455m, Baq'aa 700m,Madaba 785,Qaser 940m, Shihan and Rabba 960m, and Majra 1100m. Runoff was medium to slow, and the degree of soil erosion is minimum (31).

3.23 Climate

The climate belongs to the mediterranean type, that is characterized by a hot dry summer and cool winter. Winter starts around mid November and summer starts around end of April. The mean annual precipitation varies from place to another. For example in Irbid it ranges from 300-400 mm, Ramtha 300 mm, Madaba 300-400mm, Baq'aa 350mm,Karak 300mm. Generally, precipitation increases from south to north. The mean winter temperature varies from 6°C to 10°C, and the mean summer temperature varies from 23°C to 27°C . Relative humidity varies from43% in winter to 71% in summer. Evaporation ranges from 2.7mm/day in winter to 12.4mm in summer(31).

3.24 Vegetation

Cereals, Legumes, and summer crops,such as wheat,are the main crops grown in the study area. Natural vegetation was absent within the selected locations. The natural forestry trees in the northern part (Irbid region) were: Pinus

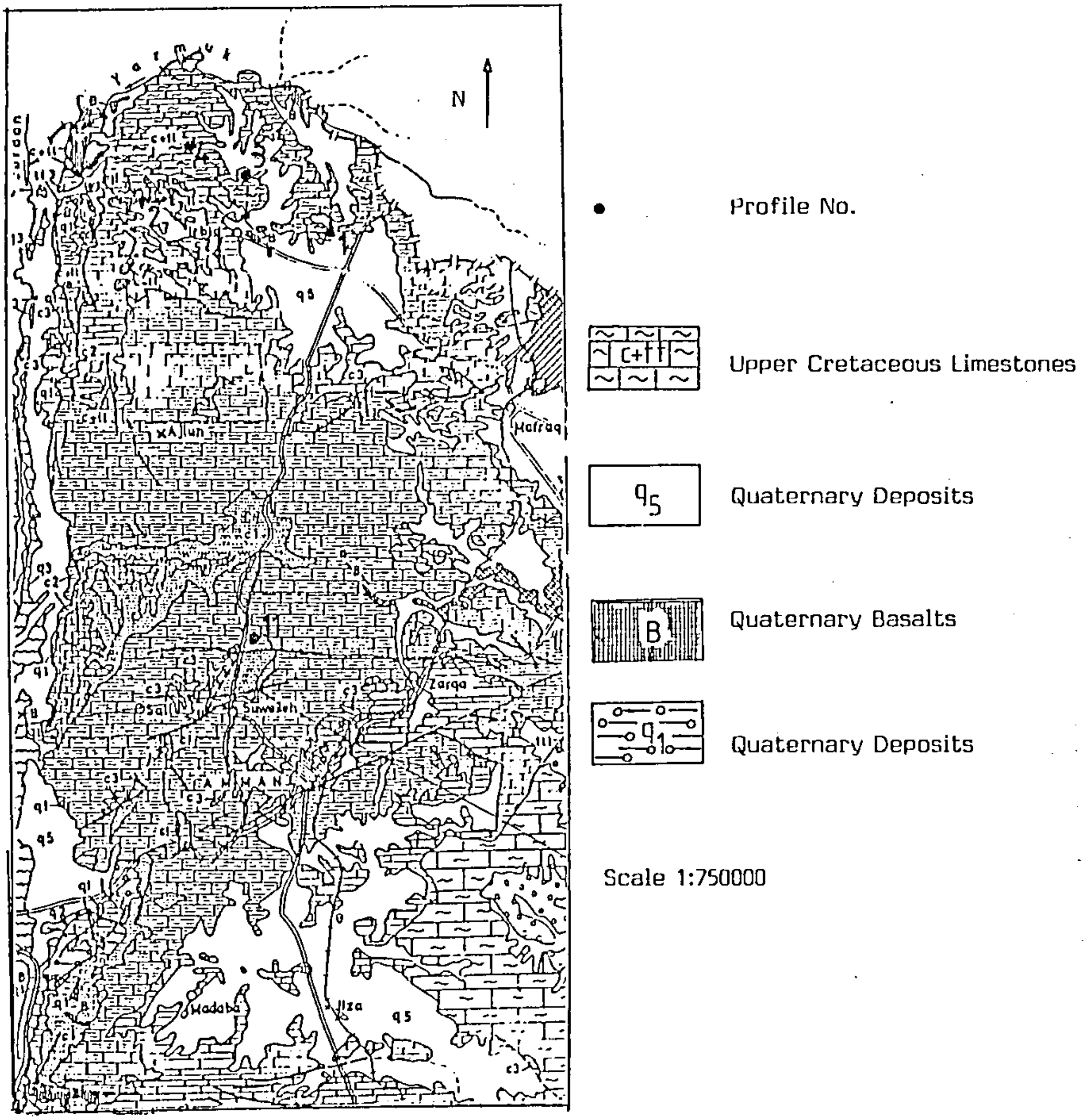


Fig2- Geological Map Of Irbid And Baq'aa Area
(Bender 1975)

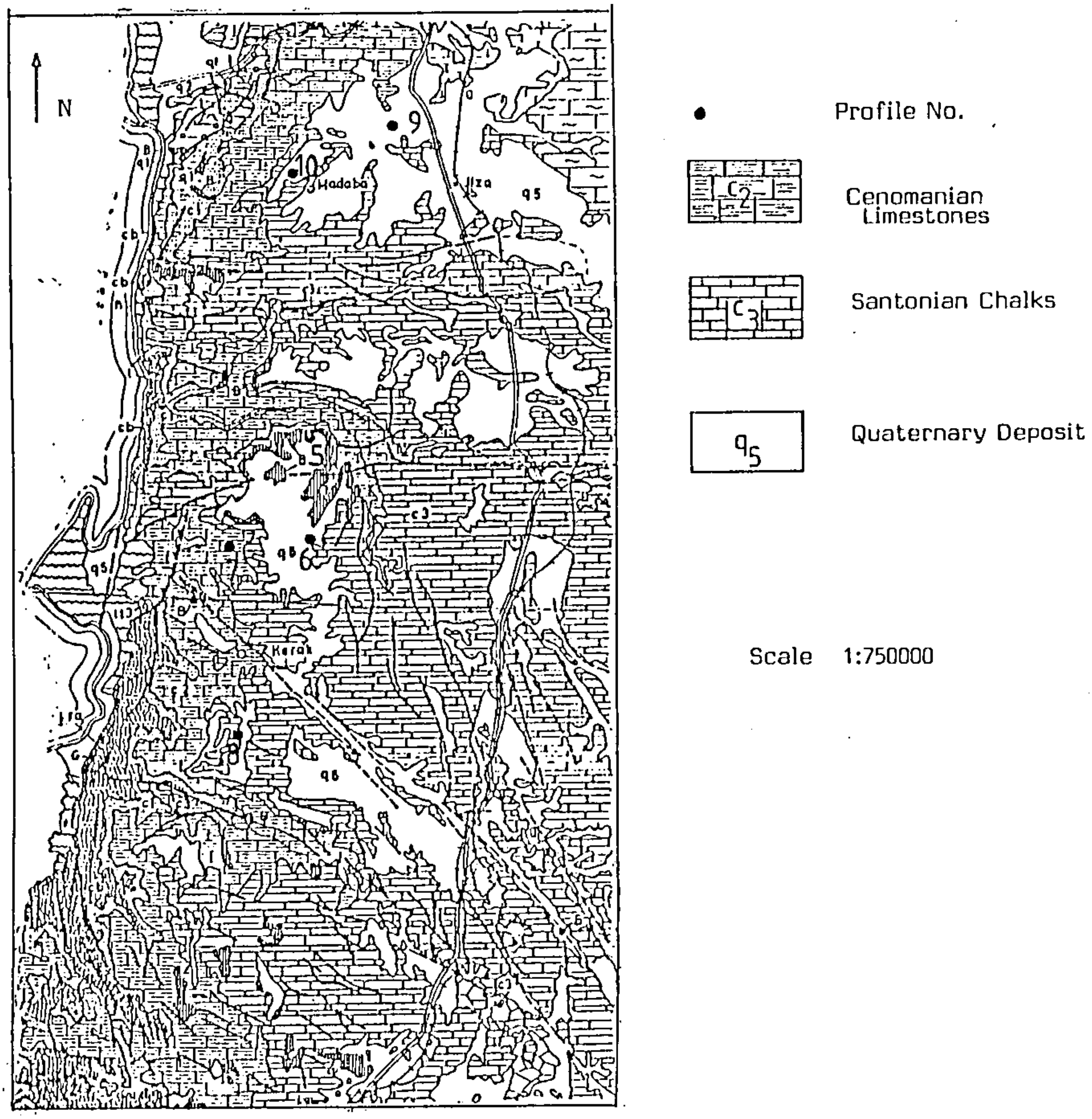


Fig. 3 - Geological Map Of Madaba And Kerak Areas
(Bendef 1975)

halepensis; or an oak forest with Quercus calliporinos; Quercus infectoria and Pistacia palestina, Quercus coccifera; Quercus aegilops; Arbutus andarachine ; Cistus villosus; Calycothome and Poterium spinosium. In the southern part of the study area (Madaba and Karak) the main forest vegetation was different; it may be either of Quercus aegilops ; and Pistacia atlantica. Among the semishrubs were Anabasia articulata and Seidlitzia rosmainifolia as typical types. Other shrubs include Zilla sponisa; and Asphdeline lutea(12).

3.3 Origin and formation of the study area landscape

The pressence of calcic horizon, or carbonate rich horizons associated with high clay content in deep soils indicated that the past climate was much cooler and more humid than the present climate. Jordan eastern plateau have been carved from marine chalks, a mixture of chalks with flint, and marls accompanied by subsidiary limestones. Gravels, sands, silts and muds of terrestrial, and sometimes lacustrine origin infill the depressions . The age is ranging from possible miocene through pliocene to certain Quaternary (12).

Each succesive opening and downward movement of the Jordan rift valley has lowered the base-level and rejuvenated the streams draining into the depressions. Thus it has permitted them to cut further eastward in the plateau capturing additional areas for the drainage basin of the rift (12).

Since soils are part of the landscape; and zero time of soil formation of the land surface. Thus all landscapes were constructional or erosional;or a combination of these two(34). Eoalian materials are significant to soil development (45).

3.4 Field investigation

3.41 Soil profile descriptions

3.411 Profile no. 1

General information

Location	: 500 m west of Ramtha circle.
Parent material	: Hard limestone / colluvium.
Climate	: 300 mm precipitation. The mean maximum temperature is 22.5°c and the minimum temperature is 10.4°c. Relative humidity is 57%. The evapotranspiration is 1700 mm /year.
Topography	: 1-2% concave-linear. Elevation is 590m.
Land use	: Wheat.
Cracks	: 5 cm wide, maximum depth 77 cm.
Slickensides	: First slickensides at 70 cm.
Color based on	: Moist samples.
Date of sampling	: August, 1985.
Classification	: Fine, Smectitic, Thermic, Vertic Xerochrepts.

Profile description

Hor.	Depth/cm	
Ap	0-22	Brown-dark brown (7.5YR4/4), silty clay loam, medium coarse subangular blocky + granular, hard-v.hard, friable, sticky, plastic, common fine roots, rounded (3cm) gravels, dense plough layer below this

		depth, abrupt boundary.
B21	22-70	Brown-dark brown (7.5YR4/4), silty clay loam, moderate coarse prismatic breaks to strong medium angular and subangular blocky, s.firm, extremely hard, sticky, plastic, few fine roots, the upper 20 cm is plough pan, massive-prismatic, clay coating on ped surface, gradual boundary.
B22	70-100	Brown-dark brown (7.5YR4/4), silty clay strong coarse prismatic that breaks to angular blocky, hard, friable, sticky, plastic, few-common fine roots, few-common medium carbonate concretions (hard in center), abundant clay and organic matter coating on ped surface, few slickensides, few limestone gravels (1cm), oblique and horizontal medium pores, clear boundary.
B23	100-132	Brown-dark brown (7.5YR4/4), silty clay strong coarse prismatic that breaks to subangular blocky, hard, friable, sticky, plastic, few fine roots, organic matter and clay coating, many medium carbonate concretions, roots grow on and inside ped surfaces, few

		gravels, abundant clay coating on prism surface, charcoal, oblique and horizontal fine - medium pores, shiny faces, gradual boundary.
B24	132-160	Brown-dark brown (7.5YR4/4), silty clay, moderate coarse subangular blocky, s.hard, friable, sticky, plastic, v.few fine roots, v.weak pressure faces, v.few (3cm) chert gravels , shiny faces, earthwarm cast, charcoal is present.

3.412 Profile No. 2

General information

Location : 200 m west of Jamha.

Parent material : Hard limestone, colluvium.

Climate : 500 mm precipitation. The mean maximum temperature is 19.8°c and the mean minimum temperature is 9.5°c. Relative humidity is 54%. The evapotranspiration is 1500 mm/ year.

Topography : 1%, linear. Elevation is 570m.

Land use : Fallow.

Cracks : Maximum depth 100 cm, not open in august because of self mulching.

Slickensides : First slickensides at 50 cm.

Color based on : Moist samples.

Date of sampling : August, 1985.

Classification : Very fine, Smectitic, Thermic, Typic pelloxererts.

Profile description

	Depth/cm	
Ap	0-20	Very dark grayish brown-dark brown, (10YR3/2.5) clay, moderate medium angular blocky, v.hard, friable, sticky, plastic, few-common fine roots, some small gravels, abrupt boundary.
B21	20-50	Black, (5YR2.5/1), clay, moderate coarse prismatic that breaks to moderate coarse angular and subangular blocky, extremely hard, s.firm, v.sticky, v.plastic, few fine -medium roots, pressure faces, v.small gravels, gradual wavy boundary.
B22	50-95	Black, (5YR2.5/1), clay, strong coarse angular blocky, parellelped structure, pressure faces, angular intersecting slickensides (150 cm^2), extremely hard, s.firm, v.sticky, v.plastic, few fine roots growing on ped surfaces, some gravels, diffuse wavy boundary.
B23	95-135	Black, (5YR2.5/1), clay, strong coarse angular blocky, parellelped structure, angular intersecting slickensides (150 cm^2), pressure faces, s.firm-firm, extremely hard, v. sticky, v.plstic, very few fine roots grow-

		ing on ped surfaces, few fine carbonate concretions diffuse boundary.
Cr	135+	Silicified hard limestone.

3.413 Profile No. 3

General information

Location : 200 m east of Kherja.

Parent material : Basalt associated with hard limestone, colluvium.

Topography : 2%, linear. Elevation is 455 m.

Land use : Wheat.

Climate : 450 mm precipitation. The mean maximum temperature is 22.4°c and the mean minimum temperature is 11.9°c. Relative humidity is 56%. The evapotranspiration is 1600 mm/year.

Cracks : 6-7 cm wide, 100 cm deep, still open in august.

Slickensides : First slickenside at 55 cm, parellelped structure below 55 cm.

Color based on : Moist samples.

Date of sampling : August, 1985.

Classification : Fine,Smectitic,Thermic,Typic Chromoxererts.

Profile description

Hor.	Depth/cm	
Ap	0-15	Brown to dark brown-dark yellowish brown,

		(7.5YR4/4) to (10YR4/4), clay, moderate medium granular and weak medium subangular blocky, s.hard to hard, friable, sticky, plastic, few common fine and medium roots, many small gravels, clear boundary.
B21	15-68	Dark reddish brown, (5YR3/3-3/2), clay, the top 20 cm is plough pan, moderate coarse prismatic that breaks to coarse moderate subangular blocky, extremely hard, s.firm, v.sticky, v.plastic, few to common fine roots, some earthwarm cast, few shiny surfaces, width of the cracks at the bottom is 1-2 cm, gradual boundary.
B22	68-105	Dark reddish brown to dark brown, (5YR3/2)-(7.5YR3/2), clay, very coarse strong angular blocky, parellelped structure is less pronunced than the underlying horizon, angular intersecting slickensides, few fine-medium roots, extremely hard, s.firm, v.sticky, v.plastic, diffuse boundary.
B23	105-155+	Very dark brown, (7.5YR3/2), clay, very coarse strong angular blocky, parellelped structure, angular intersecting slickens-

ides (150 cm^2), extremely hard, firm, v.sticky, v.plastic, very few fine to medium carbonate concretions, some coating inside pores, small rounded edge gravels are present charcoal are present.

3.414 Profile No. 4

General information

Location	: North of Maru station.
Parent material	: Basalt associated with limestone, colluvium.
Climate	: 400 mm precipitation. The mean maximum temperature is 22.0°c and the mean minimum temperature is 11.6°c. Relative humidity is 57%. The evapotranspiration is 1600 mm/ year.
Topography	: 1% linear flat. Elevation is 460 m.
Land use	: Wheat.
Cracks	: 6-7 cm wide, 90 cm deep.
Slickensides	: First slickenside at 50 cm, (400 cm^2).
Color based on	: Moist samples.
Date of sampling	: August, 1985.
Classification	: Fine,Smectitic,Thermic,Typic Chromoxererts.

Profile description

Hor.	Depth/cm	
Ap	0-15	Dark reddish brown, (5YR3/3), clay, weak medium granular + medium subangular blocky, hard, s.firm, sticky, plastic, few-common

		fine to medium roots, abrupt wavy boundary.
B21	15-60	Dark reddish brown,(5YR3/3), clay, moderate strong prismatic that breaks to coarse moderate subangular blocky and angular (massive inside), extremely hard, s.firm, sticky, plastic, few-common fine to medium roots, shiny faces, with some pressure faces, many limestone gravels, some shells, gradual wavy boundary.
B22	60-105	Dark reddish brown, (5YR3/2.5), clay, strong coarse angular blocky, parellelped structure, very few fine roots growing on ped surface, angular intersecting slickensides (400 cm^2), pressure faces, extremely hard, s.firm, v. sticky, v.plastic, very few fine carbonate concretions, charcoal and shells are present, round edge gravels are present, diffuse wavy boundary.
B23	105-160	Dark reddish brown, (5YR3/2.5), clay, strong coarse angular blocky, parellelped structure, angular intersecting slickensides, pressure faces, extremely hard,s.firm, v.sticky, v. plastic, very few fine roots growing on ped

		roots, some gravels, v.hard, friable, sticky, plastic, clear boundary
B21	30-80	Dark reddish brown, (5YR3/4), silty clay loam, strong coarse angular and subangular blocky, intersecting angular (50 cm^2) slickensides, v.few fine roots, v.hard, friable, sticky, plastic, very few fine secondary carbonate accumlation, black bodies, few gravels, gradual boundary.
B22	80-120	Dark reddish brown, (5YR3/4), silty clay loam, strong coarse angular blocky, parellel ped structure not very well pronunced as below, intersecting angular slickensides (100 cm^2) with pressure faces, extremely hard s.firm, sticky, plastic, very few fine roots, v.few fine carbonate secondary accumlation, few basalt and limestone gravels, gradual boundary.
B23	120-160	Dark reddish brown, (5YR3/4), silty clay loam, strong angular blocky, pressure faces, no slickensides, v.few fine roots, few fine -medium carbonate concretions, v.few weathered

ed basalt gravels, extremely hard, s.firm, sticky, plastic, charcoal is present.

3.416 Profile No. 6

General information

Location	: 150 m east of El-Qaser.
Parent material	: Basalt over limestone.
Climate	: 300 mm precipitation. The mean maximum temperature is 20.9°c and the mean minimum temperature is 10.3°c. Relative humidity is 61%. The evapotranspiration is 1800 mm/ year.
Topography	: 2-3% linear-concave. Elevation is 960 m.
Land use	: Summer, Surgham.
Cracks	: 3-6 cm wide, 130 cm deep, open in september.
Slickensides	: First slickenside at 45 cm.
Color based on	: Moist samples.
Classification	: Fine,Smectitic,Thermic,Entic Chromoxererts.

Profile description

Hor.	depth/cm.	
Ap	0-35	Reddish brown, (5YR4/4), silty clay loam, the top 7 cm is moderate medium granular, the rest is weak coarse subangular-massive (plough-pan), friable, hard, sticky, plastic, common few to medium roots, some small gravels, gradual boundary.

B21	35-70	Reddish brown, (5YR4/4), silty clay loam, strong angular blocky, parellelped structure, intersecting slickensides (100 cm^2), very hard, friable, sticky, plastic, common fine roots, few small limestone gravels, diffuse boundary.
B22	70-110	Dark reddish brown, (5YR3/4), silty clay loam, strong coarse angular blocky, parellelped structure, angular intersecting slickensides, very few fine carbonate concretions secondary accumlation, v.hard, s.firm, v.sticky, v.plastic, few to common fine roots, diffuse boundary.
B23	110-155	Dark reddish brown, (5YR3/4), silty clay loam, strong angular blocky, parellelped structure, very well pronunced pressure faces, angular intersecting slickensides, v.hard, s.firm, v.sticky, v.plastic, very few fine roots, few to medium carbonate concretions, small limestone gravels.

3.417 Profile No. 7

General information

Location	: Rabba, 100 m east of Kraim majaly olive orchard.
Parent material	: Limestone, colluvium.
Climate	: 300 mm precipitation. The mean maximum temperature is 21.0°c and the mean minimum temperatture is 10.3°c. Relative humidity is 61%. The evapotranspiration is 1800 mm/ year.
Topography	: 0-1% linear. Elevation is 920 m.
Land use	: Lentil.
Cracks	: 5-7 cm wide, 70 cm deep, very dense, open in september.
Slickensides	: First slickenside within 50 cm.
Color based on	: Moist samples.
Date of sampling	: September, 1985.
Classification	: Fine,Smectitic,Thermic,Entic Chromoxererts.

Profile description

Hor.	Depth/cm.	
Ap	0-20	Dark brown to reddish brown, (7.5YR4/4)-(5YR4/4), silty clay loam, medium moderate granular, self mulching, hard, friable, sticky, plastic, common medium roots, limestone gravels (3 cm long), abrupt boundary.

B21	20-60	Dark reddish brown, (5YR3/4), clay, very coarse angular blocky and subangular blocky to massive in some portion (plough pan), friable, extremely hard, v.sticky, v.plastic, many fine roots grown inside peds, very few fine carbonate concretions, width of open cracks is 4 cm, pressure faces, few shiny faces, black bodies, gradual boundary.
B22	60-110	Dark reddish brown, (5YR3/4), clay, strong coarse angular, parellelped structure, angular, intersecting slickensides (150 cm^2), pressure faces, v.few fine roots, black bodies, v.hard, friable, v.sticky, v.plastic, shells, very few small rounded limestone gravels, few fine carbonate concretions, diffuse boundary.
B23t	110-160	Dark reddish brown, (5YR3/4), silty clay loam, strong coarse angular blocky, parellelped structure, angular intersecing (150 cm^2), pressure faces, black bodies, very few fine roots, shells, v.hard, friable, v.stcky, v.plastic, few medium carbonate concretions, few small rounded -edge limestone gravels.

3.418 Profile No. 8

General information

Location : Majra.

Parent material : Limestone, colluvium.

Climate : 300 mm precipitation. The mean maximum temperature is 20.4°c and the mean minimum is 10.0°c. Relative humidity is 58%. The evapotranspiration is 1700 mm/year.

Topography : 2%, convex.

Land use : Wheat.

Cracks : 110 cm deep, 5-11 cm wide, still open in september.

Slickensides : First slickenside at 55 cm.

Color based on : Moist samples.

Date of sampling : September, 1985.

Classification : Fine, Smectitic, Thermic, Typic Chromoxererts.

Profile description

Hor.	Depth/cm.	
Ap	0-15	Dark reddish brown, (5YR3/4), silty clay loam, medium moderate granular, few coarse and common fine-medium roots, friable, hard, sticky, plastic, abrupt boundary.
B21	15-50	Dark reddish brown, (5YR3/4), silty clay loam, coarse moderate subangular blocky to

		massive, few-common fine and medium roots, friable-slightly firm, v.hard, sticky, plastic, many small limestone gravels, some shells, the top 25 cm is hard plough pan mostly massive, gradual boundary.
B22	50-110	Dark reddish brown, (5YR3/4), silty clay loam, strong coarse angular and subangular blocky parellelped structure, angular intersecting slickensides at 50 cm (100 cm^2), friable, to s.firm, extremely hard, v. sticky, v.plastic, few fine roots, many rounded edge limestone gravels, black bodies, gradual boundary.
B23t	110-150	Dark reddish brown, (5YR3/4), clay, strong coarse angular blocky, parellelped structure, angular intersecting slickensides, few to common fine carbonate concretions, very few fine roots, oxide coating, extremely hard, s.firm, v.plastic, v.sticky, black bodies are present.

3.419 Profile No. 9

General information

Location	: 500 m west of Mshager station, Madaba.
Parent material	: Limestone associated with chert, colluvium.
Climate	: 370 mm precipitation. The mean maximum temperature is 21.7°c and the mean minimum temperature is 9.7°c. Relative humidity is 62%. The evapotranspiration is 1400 mm/year.
Topography	: 1-2% linear-concave. Elevation is 785 m.
Land use	: Wheat.
Cracks	: 5-7 cm wide, 90 cm deep, open below the surface 4 cm.
Slickensides	: First slickenside at 55 cm.
Color based on	: Moist samples.
Date of sampling	: September, 1985.
Classification	: very fine, Smectitic, Thermic, Typic Chromoxererts.

Profile description

Hor.	Depth/cm.	
Ap	0-20	Dark reddish brown-dark brown (5YR3/4)-(7.5YR4/4), clay, the top 3 cm is self mulch, the rest is moderate coarse subangular blocky and granular to massive, friable, v.hard, sticky, plastic, many fine and medium roots, many hard limestone and chert (4 cm), clear boundary.

B21	20-60	Dark reddish brown, (5YR3/4), silty clay loam, coarse moderate subangular to massive, v.hard, friable-s.firm, sticky, plastic, few to common fine roots, rounded edge limestone gravels, the top 3 cm of this horizon is plough pan, gradual boundary.
B22	60-120	Dark reddish brown, (5YR3/4), silty clay loam, strong coarse angular blocky, parellelped structure, angular slickensides (100-cm^2), pressure faces, v.hard, firm, v.sticky, v.plastic, limestone gravels, few to common fine roots, diffuse boundary.
IIB23	120-160	Dark reddish brown, (5YR3/4), clay, strong coarse angular blocky, parellelped structure , angular intersecting slickensides (100-150cm^2), pressure faces, common to medium carbonate concretions, black bodies, charcoal, v.hard, firm, v.sticky, v.plastic, small limestone gravels.

3.4110 Profile No. 10

General information

Location : 2 Km west of Madaba, 20 m south of the main road to Nebo Mountain.

Parent Material : Hard limestone associated with chert, colluvium.

Climate : 300 mm precipitation, The mean maximum temperature is 22.0°c and the mean minimum temperature is 10.0°c. Relative humidity is 62%. The evapotranspiration is 1400 mm /year.

Topography : 1% convex-linear. Elevation is 795 m.

Land use : Annual crops.

Cracks : Very dense cracking pattern, 5-7 cm wide and 160 cm deep, open 2 cm at 140 cm.

Slickensides : First slickenside at 60 cm, parellelped structure in B21 but not very well pronunced.

Date of sampling : September, 1985.

Color based on : Moist samples.

Classification : Very, Fine, Smectitic, Thermic, Typic Chromoxererts.

Profile description

Hor.	Depth/cm.	
Ap	0-25	Dark reddish brown, (5YR3/4), clay, moderate medium subangular blocky, common fine and medium subangular blocky, common

		fine and medium roots, hard, friable, sticky, plastic, few chert gravels, gradual boundary.
B21	25-90	Dark reddish brown, (5YR3/3), clay, very strong coarse prismatic that breaks to strong coarse angular and subangular blocky, extremely hard, s.firm, v. sticky, v.plastic, common fine and medium roots, v.few fine secondary carbonate accumlation, parellelped structure, slickenside at 60 cm , slightly angular but not very well expressed, clay coating, shiny faces, some pressure faces, few chert gravels, diffuse boundary.
B22	90-130	Dark reddish brown, (5YR3/3), clay, strong coarse prismatic break to coarse angular blocky, few horizontal slickenside, extremely hard, s.firm, v.sticky, v.plastic, few-common medium distinct secondary carbonate accumlation, few-common fine roots, organic matter, oxide and clay coating, pressure and shiny faces on the prism sides, some shells, clear boundary.

Profile description

Hor.	Depth/cm	
Ap	0-40	Dark reddish brown (5YR3/4), clay, medium coarse subangular blocky + granular, v.hard, s.firm-firm, sticky, plastic, few small rounded edge gravels, many fine to medium roots, gradual boundary.
B21	40-100	Reddish brown (5YR4/4), clay, strong coarse prismatic that breaks to strong medium angular blocky, parellelped structure, angular intersecting slickensides, extremely hard, firm, v.sticky, v.plastic, common fine roots, very few small rounded gravels, organic matter coating , pressure faces, few fine secondary car ate accumlation, diffuse boundary.
IIB22	100-170	Reddish brown (5YR4/4), clay, strong coarse prismatic that breaks to strong medium subangular blocky,parellelped structure, angular intersecting slickensides, extremely hard, firm, v.sticky, v.plstic, pressure faces, organic matter and oxides coating, few fine roots, few medium carbonate concretions, diffuse boundary.

IIB23	170-210	Red-dark red (2.5YR4/6-3/6), clay, strong coarse angular blocky, very well pronunced parellelped structure, angular slickensides, few to common coarse carbonate concretions, extremely hard, v.firm, v.sticky, v.plastic, oxides coating the slickensides, the gravels and inside the root channels,clear boundary.
IIIB24ca	210-270	Red-dark red (2.5YR4/6-3/6), clay, strong coarse angular blocky, very well pronunced parellelped structure, angular intersecting slickensides, abundant coarse distinct secondary carbonate accumlation and cemented concretions, oxides coating the slickensides and inside the carbonate concretions, extremely hard, v.firm, v.sticky, v.plastic, clear boundary.
IIIB25ca	270-350	Dark red (2.5YR3/6), clay, strong coarse angular blocky, parellelped structure, slickensides all over the faces, oxides coting, extremely hard, v.firm, v.sticky, v. plastic, abundant coarse calcium carbonate concretions.

3.5 Methods

3.51 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.

3.52 Physical measurements

3.521 Particle-size distribution

Natural unground samples were soaked in 0.5N sodium acetate pH 5 to remove carbonates (16).

Organic matter was then removed by heating the soil sample with 31% H_2O_2. Sodium hexametaphosphate 6% was added and overnight shaking followed by sonic vibration which was used to maintain maximum dispersion. The clay fraction was measured by the pipette method (16). Sand fractions were seperated by standard sieves.

3.522 Bulk-density

Bulk density was determined on natural clods by saran resin method (8).

3.53 Chemical determinations

3.531 Organic carbon

Organic carbon was determined by the potassium dichromate method (35).

3.532 Soil-pH

Soil pH was determined in 1:1 soil to water ratio (6).

3.533 Soluble salts

Soluble salts were determined by measuring the electrical conductivity in 1:2.5 soil to water extract (6).

3.534 Extractable cations

Extractable Ca, Mg, K, and Na, were obtained by extracting soil with 1 N NH4OAC pH 7. Extractable sodium and potassium were measured by flamephotometer. Extractable calcium and magnesium were determined by the versenate titration method (13).

3.535 Cation exchange capacity

Cation exchange capacity for soil and carbonate free clay was by Bower method (7).

3.536 Free iron oxides

Free iron oxides for total soils and clay was extracted using sodium citrate 0.3 M according to Mehra and Jackson method (30). Extracted iron was measured by the ortho-phenanthroline colorimetric method (24).

3.537 Carbonates

Carbonates in sand, silt, and clay fractions were determined by acid neutralization. Silt and clay were collected by sedimentation. Sand fractions were collected by using standard sieves (33).

3.54 Mineralogical examination

X-Ray diffraction

Carbonate and iron oxide free clay was prepared before X-ray analysis. The X-ray diffraction curves were obtained for the following treatements;

1- Magnesium saturation,

2- Magnesium saturation + Ethyleneglycol.,

3- Potassium saturation,

4- Potassium saturation + heating for 4 hours at 550°C.

The treatements for silt included magnesium and glycolation only. Philips X-ray diffraction apparatus, model PWII30/90 was used in the X-ray analysis (24).

3.55 Statistical Analysis

Statistical analyses was carried out for all the studied physical and chemical properties. The analyses was done for the following attributes;

1. Surface and subsurface horizons,
2. Parent material type, and
3. Amounts of annual rainfall.

Raw data are shown in Appendix C, and the coefficent of variation was calculated (by dividing the mean by the standard deviation as percent) and it was used to test the homogenity of soil attributes.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Soil pH

pH values increased gradually with depth for Ramtha soil, (parent material is limestone, rainfall is 300mm) Similar pattern was observed for Qaser soil,(parent material is basalt, rainfall is 300mm), Majra soil (parent material is limestone, rainfall is 300mm), Mshgaer soil (parent material is limestone, rainfall is 370mm), Madaba soil (parent material is limestone, rainfall is 300mm), and Shihan soil (parent material is basalt, rainfall is 250mm), except that shihan soil pH values were slightly higher. The increase in pH with depth was also associated with increase in carbonates for all these soils (Tables 1,2, and 3).

pH values for Jamha soil followed the same pattern presented above except that pH values were lower because of higher rainfall and lower carbonates (parent material is limestone, rainfall is 500mm).

The pH values for Kherja and Maru soils which developed from basalt and recieve 450 mm and 400 mm precipitation, respectively, were uniform throughout the soil profile.

pH values for Baq'a soil (parent material is limestone, rainfall is 350 mm) increased with depth to 100 cm, afterwhich it remained uniform. The carbonates decreased with depth and pH values could not be correlated with carbonates content. This might be due to the increase in sodium content which was seven folds higher in the subsurface compared to that at the surface (Table 3).

The above results suggested that pH values were much related to carbonates regardless of the parent material type. pH values were affected by precipitation, and decreased as rainfall increased.

Overall variation for pH values was very low, where C.V. was 1.9. Mean value for surface (7.8) was slightly lower than that for the subsurface (8.0). Variation in pH for surface horizon was lower than for subsurface, where C.V values were 1.6, and 1.9 respectively.

Variation in pH for soils developed on basalt or limestone was very low, C.V. values were 2.2, and 1.4 respectively. Mean pH value was lower for soils developed in high rainfall zone, regardles of the parent material (Table 29).

The coefficent of variation values suggested higher pH variation for soils which recieved 400-500 mm precipitation (C.v= 16.6) compared to the other soils recieving less amounts.

4.2 Carbonate

Total carbonates in Jamha soil was uniformly distributed throughout the soil. Carbonate associated with clay fraction increased with increasing depth indicating carbonate leaching (fig. 4A).

Carbonate associated with silt fraction increased towards the surface, suggesting accumulation on the surface. Carbonate in sand fraction was uniformly distributed within the soil profile. This might be due to churning process which seemed to be active in this soil (Table 1).

Rabba and Majra soils followed the same pattern, except that carbonate content was highest in areas with low rainfall and lowest in areas with high rainfall (Table 2). The pressence of carbonate concretions in the subsurface horizons of the above mentioned soils indicated that leaching process was high probably because of more humid climate prevailing during past time (figs. 4B and 4C).

Total carbonate in Kherja soil was uniformly distributed. Carbonate associated with clay fraction increased with depth. This variation indicated carbonate leaching within this solum (Table 1). Carbonate associated with silt fraction increased towards the the soil surface which indicated silt accretion on the surface. Carbonate associated with silt fraction increased towards the distributed throughout the soil profile. Carbonate associated with fine sand increased with depth. This might be due to carbonate concretions pressence, and to leaching process showing the depth of vertical water movement (fig. 5a).

Maru and Shihan soil exhibited similar pattern, except that Shihan soil had higher carbonate content because of lower precipitation (Tables 2 and 3).

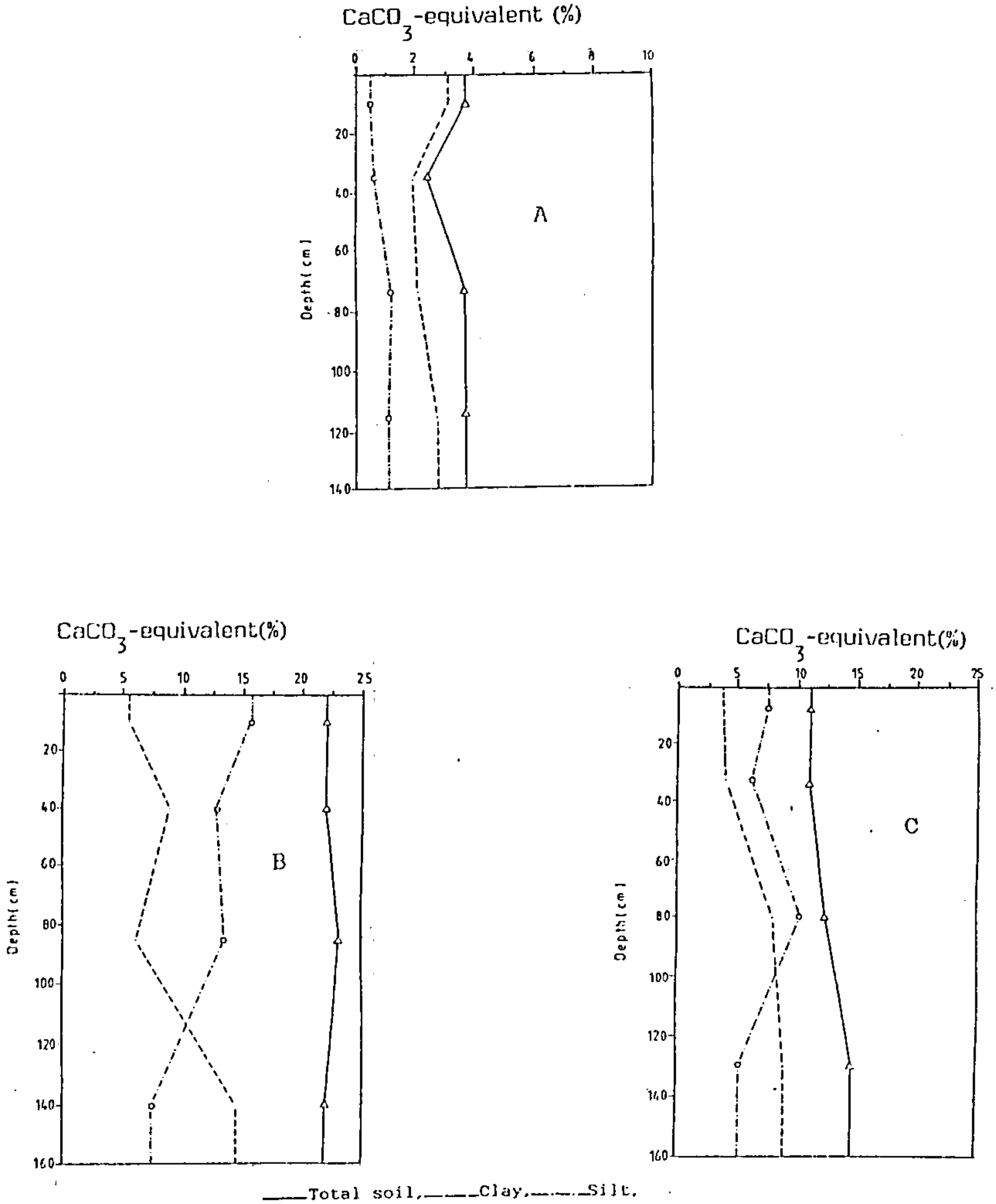


Fig.4- Calcium Carbonate-equivalent distribution in different soil fractions-depth for limestone derived soils.

Total carbonate for Baq'a soil decreased with depth. Carbonate in clay fraction increased with depth in the upper 100 cm, below

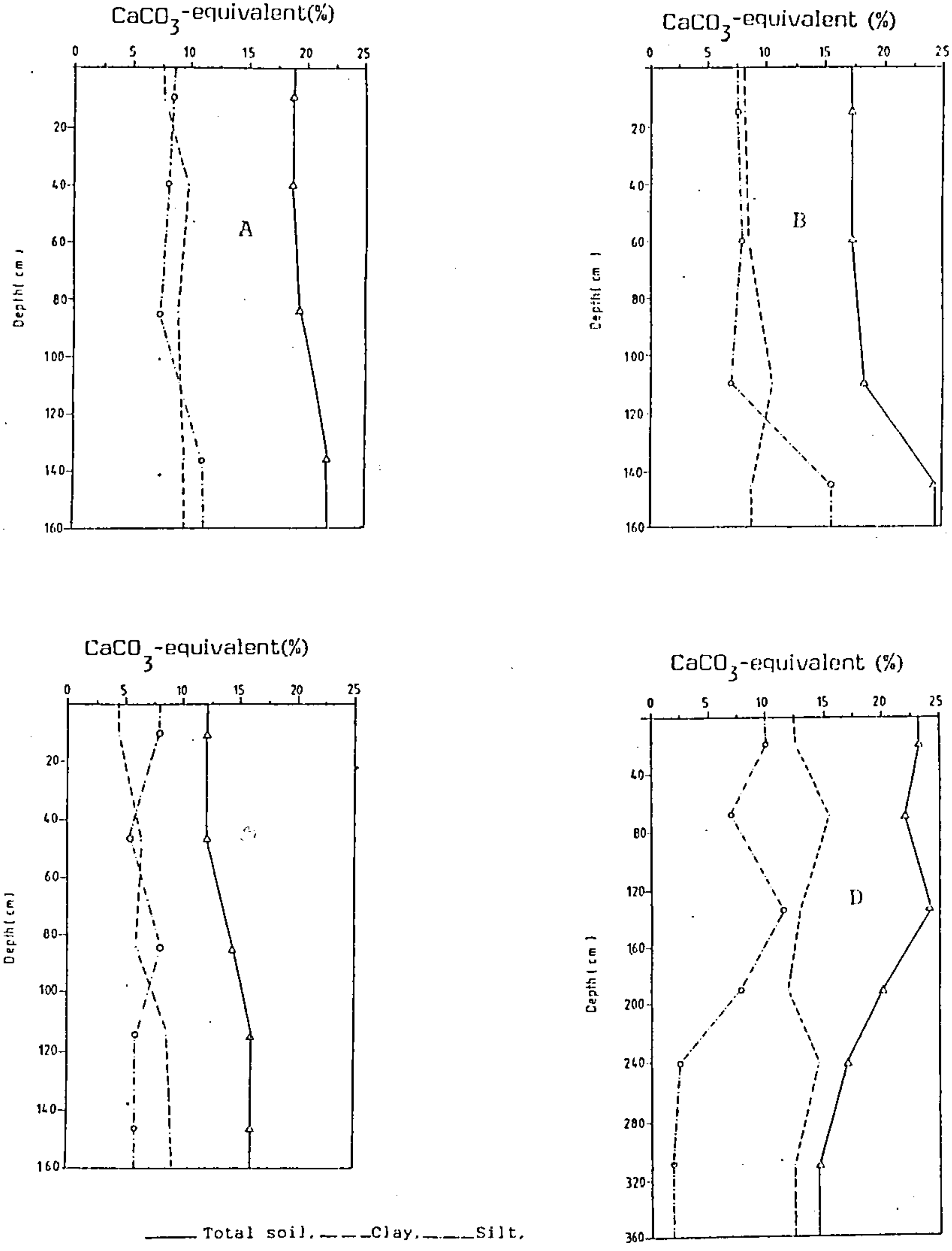


Fig. 6- Calcium Carbonate-equivalent distribution in different soil fractions-depth for limestone derived soils.

which it remained uniform down to the bottom of the soil profile Particle size distribution suggested lithological discontinuity in this zone. Carbonate associated with silt increased towards the surface (fig.6d). Carbonate in sand fractions were uniformly distributed. The carbonate distribution suggested that this soil profile could be divided into three sections (Table 3).

The above results suggested that limestone derived soils have more carbonate than basalt derived soils. This might be due to higher calcium carbonate in limestone soils. Carbonate was found to be affected by precipitation, where it increased as rainfall decreased. Mshager and Baq'a soils which recieve higher rainfall than other soils had higher carbonates. This could be attributed to the high clay content in these soils which retard leaching intensity.

Overall variation in carbonate content for total soil, clay, silt, and sand fractions was high. The coefficent of variation values were 45.8, 53.7, 61.3, and 59.9 respectively.

Carbonate mean vlaues in sand fraction were the same for surface and subsurface horizons. While for silt, surface horizons mean (8.1) was higher than for subsurface (7.0).

Mean total carbonate (14.9) was higher for subsurface than for surface horizons (14.4). Mean value for carbonate in clay was higher for subsurface (7.3) than for the surface (5.7).

The coefficent of variation values suggested high variation in carbonate for total soil, clay, silt, and sand fractions at surface and subsurface horizons (Tables 28 and 29).

Mean carbonate value for sand fraction were the same for basalt and limestone soils. While, for silt, clay, and total soil, they were higher for soils developed on limestone than for those developed on basalt.

Mean carbonates value for total soil in soils recieving 350-400 mm, was higher than for those recieving less or higher precipitation. Silt and clay exhibited similar pattern. Carates mean vlaue for sand fraction for soils recieving 250-350 mm was higher than that for soils recieving higher amounts of rainfall. The coefficent of variation values suggested high variation in carbonates for total soil, clay, silt, and sand fractions for soils recieving different amounts of rainfall (Tables 28 and 29).

4.3 Soil organic matter

Tables 4,5,6,7,8, and 9 shows the distribution of organic matter in all studied soils. The organic matter content reached it's maximum value at the surface horizon. The organic matter content for all soils exhibited a gradual change between A and B horizons.

Kherja and Baq'a soils organic matter content exceeded one percent for the surface horizon which meet the requirment of the mollic epipedon. But due to the lack of dark layer thickness, or soft consistency, none of these qualify to have a mollic epipedon.

The organic matter was found to be similar in soils regardless of the parent material. The most clearly related factor was rainfall where organic matter increased as rainfall increased. Overall variation in organic matter was high (C.V=50.2).

Mean value for organic matter at the surface horizons (0.7) was higher than that at the subsurface (0.3). Coefficent of variation for the surface (35.8) was lower than for the subsurface (41.2). C.V. values suggested slightly higher organic matter variation in soils developed on basalt (C.V=51.9) than soils developed on limestone (C.V=48.2). Mean value for basalt derived soils (0.5) was slightly higher than for those derived from limestone (0.4). Variation in organic matter content was higher for soils recieving 400-500mm (0.6) than for those recieving 350-400 mm (0.4). Coefficent of variation for soils recieving 350-400 mm (C.V=71.2) was higher than for other soils (Table 26).

4.4 Extractable cations

Calcium

Calcium was the most dominant extractable cation followed by magnesium, sodium, and potassium (Tables ,5,6,7,8, and 9). The extractable calcium in all soils showed accumulation on on the soil surface and decreased slightly with depth. Calcium constiutes the dominant exchangeable cation in the calcareous soils (2).

Extractable calcium increased as precipitation increased. This was obvious in Jamha soil, Kherja soil, and Maru soil which had the highest extractable calcium.

Extractable calcium was found to be higher for limestone derived soils than that for basalt derived soils. This could be attributed to more calcium carbonate in the parent material of the limestone derived soils.

Extractable calcium overall variation was very low (C.V=6.8). Mean value of extractable calcium at the surface horizons (47.7) was higher than that for the subsurface horizons (46.6). Overall variation in extractable calcium was very low at the surface and subsurface horizons (Table 30).

Mean extractable calcium was higher in soils developed on basalt (48.8) than those developed on limestone (45.9). Variation in extractable calcium was higher in soils developed on either basalt or limestone where C.V. values were 4.9, and 7.9 respectively (Table 30).

Mean value of extractable calcium was higher for soils recieving higher rainfall regardless of the parent material. Variation was low for soils recieving 400-500mm (C.V=7.8) and very low for soils recieving 350-400 mm (C.V=0.8) and low for soils recieving 250-350 mm.

Magnesium

Magnesium constitutes the dominant exchange cation in the basalt derived soils. The levels of exchangeable magnesium reflects the effect of rainfall, being higher for those developed in drier climate (2).

Magnesium distribution was uniform for most of the studied soils. Slight difference however was found between surface and subsurface horizons (Tables 4,5,6,7,8 and 9).

Mshager and Madaba soils had higher amounts of extractable magnesium than that for Qaser and Shihan soils. This might be due to higher rainfall especially in Mshager soil.

Extractable magnesium was found to be related to amount of rainfall. It was obvious that as rainfall increases magnesium decreases. But in Baq'a soil extractable magnesium was higher than for other soils recieving more rainfall. This could be attributed to the high clay content in this soil which decreased leaching intensity.

Overall variation in extractable magnesium was medium (C.V=22.7). Mean value for surface horizons (8.7) was close to that of the subsurface horizons (8.9). Coefficents of variation were 27.4 and 21.5 for surface and subsurface respectively, (Table 30). Mean extractable magnesium for soils developed on basalt (9.2) was higher than for those developed on limestone (8.7). Variation in soils extractable magnesium for basalt soils (27.5) was higher than for limestone soils (17.9). Mean extractable magnesium was found to be higher for soils recieving 350-400 mm precipitation.

The coefficent of variation values suggested higher extractable magnesium variation for soils recieving 400-500 mm (C.V.%=29.4), than for those recieving 350-400 mm (C.V=11.2) and soils recieving 250-350 mm (C.V.%=18.2).

Sodium

Extractable sodium increased with depth in all the studied soils. The accumulation of sodium in the subsurface horizons correlates with the pH values.

The analysis indicated that sodium was related to rainfall regardless of the parent material and it decreased as rainfall increased.

Mshager and Baq,a soils which recieve high precipitation, should have low amounts of extractable sodium, but sodium was found to be higher than in other soils with lower amounts of rainfall. This could be attributed to the high clay content of these soils which restrict leaching process.

Overall variation in extractable sodium was very high (C.V%=97.1). Mean value for surface horizons (0.5) was lower than that for the subsurface horizons was higher (86.2) than for the surface horizons (33.4). Variation in extractable sodium for limestone soils was higher (106.1) than that for basalt soils. Mean extractable sodium value for soils developed on basalt (1.2) was slightly less than those developed on limestone (1.5).

Mean extractable sodium for soils recieving 350-400 mm (2.8) was higher than that for those recieving 400-500 mm and 250-350 mm (Table 31).

The coefficent of variation values suggested higher variation in extractable sodium for soils recieving 350-400 mm (C.V%=79.2), than for those recieving 400-500 mm (C.V%=64.0) and those recieving 250-350 mm (C.V%=60.0).

Potassium

Extractable potassium behaved oppositely to extractable sodium, where surface horizons had higher extractable potassium. The increase in extractable potassium on the surface horizons could be related to the pressence of illite minerals which are abundant in the silt fraction reflecting the dominance of rather aridic conditions.

Extractable potassium was found to be affected by amounts of rainfall, regardless of the parent material, where it increased as rainfall decreased.

Mshager and Baq'a soil recieve higher precipitation than other soils. Although extractable potassium was higher in these soils than in other soils recieving less amounts of rainfall. This was attributed to the high clay content in these soils where leaching intensity was very low.

Overall variation of extractable potassium was very high (C.V %=84.3). Mean extractable potassium was higher in the surface horizons (1.3) than that at the subsurface (0.6). while variation was higher at the surface (C.V%=38.2). Mean extractable potassium for soils developed on basalt (0.2) was almost similar to that for soils developed on limestone(0.3). Variation in extractable potassium for soils developed on limestone was higher (C.V%=74.0) than for soils developed on basalt (C.V%=51.8). Mean extractable potassium for soils recieving 350-400 mm (1.1) was higher than that for soils recieving 400-500 mm (0.5), and soils recieving 250-350 mm (0.7). Variation was higher for soils recieving 350-400 mm than other soils (Table 30).

4.5 Electrical conductivity

Electrical conductivity values showed that the highest value was 0.64 mmhos/cm in Baq'a soil. The average electrical coductivity of the other soils was 0.22 mmhos/cm indicating that these soils are not saline.

The analysis indicated that the electrical conductivity values increased with depth suggesting leaching pattern within these soils. This could refer to an ancient humid climate (Tables 4, 5,6,7,8 and 9). Electrical conductivity was affected by amounts of precipitation regardless of the parent material.

Overall variation in electrical conductivity was high (C.V%= 44.9). Mean value for surface horizons (0.21) was slightly lower than that for the subsurface horizons (0.24). Variation for subsurface horizons was higher (C.V%=45.6) than for surface horizons (C.V%=41.0).

Mean value for soils developed on limestone was slightly higher than that for soils developed on basalt (Table 31).

Variation in electrical conductivity for soils developed on basalt (C.V%=52.9) was higher than that for soils developed on limestone (C.V%=14.8).

Mean value for soils recieving 350-400 mm (0.35) was higher than that for soils recieving 400-500 mm (0.22), and those recieving 250-350 mm (0.19). This could be due to high clay content in soils recieving 350-400 mm.

The coefficent of variation values suggested higher variation for soils recieving 350-400 mm (C.V%=49.9) than for those recieving 400-500 mm (C.V%=11.9) and those recieving 250=350 mm (C.V%=20.1).

4.6 Free iron oxides

Free iron oxides in Ramtha soil decreased with depth to 70 cm depth, and remained uniform afterwards. The free iron oxides associated with clay decreased slightly with depth to the depth of 100 cm, afterwhich it increased (Table 4).

The above mentioned indicated that most of the weathering occured at the surface horizons.

The free iron oxides in Jamha soil were uniformly distributed throughout the soil profile (Table 4). The same pattern was observed in Maru, Shihan,Mshager,Baq'a,and Qaser soils (Tables 5,6,7,8, and 9).

Free iron oxides for total soil and for clay for Kherja decreased with depth. This suggest that weathering is restricted to the surface (Table 5).

Total free iron oxides for Rabba and Majra was uniformly distributed within these soil profiles, while free iron oxides in the clay fraction in these soils decreased with depth (Table 7). Total free iron oxides for Madaba was uniformly distributed down to the depth of 130 cm, and decreased afterwards.

Free iron oxides in the clay fraction decreased with depth. The highest content was at the surface horizon Ap and at B23 horizon which coincided with the lithological discontinuity suggested by the particle size distribution (Table 8).

The results suggested that free iron oxides for soils developed on limestone was similar to that for soils developed on basalt, except for Baq'a soil which exhibited very high free iron oxide content (Table 9).

Free iron oxides correlate to certain extent with precipitation, where free iron increased with precipitation. The high free iron content on the surface horizons for most of the studied soils suggested that weathering was restricted to the surface. Overall variation for total soil (C.V%=20.0) and in clay fraction (C.V%=19.8) was medium.

Mean value for total soil at the surface and the subsurface horizons was the same. But, for clay fraction surface horizons mean (5.0) was higher than that for the subsurface (4.5). Overall variation for total soil and clay fraction at surface and subsurface horizons was medium (Table 26).

Mean value for total soil for soils developed on limestone(2.9) was higher than that for those developed on basalt (2.4), while mean values for clay fraction for soils which developed on basalt or limestone was similar for all soils regardless of the parent material.

Overall variation in free iron oxides for total soil and for clay fraction for all studied soils was medium.

Variation of total iron oxide was high for soil recieving 350-400 mm, while soil recieving 400-500 mm exhibited higher variation in the oxides of clay fraction (Table 26).

4.7 Cation exchange capacity

The total soil cation exchange capacity in Ramtha soil decreased slightly with depth. This could be due to the effect of the organic matter. The cation exchange capacity for clay showed different values between horizons. Clay of B21 had the highest (CEC) value, and B23 the lowest (Table 4).

This variation might be due to different amounts of dominant clay minerals, which resulted from illuviation. Fine clay exhibited higher CEC due to its higher negative charge.

Similar pattern in cation exchange capacity distribution was found in Kherja, Rabba, Majra, Mshager, and Madaba soils(Tables 5,7, and 8).

The cation exchange capacity in Jamha soil was uniformly distributed for total soil. Cation exchange capacity for clay indicated significant difference between horizons suggesting different dominant clay minerals (Table 4).

The soils of Maru, Shihan, Qaser, and Baq'a exhibited in cation exchange capacity for total soil and for clay as in Jamha soil (Tables 4,5,6,7,8 and 9).

(CEC) was found to be higher for soils developed on basalt than for those developed on limestone. This probably because smectite was the dominant clay mineral in basalt derived soils, while interstratified minerals dominated limestone derived soils (see mineralogy of clay and silt fractions).

Cation exchange capacity increased as rainfall increased, being highest for Jamha, Kherja and Maru soils.

Overall variation in cation exchange capacity for total soil was medium (C.V%=15.3). Mean (CEC) value for surface horizons (46.7) was higher than for the subsurface horizons (43.9). Variation was medium where C.V% was (13.6) for surface horizons and (16.0) for subsurface horizons.

Mean (CEC) value for basalt derived soils (48.3) was higher than those of limestone derived soils (42.6). Overall variation for basalt soils (C.V%=15.4) was slightly higher than for limestone soils (C.V%=13.7).

Variation for soils recieving 250-350 mm (C.V%=8.0) was higher than for soils recieving 400-500 mm, and 350-400 mm (Table 25). The statistical analysis for (CEC) of the clay fraction was similar to that for total soil.

4.8 Particle size distribution

Carbonate-free clay content in Jamha soil increased with depth. The difference between surface and subsurface did not meet the requirment of an argillic horizon. Illuviation process was possible in this profile. Clay content with carbonate followed the same pattern suggesting carbonate leaching. Silt with and without carbonate and very fine sand with carbonate and carbonate free increased towards the soil surface possibly due to aeolian activity (fig. 7a).

Sand fractions with and without carbonate showed a uniform distribution with depth. The recalculated particle size distribution on clay free basis suggested no lithological

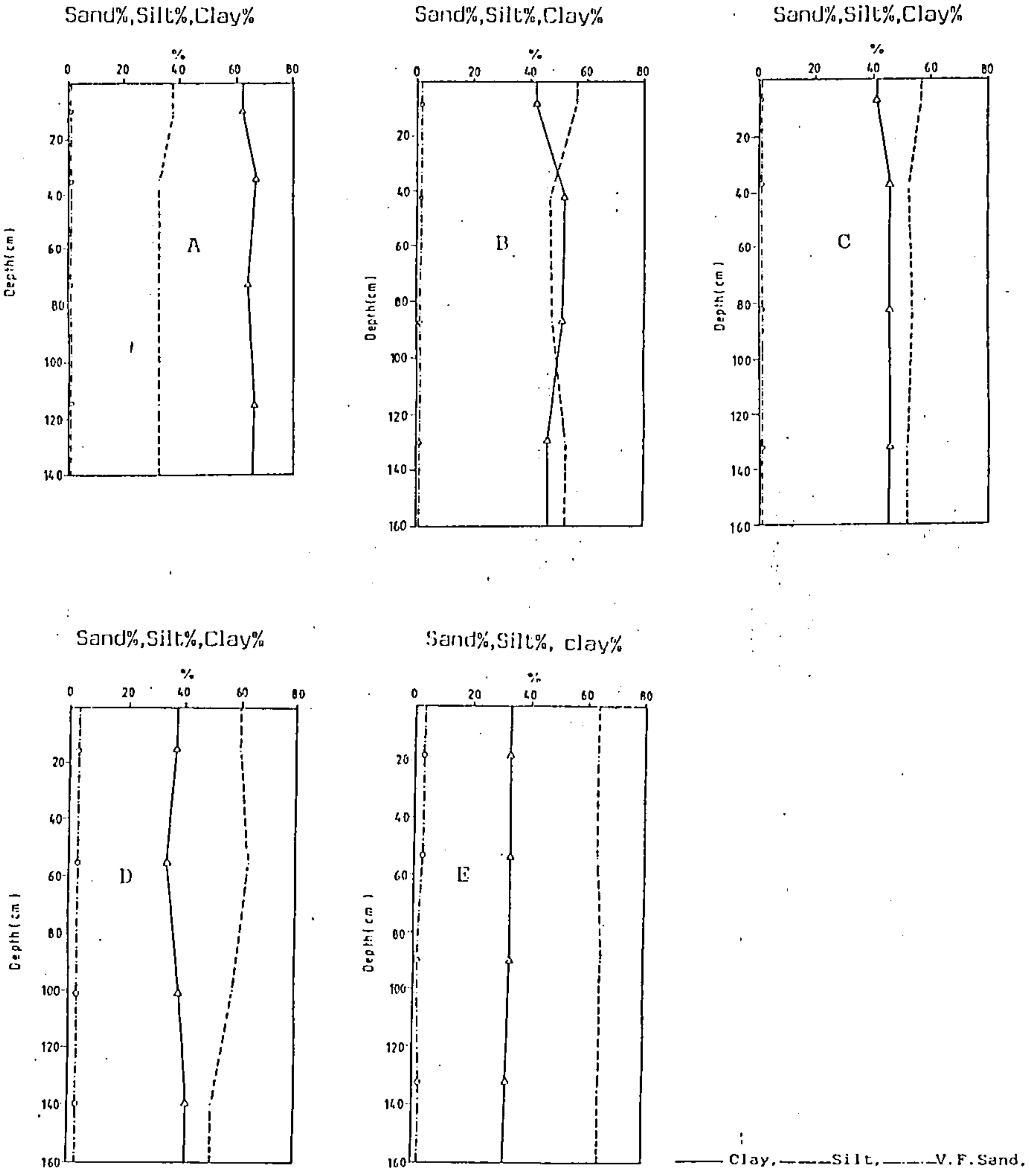


Fig. 7- Particle Size-depth distribution without carbonate for Jamha and basalt derived soils.

uniformly distributed throughout the soil profile (Table 16). The particle size distribution recalculated on clay free basis suggested no lithological discontinuity.

Clay content with and without carbonate for Mshager and Madaba soils increased with depth to B22 horizon ,where it decreased afterwards. This suggested that illuviation and carbonate leaching occured in the upper zone. Silt content without carbonate increased towards the surface, but at B23 horizon it increased and exceeded that of the surface. Sand fractions with and without carbonate were uniformly distributed throughout the soil profile (fig.s 8C and 8D, tables 18 and 19). The particle size distribution recalculated on clay free basis showed lithological discontinuity at the depth of 110 cm. for Mshager and at the depth of 130 cm for Madaba.

The distribution of different soil particles for Ramtha was similar to that of Mshager, except the absence of lithological discontinuity in Ramtha (fig. 8E, table 10).

Clay and silt content with and without carbonate for Baq'a was uniformly distributed in the upper 100 cm, afterwhich it decreased and remained uniform to the depth of 210 cm. Below this depth, clay increased and remained uniform to the depth of 350 cm. This suggested that this soil can be divided into three zones where clay content was uniformly distributed in each section (fig. 8F). Sand fractions was uniformly distributed throughout the soil profile (Table 20).

The particle size distribution recalculated on clay free basis indicated lithological discontinuity at the depths of 100 and 210 cm.

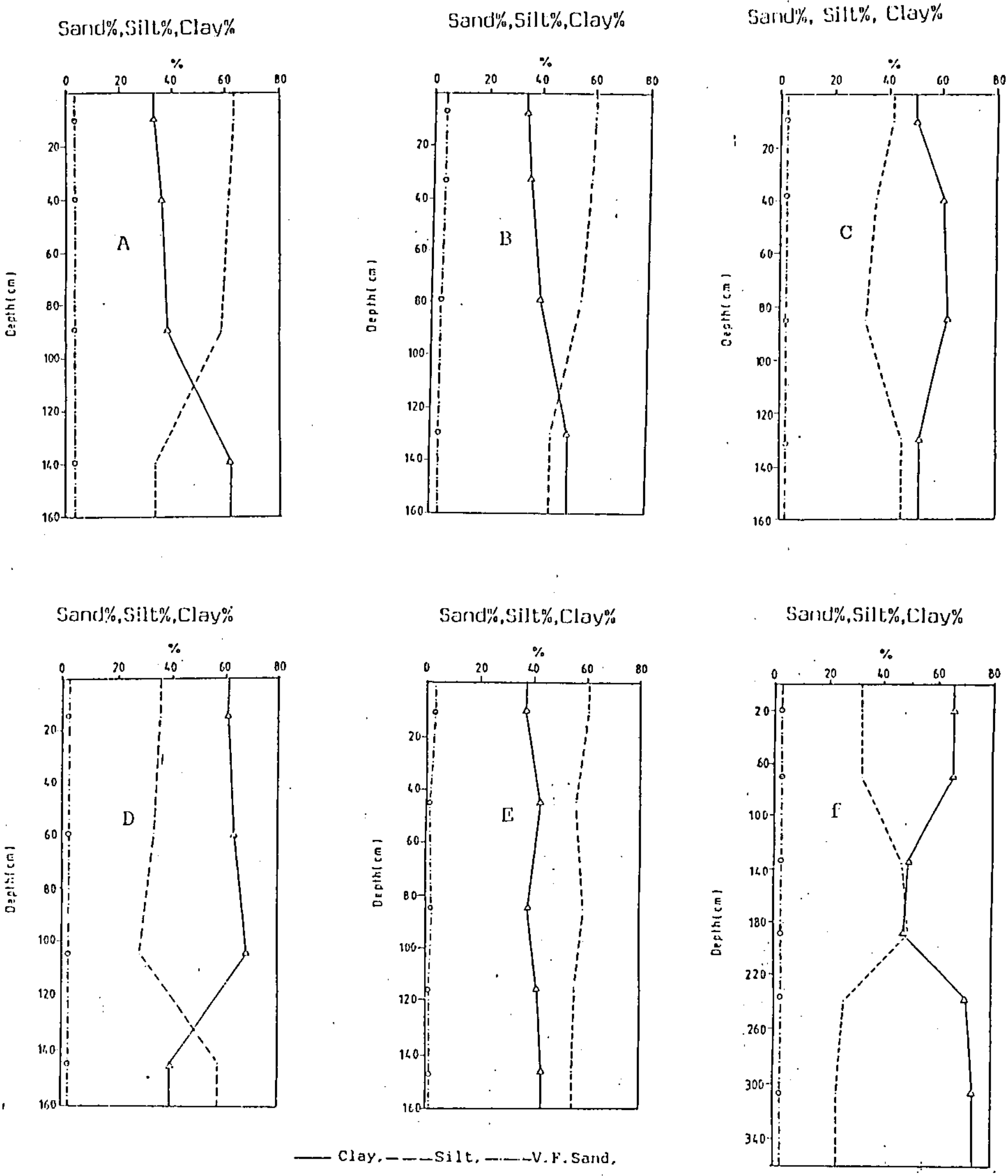


Fig. 8- Particle Size-depth distribution without carbonate for limestone derived soils.

The results indicated that limestone derived soils had higher clay content than basalt derived soils. Soils derived from limestone and their mechanical composition was similar to that of the insoluble residues of their parent limestones (2). Clay remained high and uniform throughout the upper 100 cm for most soils.

Clay content was proportional to precipitation. The increase in clay was accompanied by a correspondent decrease in amount of silt.

Overall variation in clay content was high (C.V%=27.2). Mean value at the subsurface horizons (42.1) was higher than that at the surface horizons (39.0). Variation in clay content was higher at the surface (C.V%=28.9) than at the subsurface (C.V%=27.5). Overall variation in clay content was higher for limestone derived soils (C.V%=27.6) than for basalt soils (C.V%=22.1). Clay mean for soils recieving high rainfall was higher than those with low rainfall. The coefficent of variation values suggested higher variation in clay for soils recieving 350-400mm precipitation (C.V%=27.8) than for soils recieving 400-500 mm (C.V%=25.0) and soils recieving 250-350 mm (C.V%=24.6).

Overall variation in silt content was medium (C.V%=20.0). Mean silt content for surface horizons (58.8)was higher than that for subsurface horizons(55.8). Variation ,while variation was higher for the subsurface horizons (C.V%=20.8) than for the surface horizons (C.V=18.4). Overall variation in silt content was higher for limestone derived soils than for basalt derived soils. Mean silt content was higher for soils recieving low rainfall. The coefficent of variation values suggested higher variation in silt for soils recieving 400-500 mm (C.V%=20.8) than those recieving 250-350 mm (C.V%=13.8) and soils recieving 350-400 mm (C.V%=18.9).

4.9 Bulk density and coefficent of linear extensibility (COLE)

Tables 21, 22 and 23, showed the values of bulk density on dry basis, moist basis, and the coefficent of linear extensibility. Bulk density on dry basis increased with depth for all studied soils. The minimum bulk density observed at Ap horizons. This might be due the effect of the organic matter. The increase in bulk density with depth could be attributed to lower organic matter, more compaction, sodium effect, and less aggregation. Vertisols had unusual high bulk density, typically 1.8gm/cc (48). Bulk density on dry basis followed the same pattern as that on moist basis. Bulk density was higher for limestone derived soils than that for basalt derived soils. Soils developed under higher rainfall exhibited higher bulk density.

COLE values exceeded 0.09 in all the studied soils which reflects a high shrink-swell potential.

Overall variation of bulk density was low (C.V%=5.6). Mean bulk density for surface horizons (1.7) was slightly lower than the subsurface (1.8). Overall variation for surface horizons (6.7) was higher than at the surface horizons (3.9). Mean bulk density values on dry and moist basis for soils developed on basalt or soils developed on limestone were the same (1.8), but overall variation was slightly higher for soils developed on basalt (C.V%=5.5) than those developed on limestone (C.V%=5.3).

Mean values on dry and moist basis for soils recieving 400-500mm, 350-400 mm, and 250-350 mm, were the same (1.8). Variation in soils recieving 400-500 mm was higher than other soils.

4.10 Mineralogy of clay and silt fractions

Figure (9) showed the x-ray diffraction patterns for clay and silt of Ramtha soil. The following minerals were identified in the clay fraction ; smectite / vermiculite / illite interstratified mineral, kaolinite, illite and quartz.

Comparing surface and subsurface horizons, kaolinite was uniformly distributed, whereas illite decreased slightly with depth. The increase in interlayered mineral with depth indicated that this soil had experinced strong chemical weathering. The decrease of mica content in the soil coincided with the increase in the smectite content (36).

The clay mineralogy in arid and semiarid soils was probably controlled more by parent material rather than by clay weathering during pedogenesis (7). Smectite will be the alteration product, if the released magnesium from the parent material was not leached rapidly, otherwise kaolinite will be the alteration product (22).

The mineralogy of the silt fraction suggests the pressence of quartz, kaolinite, plagioclase feldspars, illite, and interstartified vermiculite /illite. The occurence of illite and plagioclase beside to quartz was explained by the aeolian activity that prevails during an episode of arid cliamte (40).

The occurence of vermiculite / illite interstartified mineral can be attributed by the aerosolic dusts containing micaceous vermiculite (45).

The x-ray diffraction patterns for clay and silt in Jamha were showed in figure (10). The interpretation indicated the

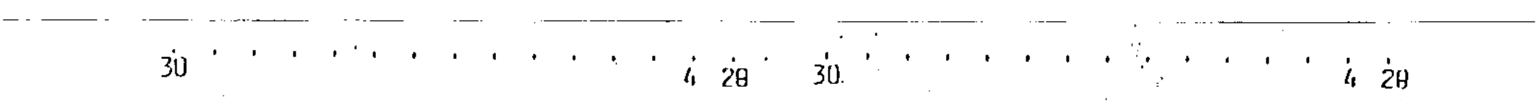


Fig. 9- X-Ray Diffraction Patterns For Ramtha Soil.

pressence of the following minerals ; vermiculite / smectite, illite, kaolinite, and quartz.

Smectite and kaolinite increased with depth, while illite increased towards the surface. This indicated that this soil experinced a strong chemical weathering which involoved high amounts of water passing through the soil profile.

Clay minerals for limestone originated soils consisted mainly from smectite, kaolinite with some illite and interstratifieds. Smectite / kaolinite ratio decreased with depth in vertisol of Mt. Hermon in Israel (39).

The rather homogenous quartz distribution pattern with soil depth suggested that churning process have been active for a long period of time.

Quartz, plagioclase feldspars, kaolinite, illite, and vermiculite / illite interstatified mineral were identified in the silt fraction.

The occurence of vermiculite / illite interstarified mineral can be attributed by the aerosolic dusts containing micaceous vermiculite (45).

The pressence of plagiocalse feldspar, and illite at the surface in the silt fraction provided an evidence of concurent aridity characterized by the addition of silt and carbonates to the surface (40).

Particle size distribution and carboante distribution supported this suggestion. Smectite was the dominant clay mineral in soils where rainfall ranged from 400-500 mm/year (40).

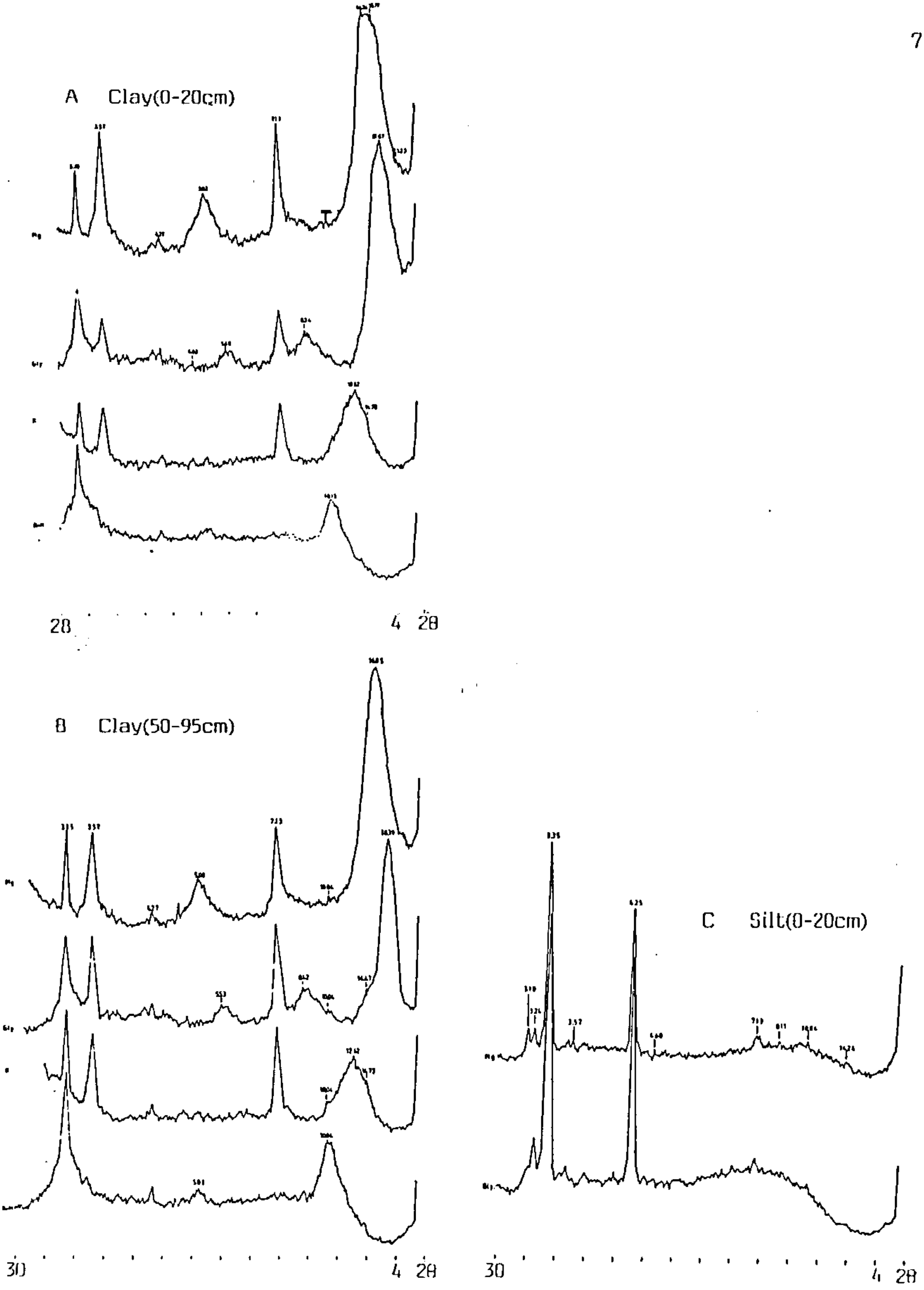


Fig. 10- X-Ray Diffraction Patterns For Jamha Soil.

Figure (11) showed the X-ray diffraction patterns for clay and silt fraction in Kherja soil. The following minerals were identified; smectite, illite, kaolinite, and quartz. Kaolinite was uniformly distributed. Illite decreased with depth. Smectite increased with depth. Dioctahedral smectite accompanied by minor quantities of disordered kaolinite were the predominant clay minerals in basalt derived soils(40).

The mineralogy of the silt fraction characterized by the pressence of quartz, kaolinite, plagioclase feldspars, illite, and vermiculite/illite.

Smectite was the dominant mineral of the vertisol clay fraction and was accompanied by considerable amounts of kaolinite. Accesory mineral was quartz. No significant differnce in clay mineral composition throughout the profiles were observed (15).

The non clay fractions of the basalt derived soils were composed of quartz and plagioclase. Particle size distribution patterns of the quartz suggested an aeolian origin for this mineral (38).

The mineralogy of clay and silt fractions for Maru, Qaser Shihan, Rabba, and Majra soils followed the same pattern as that for Kherja soil. All of these soils were developed on basalt except Rabba, and Majra soils which were developed on limestone. Figures (12,13,14,15 and 16) showed the X-ray diffraction patterns for these soils.

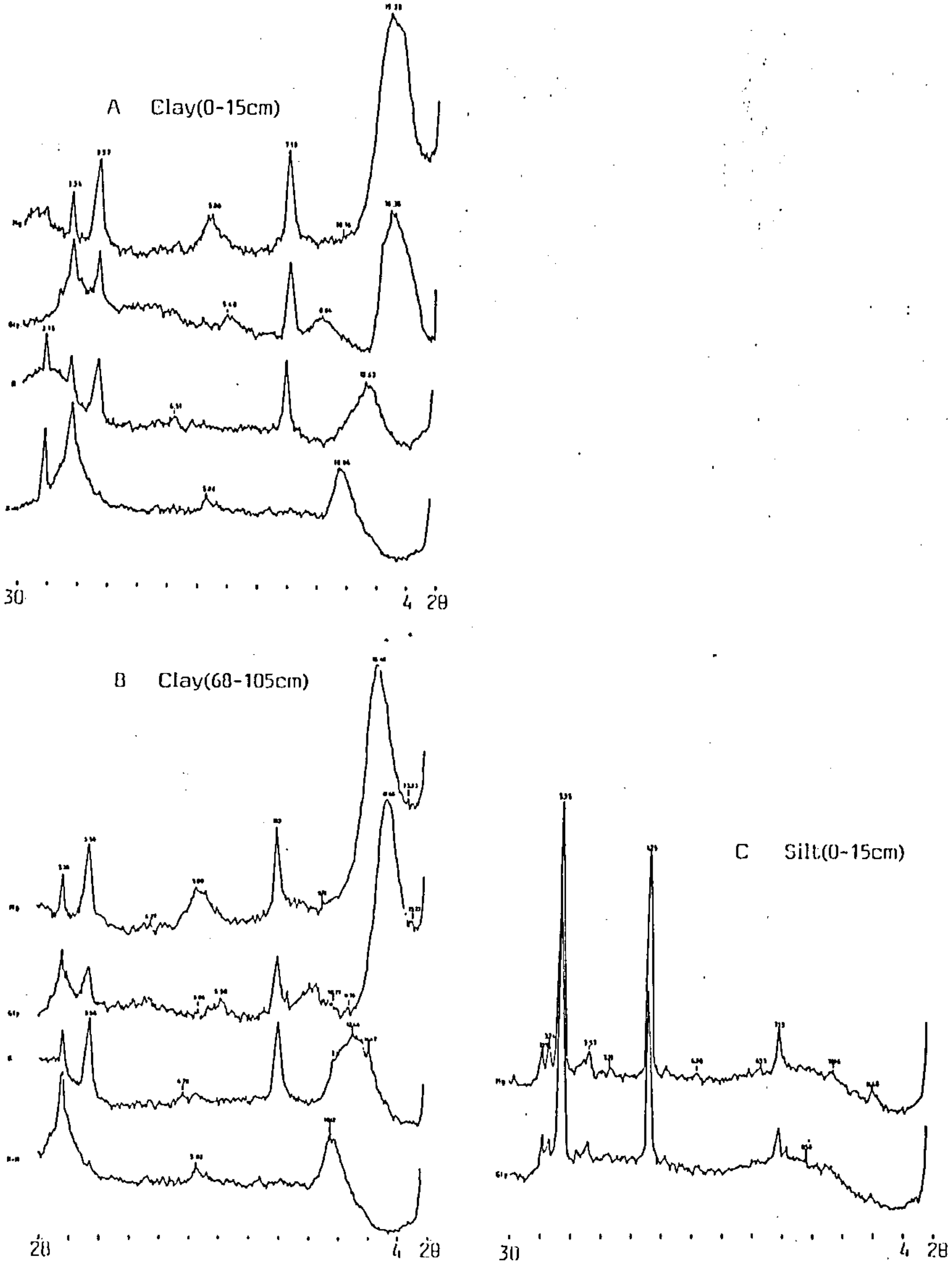


Fig. 11- X-Ray Diffraction Patterns For Kherja Soil.

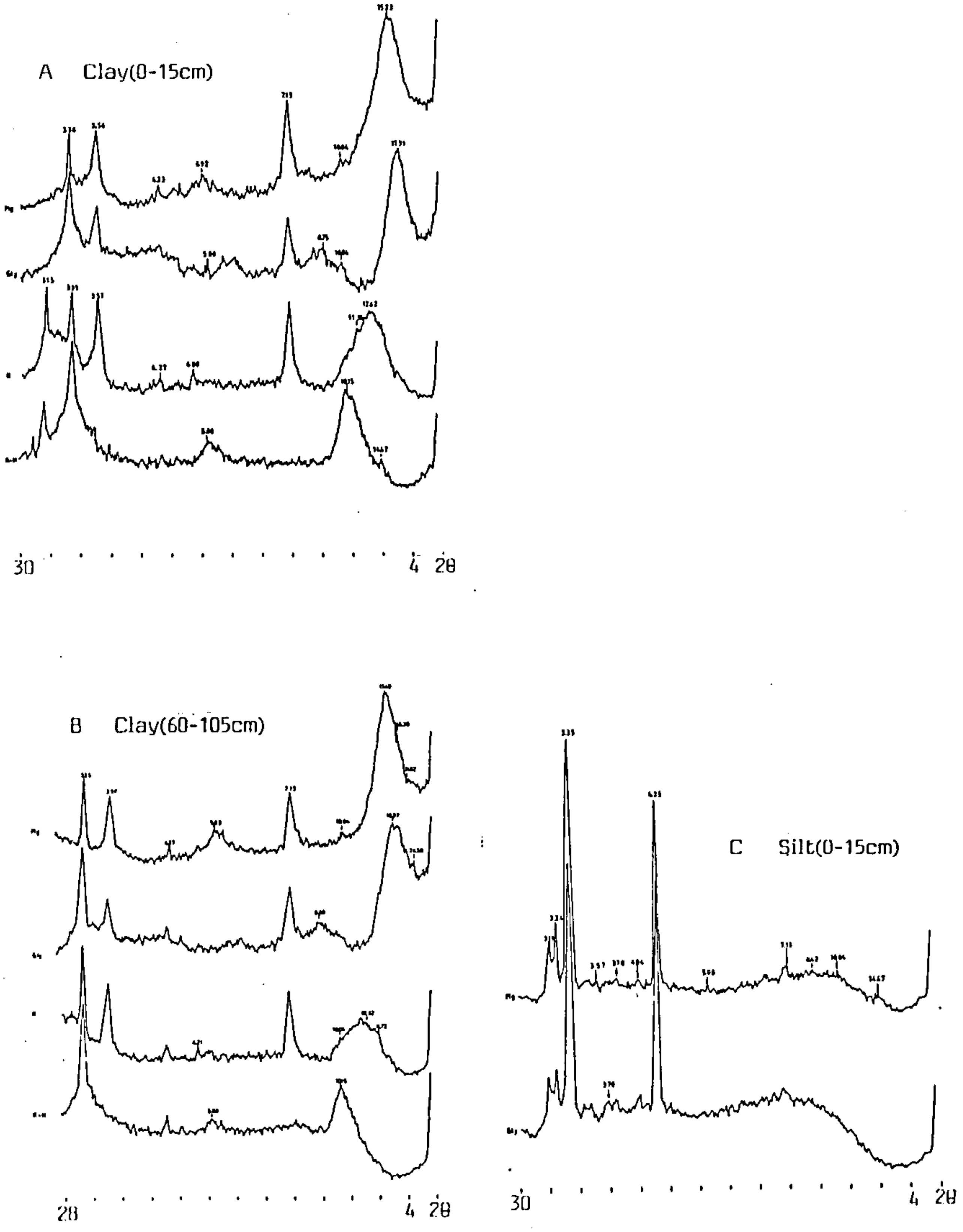


Fig. 12- X-Ray Diffraction Pattern For Maru Soil.

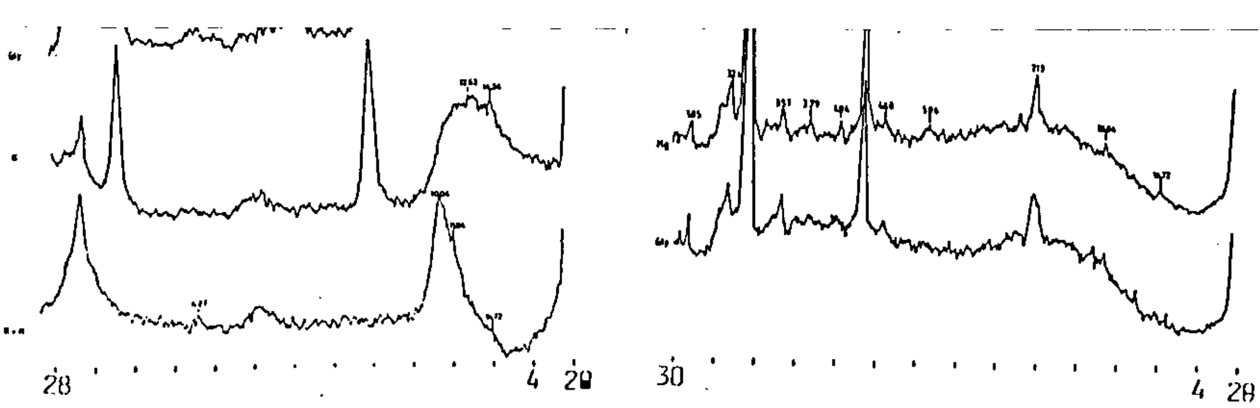


Fig. 13- X-Ray Diffraction Pattern For Shihan Soil.

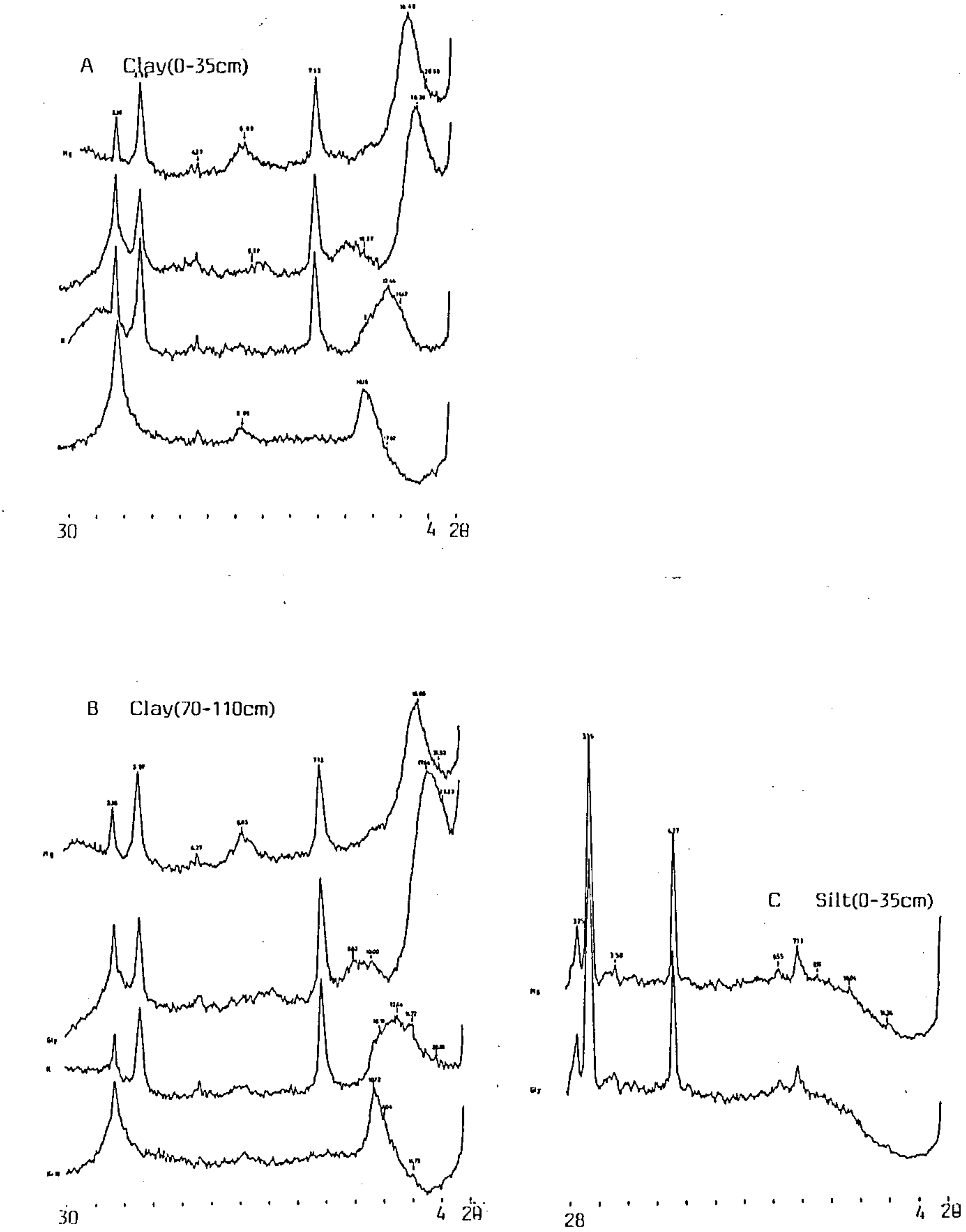


Fig. 14- X-Ray Diffraction Patterns For Qaser Soil.

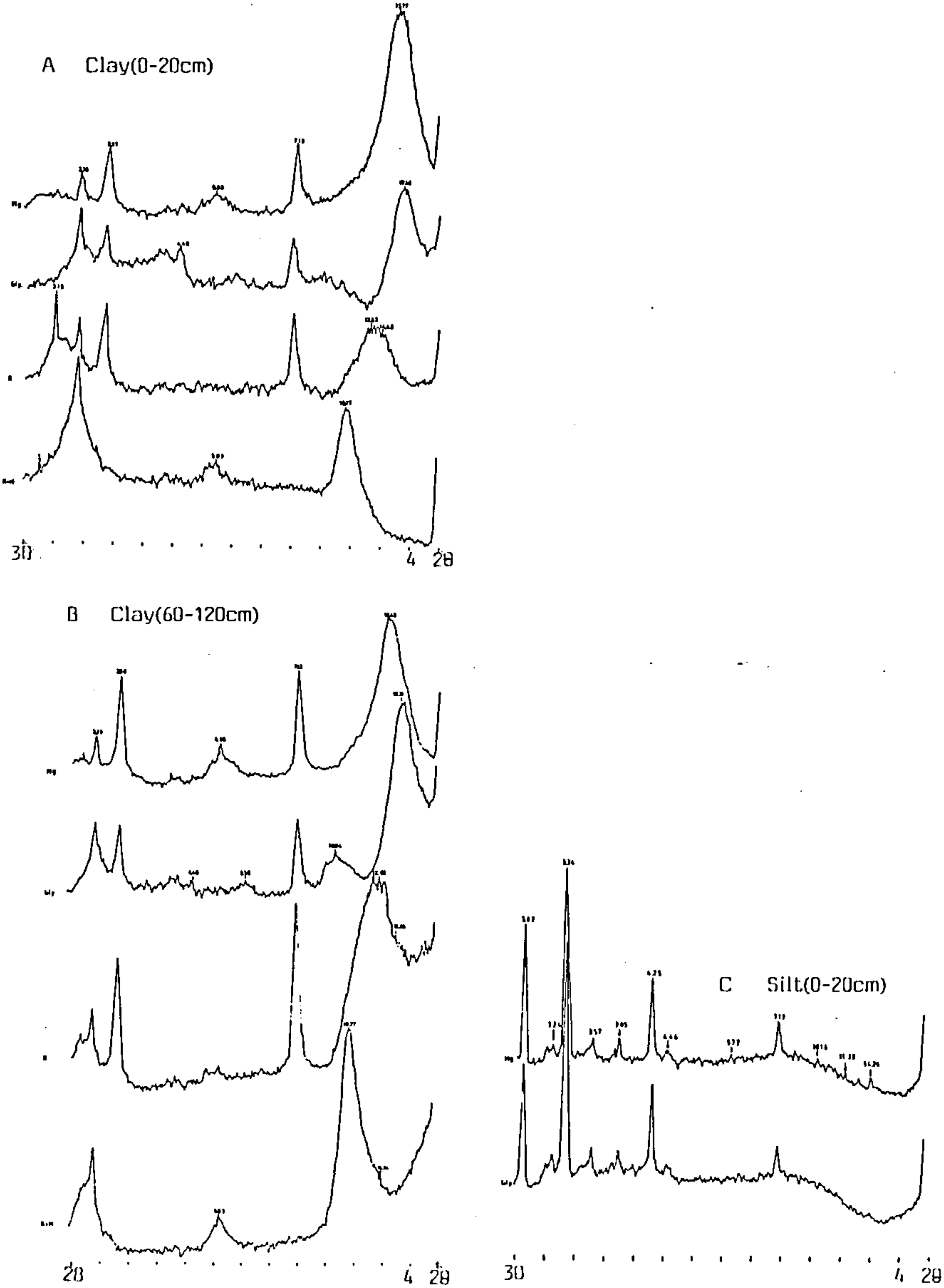


Fig. 15- X-Ray Diffraction Patterns For Rabba Soil.

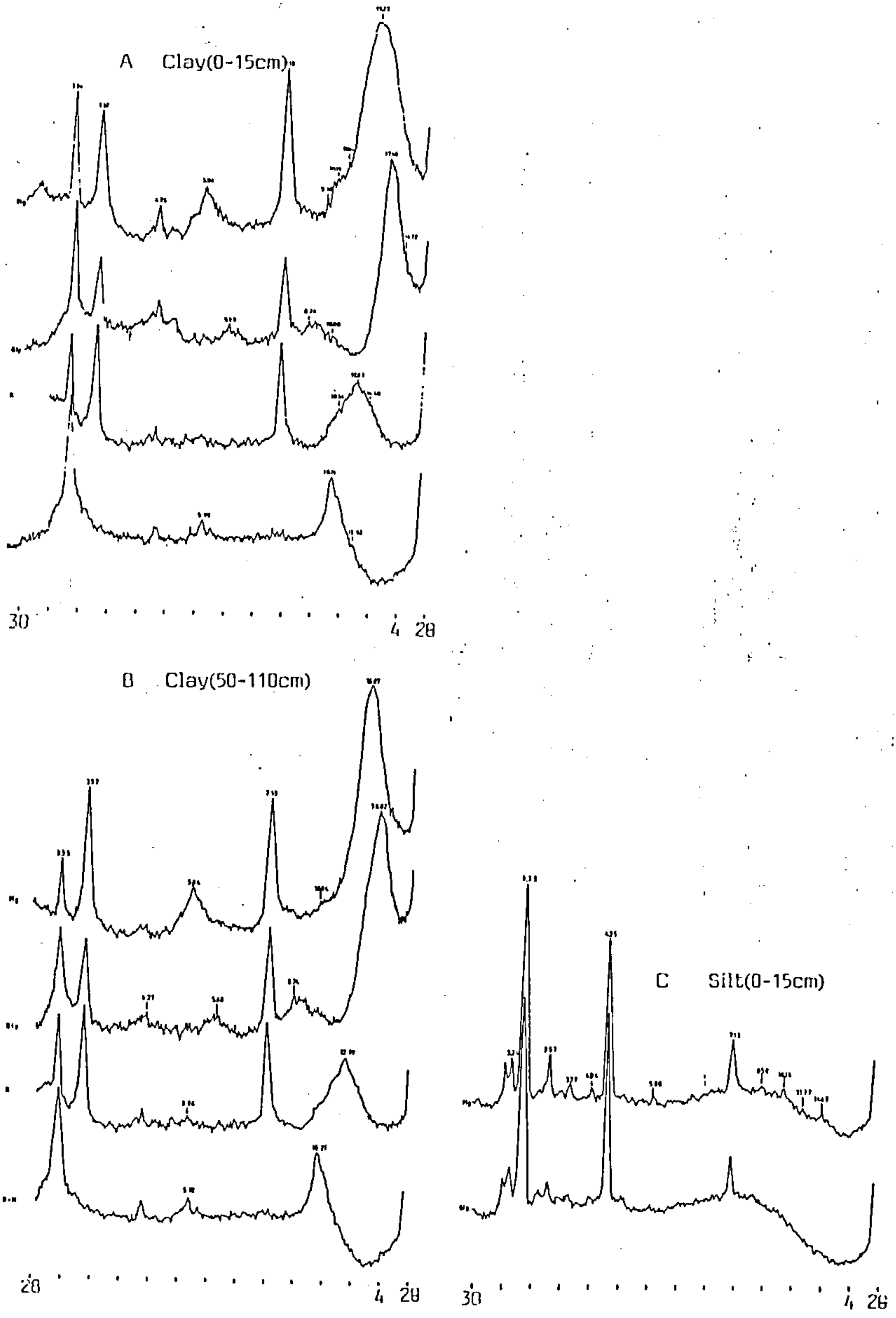
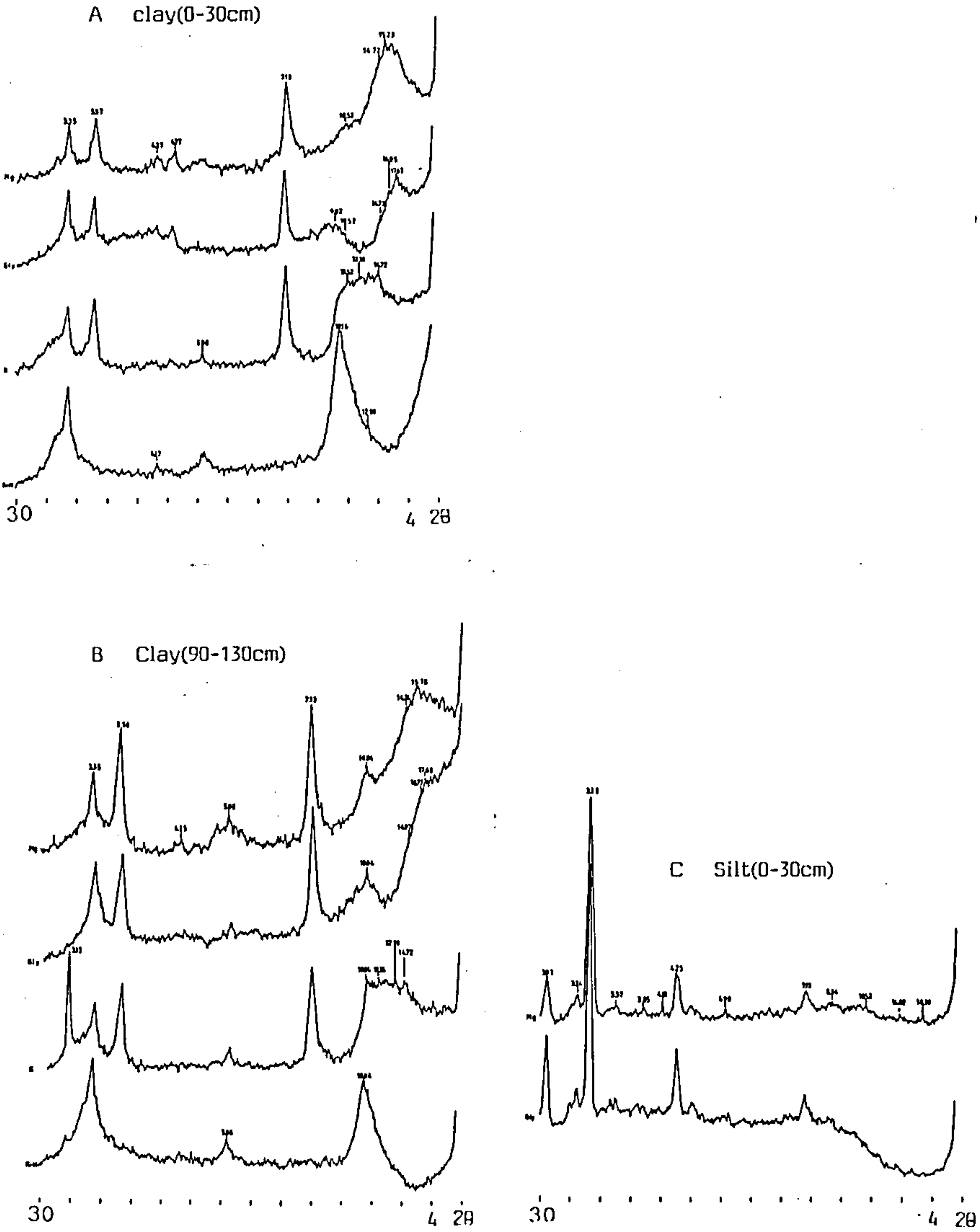


Fig. 16- X-Ray Diffraction Patterns For Majra Soil.

Figure (17) showed the X-ray diffraction patterns for clay and silt fractions in Madaba soil.The interpretation indicated the pressence of the following minerals in clay fraction; smectite/vermiculite interlayered mineral, kaolinite,illite,palygorskite and quartz.

Degree of interlayering increased with depth. Kaolinite increased while illite decreased with depth. This indicated that this soil experinced an intensive chemical weathering . The occurence of montmorin minerals as the most abundant clay mineral in limestone soils in Israel indicated that the pressence of lime in a parent material either enhanced the formation of the montmorin clay minerals or preserves them if they were originally present (4). Silt fraction contained quartz, plagioclase feldspars, kaolinite, palygorskite, and vermiculite/ palygorskite interlayered mineral. The pressence of quartz, palygorskite, and plagioclase on the surface indicated weak chemical weathering. This was indicated by Singer (40) who related the occurence of quartz and illite at the surface of soils at Golan Heights to the aeolian activity

The X-ray diffraction patterns for clay and silt fractions in Mshager soil were shown in figure (18). Silt and clay fraction mineralogy were the same as that for Madaba soil except that smectite was more abundant in Mshager soil.


A clay(0-30cm)

B Clay(90-130cm)

C Silt(0-30cm)

Fig. 17- X-Ray Diffraction Patterns For Madaba Soil.

Figure (19) showed the X-ray diffraction patterns for clay and silt fractions in Baq'aa soil. The following minerals were identified in the clay fraction smectite/ vermiculite, illite, kaolinite, palygorskite, and quartz. Kaolinite increased with depth, while palygorskite, decreased. Smectite increased with depth. This indicated that this soil experinced a strong chemical weathering. Montmorillonite and "mixed layer" clays have been reported to form an important part of the clay fraction in most areas where vertisols have been studied mineralogically (18).

Palygorskite was identified only in calcareous soils formed on the neogene sedimentary rocks (38).

Silt fraction had the following minerals; quartz, plagioclase feldspars,kaolinite,and vermiculite/palygorskite interlayered mineral. This offered an evidence to the aeolian activity.

The mineralogical interpretation suggested that mica was found in soils of low rainfall, whereas smectite and and interlayered minerals were identified in soils of high rainfall. Kaolinite content was very low to low. The soils developed on basalt had smectite as the dominant clay mineral, while those developed on limestone had interlayered minerals as the dominant clay minerals.

Fig. 19- X-Ray Diffraction Pattern For Baq'aa Soil.

CHAPTER V

SOIL GENESIS

The results obtained from physical, chemical, and mineralogical analyses were used in hypothesizing the soil development of vertisols derived from limestone of the upper createaceous age. The following sequence gives the chronological sequence through which soil development have undergone;

Stagel. This stage proceeded when the parent material was subjected to strong chemical weathering. This stage represented humid conditions characterized by high rate of clay formation as in Jamha, Rabba, and Majra soils. This is evident in pressence of high free iron oxides in the lower solum of Ramtha, Rabba, Majra, and Baq'a soils. The high clay content which was formed from hard limestone might be considered as a sufficent evidence for the intensive weathering, because of the tremendous amount of water required to leach out calcium carbonate during the weathering processes (46). At the begining of the pleistocene, humid climate dominated. This was indicated by the existence of conglomerates and the absence of evaporates (5,12). The dark color of these soils, espeically Jamha and Baq'a provided another clue for the strong chemical weathering which prevailed during the Quaternary.

The occurence of the concretions in Ramtha, Rabba, Majra, Jamha, and Baq'a soils (section 3.41) indicated intensive chemical leaching of carbonates within these soils. Total carbonates in Jamha soil was very low, with a maximum of 3.7% meq/100 gm. This suggested that the soil has developed under a more humid climate compared to the other soils. The occurence of smectite interstratified mineral as in Ramtha and Jamha soils, and the increase in kaolinite in Rabba and Jamha soils confirmed the evidence which indicate that climate was humid during this stage. It seemed that the climate in Jamha, and Baq'a soils was more humid than those in Ramtha, Rabba and Majra. This was indicated by the higher clay content, and the increase in kaolinite with increseing depth in both Jamha and Baq'a soils (Tables 11,20).

<u>StageII</u>. The processes during this stage suggested a shift in the climate from humid to arid. The jordan rift had played a significant role in accelerating geologic erosion when climate became rather arid. Colluvial activity was then dominant and resulted in the deposition of a new parent material. Fluvatile sediments were deposited in basins and depressions during the pleistocene (12). The occurence of rounded edge limestone gravels in the lower parts of these soils (Ramtha, Jamha, Rabba, Majra, and Baq'a soils;)(section 3.41) is an indicate for the intensive colluvial activity during this period. The erosion and deposition processes created unstable landscape. This stage ended when climate, a soil forming factor, had changed from arid towards humid, initiating a new cycle of soil development.

<u>StageIII</u>. At this stage, the climate had shifted again to humid, but it was less humid than the first stage. This was indicated

by the relatively low clay content in the upper solum of Ramtha, Jamha,Rabba,Majra and Baq'a soils (Tables 10,11,16, and 20). Also the secondary calcium carbonate accumlation in these soils (see profile description). This clay content indicated a less humid climate. Clay illuviation was found in the upper solum of Ramtha, Jamha, Rabba, and Majra soils. Leaching of carbonates associated with clay had been active during this stage in all the above mentioned soils. The free iron oxides were higher at the surface horizons in Ramtha and Majra soils suggesting that weathering was restricted to the surface horizons. Higher leaching rates would produce more clay sized material, and clay minerals that belong to more advanced weathering stages (41).

StageIV. This stage represented the present soil development. During this stage climate changed gradually towards aridic. The present arid climate prevailed for the last 5,000-10,000 years (46).The arid climate had initiated the accumulation of calcareous silt on the surface for Ramtha, Jamha, Rabba, Majra, and Baq'aa soils. Recent measurements of deposition of dust in Israel confirmed that aeolian dust was indeed a significant contributor to limestone derived soils(47). The pressence of clay coating in Ramtha soil profile suggested that shrink-swell pattern was absent or had commenced recently. Turbation probably by wetting and drying destroyed the clay skins. Clay skins were absent in horizons of high shrink-swell potential. This might be the reason behind the absence of clay coatings in Jamha, Rabba, and Majra soils, which had a COLE value more than 0.10. The occurence of quartz, illite, plagioclase and palygorskite in the silt fraction on the surface of Ramtha, Jamha,Rabba,Majra, and Baq'aa soils, indicated aeolian activity. Older mature soils contained more quartz and less weatherable minerals than young soils(47). Palygorskite in paleosols occured only due to arid conditions(41). The above mentioned hypothesis described the soil development in Ramtha, Jamha, Rabba, Majra, and Baq'aa soils, except that Jamha soil seemed to be subjected to more intensive chemical weathering than these soils. This was indicated by the high clay content and black color of the soil (see profile description). Baq'aa soil seemed to be older and more mature than these soils, where it had been subjected to more intensive chemical weathering, especially during the first stage. Apparently due to it's topographical configuration, the soil in this location had recieved higher amounts of water and for longer time. This was evidenced by the high clay content which reached 72 percent in the lower solum.

The above discussion strongly suggests that both climate and to a certain extent relief were the most effective soil forming factors for Baq'aa soil. Nevertheless, climate was the leading factor in the soil development for Ramtha, Jamha, Rabba, and Majra soils, and relief played the role of a modifier.

Soil development for Ramtha seemed to have similar soil development as Jamha, Rabba, Majra, and Baq'aa soils. This soil had been classified as vertic xerochrepts, while the other soils had been classified in the vertisols order. This might be due to the weak shrink-swell potential in this soil, or less humid climate in the previous stages of the soil development which had resulted in the development of soil properties not enough to be qualified as vertisols.

Mshager and Madaba soils had similar pattern of soil development as those mentioned above, except that these soils consisted two solum seperated at the depth of 110cm, and 130cm respectively. This was evidenced by the recalculated size distribution on clay free basis (Tables 18,19).

The second hypothesis is advanced for soils which had been derived from limestone associated with basalt. The stages of soil development were hypothesized as follows;

Stagel. This stage represented the initial steps which started during the deposition of the parent material. A series of basalt flows occured and covered the fluvatile sediments which were deposited during the pleistocene (12). This stage is coincided with the second stage which described the development of the soil which had developed from limestone. The absence of any lithological discontinuity and the uniformity in distribution of clay, silt, and sand fractions suggested that the enviromental factors were constant during the deposition of the parent material. The occurence of the jordan valley forced the plateau to be a zone of high erosion intensity(5). Geologic erosion was accelerated when the climate became arid. The occurence of basalt and limestone gravels in the lower solum of Kherja, Maru, Shihan and Qaser soils (see profile description) supported the assumption that colluviation processes had been active during this stage. The erosional and depositional processes led to the deposition of a thick layer of colluvial material derived from limestone associated with basalt. This stage ended when the climate shifted towards humid.

Stage II. This stage represnted the soil under humid climate. The parent material which deposited in the previous stage had been subjected to a strong chemical weathering. The high clay content in the B22 horizons of Kherja, Maru, and Shihan soils were strong evidences for the intensive chemical weathering. Kherja and Maru soils experinced more humid climate and for longer time than Shihan and Qaser soils. This was evidenced by the differnces in clay content (Tables 12,13,14,15) and less carbonates in Kherja and Maru soils (Table1). The new climate enhanced the operation of the pedogenic processes such as clay illuviation in Kherja and Maru soils, and carbonates leaching in Maru and Qaser soils. Total carbonates increased at B23 horizons in Kherja and Shihan soils. Concretions increased in the lower parts for all basalt derived soils (see profile description). Although clay illuviation had been active during this stage but no argillic horizon had been formed.

Stage III. This stage started when the climate shifted again towards aridity. This was evidenced by the decrease in clay content at the surface horizons. The high calcerous silt content at the surface indicated the accretion of silt by aeolian activity in Kherja, Maru, and Shihan soils (figures 7,8,9). Also, the vertical decrease in carbonate in very fine sand was due to aeolian activity which characterized the Quaternary(40). Dioctahedral smectite and kaolinite composed the clay fractions of the paleosols which represented different regressional cycles.

With increasing rainfall the proportion of smectite in the clay fraction of soils formed from pleistocene basalts decreased(41). The occurence of illite, quartz, and palygorskite in Kherja, Maru, Shihan and Qaser soils at the surface silt fractions might be attributed to the aeolian activity. Basalt derived veritsols and associated soils, in Israel, contained 10-50 percent of quartz in the predominantly silt fraction of aeolian origin (41).

This hypothesis of soil development could be applied for Kherja, Maru and Shihan soils. All of these soils were classified as vertisols.

Kherja and Maru soils seemed to be subjected to more intensive chemical weathering than Shihan and Qaser soils. This was evidenced by the higher clay content in Kherja and Maru soils within the whole soil profiles.

Qaser soil seemed to have similar stages of soil development as those mentioned above. But the uniformity in clay, silt and sand fractions in this soil suggested that the enviromental factors were constant during the deposition of the parent material in the previous first stage. Moreover, this uniformity might be due to continous mixing of the soil due to churning processes.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Some chemical, physical, and mineralogical properties of eleven soil profiles representing the vertisols in different locations in Jordan were studied. The morpholoigcal features and the analytical results indicated the following;

Gilgai microrelief was absent in all the soils of study area. This could be due to the assumption that recently developed vertisols is not neccessary to have gilgai microrelief(14).

The parellelped structure was present in all the studied soils, except in Ramtha,soil, whereby the presence of clay coatings in some soils indicated that shrink-swell pattern was absent or had proceeded recently.

All the studied soils were classified as vertisols, except Ramtha soils which were classified as Vertic xerochrepts.

The studied vertisols were developed in areas where annual rainfall ranged from 300-500 mm. Below 300 mm rainfall, formation of vertisols is not expected within the study area.

These soils had a wide range in clay content, where 30% clay had been found in some soils like in Qaser soil, Shihan and others, and 72% like in Baq'a soil.

The limit between chromoxerert and pelloxerert was the rainfall of 450 mm/year. Vertisols developed in areas recieving less than 450 mm were classified as chromoxererts, and those recieving more than 450 mm were classified as pelloxererts.

The results showed that climate played a significant role in the development of these soils. These soils were subjected to different cycles of soil formation that can be summarized as follows;

StageI. Humid climate dominated this stage and characterized by high clay formation and accumlation, and the pressence of concretions.

StageII. The climate shifted from humid to to arid. Colluvium material derived from limestone deposited during this stage, which was evidenced by the occurence of limestone gravels in the lower solum of the studied soils. During this stage basalt was deposited and affected the genetic path of the soil where it was deposited.

StageIII. During this stage climate changed to humid again. The climate was less humid than that in the first stage. Clay illuviation and leaching of carbonates associated with clay were the main pedogenic processes during this stage.

Stage IV. This stage represented the present climate, where aridic climate prevailed. The accumlation of calcerous silt on the surface, and the occurence of palygorskite, illite, and quartz evidenced the dominance of aridic climate.

In general the properties of the studied vertisols can be summarized as follows;

1. pH values were much related to carbonates, where it increased as carbonates content increased. Accordingly, limestone derived

derived soils had higher pH values than those developed on basalt. Moreover pH values were affected by precipitation, where pH values decreased as rainfall increased.

2. The carbonate content of soil developed from limestone was higher than those of basalt parent material. This was true for surface and subsurface horizons. This might be due to the high carbonate content of the parent material. Moreover carbonates decreased as rainfall increased for both soils, where it was 2.4% for Jamha soil (rainfall=500mm) and 24.4% for Madaba soil (rainfall=300mm).
3. Organic matter content was affected by precipitation regardless of the parent material type. Soils occuring under high rainfall had higher organic matter content.
4. Extractable calcium was higher for limestone derived soils because of more calcium carbonate in the parent material. While, extractable magnesium was higher for basalt associated with limestone derived soils. This could be attributed to more magnesium carbonate in the parent material of these soils. Generally the extractable calcium and magnesium increases as rainfall increases.
5. Electrical conductivity of the studied soils was affected by amounts of precipitation, regardless of the type of the parent material, where it decreased as rainfall increased.
6. Free iron oxides increased with precipitation. Soils developed from limestone or basalt had similar amounts of free iron except for Baq'aa soil which exhibited very high iron oxide content.
7. Cation exchange capcity was higher for basalt derived soils

compared to the limestone derived soils. This was related to the dominant clay minerals, where smectite dominated the basalt derived soils and smectite-interlayered mineral dominated the limestone derived soils.

8. Clay content for the surface and the subsurface horizons was higher for limestone derived soils than that for basalt derived soils. This might be due to older and more mature soils on limestone such as Jamha and Baq'aa soils. Generally clay content increases in the whole profile as rainfall increases
9. Silt distribution for all Studied soils suggested the accumulation of this material on the surface horizons due to aeolion activity.
10. Smectite was the dominant clay mineral for basalt derived soils regardless of the precipitation. Smectite/vermiculite interlayered mineral dominated the limestone derived soils.
11. Bulk density for the studied vertisols was higher for limestone derived soils. Moreover, bulk density was higher for soils developed under higher rainfall.
12. COLE values were high, and exceeded 0.09 in all the studied soils suggesting high shrink-swell potential.

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Appendix- A: Chemical analyses

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

Hor. desig.	Depth	pH	CaCO3-Equivalent				Total
		1:1	>.1mm	.1-.05mm	.05-.002mm	<.002mm	
			Profile No. 1(Ramtha)				
Ap	o-22	7.9	0.04	0.74	6.59	4.6	12.2
B21	22-70	8.0	0.02	0.32	5.29	6.6	12.2
B22	70-100	7.9	0.02	0.25	7.81	6.1	14.6
B23	100-132	8.0	0.02	0.16	4.70	8.2	15.9
B24	132-160	8.2	0.12	0.25	4.70	8.6	15.9
			Profile No.2(Jamha)				
Ap	0-20	7.5	0.08	0.05	1.81	1.7	3.7
B21	20-50	7.7	0.01	0.01	0.60	1.9	2.4
B22	50-95	7.8	0.01	0.02	1.70	2.1	3.7
B23	95-135	7.8	0.01	0.01	1.11	2.7	3.7
			Profile No. 3(Kherja)				
Ap	0-15	7.8	0.20	0.25	3.08	3.9	7.3
B21	15-68	7.9	0.15	0.21	3.02	3.5	7.3
B22	68-105	7.9	0.02	0.11	1.88	4.3	6.1
B23	105-155	7.9	0.44	0.05	1.16	5.7	7.3
			Profile No. 4(Maru)				
Ap	0-15	7.9	0.02	0.06	3.10	3.7	6.1
B21	15-60	7.9	0.03	0.07	1.35	3.3	4.9
B22	60-105	7.9	0.03	0.03	1.27	4.9	6.1
B23	105-160	8.0	0.06	0.07	1.10	3.7	4.9

Table 2 - Chemical Analyses For Profiles 5, 6, 7 and 8.

Hor. desig.	Depth	pH 1:1	CaCO3-Equivalent >.1mm	.1-.05mm	.05-.002mm	<.002mm	Total
			%				
			Profile No. 5(Shihan)				
Ap	0-30	8.0	0.03	0.51	17.34	5.4	23.2
B21	30-80	8.1	0.08	0.46	11.03	9.3	22.0
B22	80-120	8.2	0.10	0.53	12.40	8.0	22.0
B23	120-160	7.9	0.27	0.39	9.89	12.5	23.2
			Profile NO. 6(Qaser)				
Ap	0-35	7.8	0.25	0.40	9.80	4.2	14.6
B21	35-70	7.9	0.25	0.35	8.76	3.5	13.4
B22	70-110	8.0	0.33	0.09	8.49	3.8	13.4
B23	110-155	8.0	0.36	0.29	9.01	3.5	13.4
			Profile No. 7(Rabba)				
Ap	0-20	7.9	0.16	0.56	15.75	5.6	22.0
B21	20-60	7.9	0.20	0.43	12.65	9.0	22.0
B22	60-120	8.0	0.30	0.46	13.60	6.2	23.2
B23t	120-160	8.0	0.07	0.51	7.45	14.8	22.0
			Profile No. 8(Majra)				
Ap	0-15	7.9	0.21	0.24	7.54	3.7	11.0
B21	15-50	7.9	0.20	0.24	6.22	4.3	11.0
B22	50-110	8.0	0.21	0.20	10.15	7.9	12.2
B23t	110-150	7.9	0.23	0.23	5.15	9.0	14.6

Table 3 - Chemical Analyses For Profiles 9, 10 and 11.

Hor. desig.	Depth	pH	CaCO3-Equivalent				Total
		1:1	>.1mm	.1-.05mm	.05-.002mm	<.002mm	
			%				
			Profile No. 9(Mshgar)				
Ap	0-20	7.8	0.44	0.10	8.2	8.2	18.3
B21	20-60	7.9	0.09	0.32	9.32	8.6	18.3
B22	60-110	8.0	0.30	0.37	12.10	4.2	19.5
IIB23	110-160	8.1	0.13	0.33	11.05	9.6	22.0
			Profile No. 10(Madaba)				
Ap	0-30	7.9	0.04	0.35	7.48	8.0	17.1
B21	30-90	8.1	0.05	0.40	8.03	8.4	17.1
B22	90-130	8.1	0.10	0.34	7.06	10.5	18.3
IIB23ca	130-160	8.1	0.13	0.56	15.60	7.9	24.4
			Profile No. 11(Baq'aa)				
AP	0-40	7.6	0.23	0.31	10.00	12.6	23.2
B21	40-100	8.1	0.15	0.09	6.90	15.4	22.0
IIB22	100-170	8.2	0.18	0.16	11.64	12.9	24.4
IIIB23	170-210	8.2	0.16	0.20	7.72	11.9	19.5
IIIB24ca	210-270	8.2	0.14	0.11	2.37	14.7	17.1
IIIB25ca	270-350	8.2	0.18	0.12	1.94	12.6	14.6

Table 5 - Chemical Analyses For Profiles No. 3 and 4 (Kherja and Maru)

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	0-15	1.0	2.5	5.3	0.23	57.1	112.7	53.3	14.8	1.5	0.4
B21	15-68	0.6	1.9	3.5	0.22	55.3	104.0	46.2	8.5	0.9	0.6
B22	68-105	0.5	1.7	4.9	0.21	57.4	112.4	46.1	7.9	0.5	0.9
B23	105-155	0.4	2.3	2.2	0.22	52.6	98.1	46.3	8.1	0.6	1.4
					Profile No.4						
Ap	0-15	0.7	2.7	5.8	0.25	54.8	121.6	55.2	8.6	0.4	0.5
B21	15-60	0.7	2.7	5.8	0.21	57.5	111.3	55.4	9.1	0.2	0.8
B22	60-105	0.4	2.7	5.5	0.24	52.5	95.8	53.4	8.5	0.2	1.6
B23	105-160	0.3	2.1	4.7	0.24	53.5	105.6	53.9	15.9	0.6	2.5

Table 7 - Chemical Analyses For Profiles No. 7 and 8 (Rabba

or. esig.	Depth	Organic matter	Free Fe_2O_3		Electrical conductivity	Cation exchange	
			Soil	Clay		Soil	Clay
	cm	%			mmhos/cm		
					Profile No.7		
p	0-20	0.4	2.9	5.0	0.20	41.0	132.8
21	20-60	0.4	3.1	3.5	0.16	39.6	100.1
22	60-120	0.3	2.9	5.7	0.19	45.7	128.7
23t	120-160	0.1	2.5	4.0	0.21	36.2	80.0
					Profile No.8		
p	0-15	0.6	3.1	6.6	0.13	42.4	129.4
21	15-50	0.6	3.4	5.6	0.17	43.0	130.4
22	50-110	0.5	3.3	5.3	0.17	39.0	97.3
23t	110-150	0.3	2.7	4.7	0.21	38.3	88.3

Table 6 - Chemical Analyses For Profiles No. 5 and 6 (Shihan and Qaser)

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.5						
Ap	0-30	0.4	2.1	4.8	0.19	40.0	117.5	46.5	8.6	0.6	0.7
B21	30-80	0.4	2.1	4.1	0.21	38.3	109.9	46.3	8.5	0.5	1.1
B22	80-120	0.3	2.5	4.3	0.23	43.0	98.1	46.8	9.5	0.5	1.4
B23	120-160	0.2	1.9	3.8	0.30	37.0	94.9	45.8	7.9	0.5	1.8
					Profile No.6						
Ap	0-35	0.5	2.0	4.0	0.16	43.5	118.6	47.0	8.2	0.7	0.4
B21	35-70	0.3	2.0	5.3	0.19	45.2	126.5	46.9	9.2	0.5	0.9
B22	70-110	0.4	2.0	4.4	0.20	41.7	109.7	44.6	6.1	0.5	1.5
B23	110-155	0.1	2.0	5.5	0.27	43.0	82.1	46.5	7.8	0.5	2.2

Table 8 - Chemical Analyses For Profiles No. 9 and 10 (Mshgar and Madaba)

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.9						
Ap	0-20	0.6	2.7	4.2	0.15	43.5	84.5	46.4	8.4	1.3	0.8
B21	20-60	0.4	2.5	4.0	0.18	41.7	133.5	46.8	9.0	0.6	0.4
B22	60-110	0.4	2.7	4.5	0.19	48.3	106.6	46.9	9.7	0.5	0.8
IIB23	110-160	0.2	2.7	3.9	0.18	38.3	86.4	47.3	9.0	0.5	1.2
					Profile No.10						
Ap	0-30	0.6	2.7	5.1	0.13	47.8	93.2	46.4	8.6	1.4	0.3
B21	30-90	0.4	2.5	3.7	0.16	40.0	79.2	46.4	9.2	0.7	0.5
B22	90-130	0.3	3.3	3.1	0.17	36.5	103.2	46.9	10.2	0.8	0.8
IIB23ca	130-160	0.2	3.3	5.4	0.19	36.1	108.3	46.9	10.6	0.7	0.8

Table 9 - Chemical Analyses For Profile No.11 (Baq'aa)

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.11						
Ap	0-40	1.2	3.4	4.8	0.44	43.5	122.3	46.5	9.4	3.6	0.8
B21	40-100	0.4	3.1	4.8	0.47	38.3	90.6	46.9	10.6	0.8	2.9
IIB22	100-170	0.5	3.3	4.7	0.55	40.4	85.0	46.3	10.5	0.9	4.8
IIB23	170-210	0.2	3.6	4.9	0.42	40.4	83.6	46.2	10.9	1.0	5.3
IIIB24ca	210-270	0.2	4.2	3.7	0.32	42.2	73.1	47.1	11.8	1.0	5.4
IIIB25ca	270-350	0.2	4.0	4.2	0.64	45.2	82.3	46.6	11.3	1.0	5.5

Table 10- Particle Size Distribution For Profile No. 1 (Ramtha)

Hor.desig.	Depth cm	Sand			Silt	Clay
		$>$.25mm	.25-.1mm	.1-.05mm	.05-.002mm	$<$.002mm
		%				
			CO_3-Free			
Ap	0-22	0.09	0.06	2.6	60.3	37.0
B21	22-70	0.26	0.03	1.1	56.4	42.1
B22	70-100	0.03	0.03	1.9	59.4	38.6
B23	100-132	1.22	0.03	1.1	56.0	41.6
B24	132-160	0.09	0.15	0.9	55.4	43.4
			With CO_3			
Ap	0-22	0.08	0.05	2.3	65.1	32.5
B21	22-70	0.23	0.03	1.0	61.7	37.0
B22	70-100	0.03	0.03	1.6	65.3	33.0
B24	100-132	1.03	0.03	1.0	63.0	35.0
B25	132-160	0.08	0.05	0.8	62.5	36.5
		Particle Size Distribution-Calculated on Clay-free Basis				
Ap	0-22	0.14	0.10	4.1	95.7	
B21	22-70	0.45	0.05	1.9	97.5	
B22	70-100	0.05	0.05	3.1	96.8	
B23	100-132	2.09	0.05	1.9	95.9	
B24	132-160	0.16	0.27	1.7	97.8	

Table 12 - Particle Size Distribution For Profile No. 3 (Kherja)

Hor.desig.	Depth cm	Sand			Silt	Clay
		>.25mm	.25-.1mm	.1-.05mm	.05-.002mm	<.002mm
		%				
		CO_3-Free				
Ap	0-15	0.11	0.38	1.1	56.3	42.1
B21	15-68	0.08	0.22	0.9	46.9	51.1
B22	68-105	0.08	0.05	0.9	47.9	51.1
B23	105-155	0.29	0.76	0.4	52.7	45.9
		with-CO_3				
Ap	0-15	0.10	0.35	1.0	59.6	39.0
B21	15-68	0.08	0.20	1.0	50.8	48.0
B22	68-105	0.08	0.05	0.8	48.9	48.0
B23	105-155	0.28	0.70	0.4	56.1	42.5
		Particle Size Distribution-Calculated on Clay-free Basis				
Ap	0-15	0.19	0.66	1.9	97.2	
B21	15-68	0.17	0.46	2.1	97.2	
B22	68-105	0.16	0.10	1.7	97.9	
B23	105-155	0.53	1.40	0.8	97.3	

Table 13 - Particle Size Distribution For Profile No. 4 (Maru)

Hor.desig.	Depth cm	Sand			Silt	Clay
		>.25mm	.25-.1mm	.1-.05mm	.05-.002mm	<.002mm
		%				
		CO$_3$-Free				
Ap	0-15	0.80	0.03	0.4	57.8	41.0
B21	15-60	0.08	0.05	0.6	53.0	46.3
B22	60-105	0.30	0.05	0.3	53.5	45.8
B23	105-160	0.32	0.11	0.7	52.1	46.8
		With-CO$_3$				
Ap	0-15	0.80	0.03	0.4	60.3	38.5
B21	15-60	0.08	0.05	0.6	55.3	44.0
B22	60-105	0.28	0.05	0.3	56.4	43.0
B23	105-160	0.30	0.10	0.6	54.5	44.5
		Particle Size Distribution-Calculated on Clay-free Basis				
Ap	0-15	1.36	0.05	0.7	97.9	
B21	15-60	0.15	0.09	1.2	98.6	
B22	60-105	0.55	0.09	0.6	98.7	
B23	105-160	0.60	0.21	1.2	97.9	

Table 14 - Particle Size Distribution For Profile No. 5 (Shihan)

Hor.desig.	Depth cm	Sand			Silt	Clay
		>.25mm	.25-.1mm	.1-.05mm	.05-.002mm	<.002mm
		%				
		CO_3-Free				
Ap	0-30	0.07	0.03	2.8	60.0	37.1
B21	30-80	0.29	0.10	2.6	63.0	34.0
B22	80-120	0.06	0.13	2.8	57.9	39.1
B23	120-160	0.13	0.33	2.2	55.1	42.3
		With-CO_3				
Ap	0-30	0.05	0.03	2.1	69.3	28.5
B21	30-80	0.23	0.08	2.1	71.1	26.5
B22	80-120	0.05	0.10	2.2	67.2	30.5
B23	120-160	0.10	0.30	1.6	65.5	32.5
		Particle Size Distribution Calculated on Clay-free Basis				
Ap	0-30	0.11	0.05	4.5	95.4	
B21	30-80	0.44	0.15	4.0	95.4	
B22	80-120	0.10	0.21	4.6	95.1	
B23	120-160	0.23	0.57	3.7	95.5	

Table 15- Particle Size Distribution For Profile No. 6 (Qaser)

Hor.desig.	Depth cm	Sand			Silt	Clay
		>.25mm	.25-.1mm	.1-.05mm	.05-.002mm	<.002mm
				%		
			CO_3-Free			
Ap	0-35	0.09	0.32	2.6	64.2	32.8
B21	35-70	0.23	0.44	2.4	64.0	32.9
B22	70-110	0.50	0.44	0.6	65.6	32.9
B23	110-155	0.12	0.46	1.7	65.4	32.3
			With-CO_3			
Ap	0-35	0.08	0.28	2.3	69.4	28.0
B21	35-70	0.20	0.38	2.1	68.8	28.5
B22	70-110	0.43	0.38	0.5	70.2	28.5
B23	110-155	0.10	0.40	1.5	70.0	28.0
Particle Size Distribution Calculated on Clay-free Basis						
Ap	0-35	0.13	0.48	3.9	95.5	
B21	35-70	0.34	0.66	3.6	95.4	
B22	70-110	0.75	0.66	0.9	97.7	
B23	110-155	0.18	0.68	2.6	96.6	

Table 16 - Particle Size Distribution For Profile No. 7 (Rabba)

Hor.desig.	Depth cm	Sand			Silt	Clay
		>.25mm-	.25-.1mm	.1-.05mm	.05-.002mm	<.002mm
				%		
			CO_3-Free			
Ap	0-20	0.03	0.22	3.0	64.0	32.7
B21	20-60	0.35	0.26	2.5	61.0	35.9
B22	60-120	0.26	0.36	2.9	58.1	38.4
B23t	120-160	0.16	0.10	3.0	33.3	63.5
			With-CO_3			
Ap	0-20	0.03	0.18	2.4	72.0	25.5
B21	20-60	0.28	0.20	2.0	69.5	28.0
B22	60-120	0.20	0.28	2.2	67.8	29.5
B23t	120-160	0.13	0.08	2.4	47.9	49.5
		Particle Size Distribution Calculated on Clay-free Basis				
Ap	0-20	0.04	0.33	4.5	95.1	
B21	20-60	0.55	0.41	4.0	95.1	
B22	60-120	0.42	0.58	4.7	94.3	
B23t	120-160	0.44	0.27	8.2	91.1	

Table 17 - Particle Size Distribution For Profile No. 8 (Majra)

Hor.desig.	Depth cm	Sand			Silt	Clay
		>.25mm	.25-.1mm	.1-.05mm	.05-.002mm	<.002mm
		%				
			CO_3 Free			
Ap	0-25	0.84	0.42	3.8	60.1	34.8
B21	15-50	1.12	0.42	3.6	58.3	36.5
B22	50-110	1.28	0.43	3.0	55.4	39.9
B23t	110-150	1.17	0.44	2.5	45.0	50.9
			With-CO_3			
Ap	0-15	0.75	0.38	3.4	64.5	31.0
B21	15-50	1.00	0.38	3.2	63.0	32.5
B22	50-110	1.13	0.38	2.7	60.8	35.0
B23t	110-150	1.00	0.38	2.1	53.0	43.5
		Particle Size Distribution Calculated on Clay-free Basis				
Ap	0-15	1.29	0.64	5.8	92.2	
B21	15-50	1.76	0.66	5.7	91.9	
B22	50-110	2.13	0.71	5.0	92.1	
B23t	110-150	2.38	0.90	5.1	91.6	

Table 18 - Particle Size Distibution For Profile No. 9 (Mshgar)

Hor.desig.	Depth cm	Sand			Silt	Clay
		>.25mm	.25-.1mm	.1-.05mm	.05-.002mm	<.002mm
		%				
		CO_3-Free				
Ap	0-20	0.23	0.15	2.4	42.1	55.1
B21	20-60	0.49	0.12	2.0	36.8	60.6
B22	60-110	0.22	0.37	2.4	34.9	62.1
IIB23	110-160	0.70	0.16	2.1	50.9	46.2
		With-CO_3				
Ap	0-20	0.20	0.13	2.1	52.5	45.0
B21	20-60	0.40	0.10	1.6	48.4	49.5
B22	60-110	0.18	0.30	2.0	45.6	52.0
IIB23	110-160	0.55	0.13	1.6	61.7	36.0
Particle Size Distribution Calculated on Clay-free Basis						
Ap	0-20	0.51	0.33	5.4	93.7	
B21	20-60	1.24	0.30	5.1	93.4	
B22	60-110	0.58	0.98	6.4	92.3	
IIB23	110-160	1.24	0.30	3.8	94.5	

Table 19 - Particle Size Distribution For Profile No. 10(Madaba)

Hor.desig,	Depth cm	Sand >.25mm	Sand .25-.1mm	Sand .1-.05mm	Silt .05-.002mm	Clay <.002mm
		%				
		CO_3-Free				
Ap	0-30	0.15	0.06	2.1	36.7	60.9
B21	30-90	0.18	0.06	2.5	34.0	63.3
B22	90-130	0.24	0.12	2.5	29.3	67.9
IIB23ca	130-160	0.17	0.17	2.4	57.6	39.7
		With-CO_3				
Ap	0-30	0.13	0.05	1.8	47.5	50.5
B21	30-90	0.15	0.05	2.0	45.3	52.5
B22	90-130	0.20	0.10	2.0	42.2	55.5
IIB23ca	130-160	0.13	0.13	1.8	67.9	30.0
		Particle Size Distribution Calculated on Clay-free Basis				
Ap	0-30	0.38	0.15	5.5	94.0	
B21	30-90	0.49	0.16	6.7	92.7	
B22	90-130	0.75	0.37	7.6	91.2	
IIB23ca	130-160	0.28	0.28	4.0	95.4	

Table 20 - Particle Size Distribution For Profile No. 11 (Baq'aa).

Hor.desig.	Depth	Sand			Silt	Clay
		>.25mm	.25-.1mm	.1-.05mm	.05-.002mm	<.002mm
		%				
			CO$_3$-Free			
Ap	0-40	0.17	0.66	1.6	31.2	66.4
B21	40-100	0.61	0.45	1.3	31.7	66.0
IIB22	100-170	0.53	0.56	1.3	48.7	48.9
IIB23	170-210	0.62	0.56	1.2	49.3	48.3
IIIB24ca	210-270	0.72	0.72	1.3	26.7	70.6
IIIB25ca	270-350	1.20	1.17	1.6	23.4	72.6
			With-CO$_3$			
Ap	0-40	0.13	0.50	1.2	47.2	51.0
B21	40-100	0.48	0.35	1.0	46.7	51.5
IIB22	100-170	0.40	0.43	1.0	61.2	37.0
IIB23	170-210	0.50	0.45	1.0	61.6	36.5
IIIB24ca	210-270	0.60	0.60	1.1	39.2	58.5
IIIB25ca	270-350	1.02	1.00	1.4	34.6	62.0
			Particle Size Distribution Calculated on Clay-free Basis			
Ap	0-40	0.51	1.96	4.7	92.8	
B21	40-100	1.79	1.32	3.6	93.2	
IIB22	100-170	1.04	1.10	2.5	95.4	
IIB23	170-210	1.20	1.08	2.3	95.4	
IIIB24ca	210-270	2.45	2.45	4.4	90.7	
IIIB25ca	270-350	4.38	4.27	5.9	85.5	

Table 21 - Dry (D_{b_d}), Moist (D_{b_m}) Bulk Density And Coefficent Of Linear Extensibility (COLE).

Hor.	Depth	D_{b_d}	D_{b_m}	(COLE)
		g/cm³		
		Profile No. 1(Ramtha)		
Ap	0-22	1.63	1.31	0.07
B21	22-70	1.82	1.42	0.09
B22	70-100	1.77	1.40	0.08
B23	100-132	1.85	1.48	0.08
B23	132-160	1.80	1.48	0.07
		Profile No. 2(Jamha)		
Ap	0-20	1.65	1.25	0.10
B21	20-50	1.72	1.30	0.10
B22	50-95	1.82	1.32	0.11
B23	95-135	1.70	1.32	0.09
		Profile No. 3(Kherja)		
Ap	0-15	1.58	1.28	0.07
B21	15-68	1.78	1.40	0.08
B22	68-105	1.85	1.43	0.09
B23	105-155	1.91	1.42	0.10
		Profile No.4(Maru)		
Ap	0-15	1.84	1.38	0.10
B21	15-60	1.89	1.38	0.11
B22	60-105	1.79	1.38	0.09
B23	105-160	1.75	1.36	0.09

Table 22 - Dry (D_{b_d}), Moist (D_{b_m}) Bulk Density And Coefficent Of Linear Extensibility (COLE).

Hor.	Depth	D_{b_d}	D_{b_m}	COLE
		g/cm³		
		Profile No. 5(Shihan)		
Ap	0-30	1.64	1.35	0.07
B21	30-80	1.86	1.44	0.09
B22	80-120	1.90	1.44	0.09
B23	120-160	1.88	1.45	0.09
		Profile No. 6(Qaser)		
Ap	0-35	1.73	1.29	0.10
B21	35-70	1.84	1.42	0.09
B22	70-110	1.93	1.46	0.10
B23	110-155	1.88	1.43	0.10
		Profile No. 7(Rabba)		
Ap	0-20	1.80	1.49	0.07
B21	20-60	1.87	1.42	0.10
B22	60-120	1.88	1.45	0.09
B23t	120-160	1.92	1.48	0.09
		Profile No. 8(Majra)		
Ap	0-15	1.93	1.38	0.12
B21	15-50	1.85	1.40	0.10
B22	50-110	1.89	1.40	0.11
B23t	110-150	1.84	1.37	0.10

Table 23 - Dry (D_{b_d}), Moist (D_{b_m}) Bulk Density And Coefffícent Of Linear Extensibility (COLE).

Hor.	Depth	D_{b_d}	D_{b_m}	COLE
		g/cm³	g/cm³	
		Profile No. 9(Mshgar)		
Ap	0-20	1.78	1.30	0.11
B21	20-60	1.82	1.31	0.12
B22	60-110	1.88	1.38	0.11
IIB23	110-160	1.91	1.42	0.10
		Profile No. 10(Madaba)		
Ap	0-30	1.63	1.18	0.11
B21	30-90	1.71	1.36	0.08
B22	90-130	1.73	1.35	0.09
IIB23ca	130-160	1.83	1.41	0.09
		Profile No. 11(Baq'aa)		
AP	0-40	1.59	1.23	0.09
B21	40-100	1.75	1.29	0.11
IIB22	100-170	1.79	1.31	0.11
IIB23	170-210	1.88	1.35	0.12
IIIB24ca	210-270	1.65	1.29	0.09
IIIB25ca	270-350	1.72	1.27	0.11

Appendix - C: Statistical Analyses

Table

Table 24 - Statistical Analysis For Clay And Silt

Analysis	Min.	Mean	Max.	C.V%
		Clay/with-CO_3		
All	25.5	41.4	65.5	27.7
Surface	25.5	39.0	60.0	28.9
Subsurface	26.5	42.1	65.5	27.5
L.Stone	25.5	44.1	65.5	27.6
Basalt	26.5	36.2	48.0	22.1
Rcod-1	38.5	49.9	65.5	20.1
Rcod-2	36.0	47.9	62.0	19.1
Rcod-3	25.5	34.7	55.5	25.0
		Clay/CO_3-Free		
All	32.3	48.5	72.6	25.6
Surface	32.7	45.7	32.7	28.2
Subsurface	32.3	49.3	72.6	25.0
L.Stone	32.7	52,4	72.6	24.7
Basalt	32.3	40.9	51.8	16.4
Rcod-1	41.0	52.6	67.1	18.5
Rcod-2	46.2	59.7	72.6	16.1
Rcod-3	32.3	42.0	67.9	25.4
		Silt/with-CO_3		
All	33.7	56.5	71.9	20.0
Surface	39.0	58.8	71.9	18.4
Subsurface	33.7	55.8	71.1	20.8
L.Stone	33.7	53.6	71.9	22.2
Basalt	48.9	62.1	71.1	12.3
Rcod-1	33.7	48.7	60.3	20.8
Rcod-2	34.6	49.9	61.7	18.9
Rcod-3	42.2	62.8	71.9	13.8

Table 25- Statistical Analysis For Silt and Cation exch. Capci.

Analysis	Min.	Mean	Max.	C.V%
		Silt/CO_3-free		
All	23.4	49.1	65.6	25.0
Surface	31.8	51.8	64.2	23.8
Subsurface	23.4	48.2	65.5	25.5
L.Stone	23.4	44.9	64.0	28.1
Basalt	46.9	57.2	65.6	10.6
Rcod-1	32.1	46.2	57.8	21.5
Rcod-2	23.4	37.6	50.9	25.9
Rcod-3	29.3	55.0	65.6	19.3
		C.E.C/clay		
All	73.1	102.9	133.5	16.4
Surface	84.5	112.2	132.8	15.0
Subsurface	73.1	100.0	133.5	16.1
L.Stone	73.1	100.5	133.5	18.7
Basalt	82.1	107.4	121.6	10.7
Rcod-1	95.8	108.3	121.6	7.6
Rcod-2	73.1	94.8	133.5	20.6
Rcod-3	74.1	103.5	132.8	17.6
		C.E.C/Total		
All	35.9	44.5	57.5	15.5
Surface	40.0	46.7	57.1	13.6
Subsurface	35.9	43.9	57.5	16.0
L.Stone	35.9	42.6	56.2	13.7
Basalt	37.0	48.3	57.5	15.4
Rcod-1	52.5	55.0	57.5	3.3
Rcod-2	38.2	42.2	48.3	7.4
Rcod-3	35.9	40.4	47.8	8.3

Table 26 - Statistcal Analysis For Free Iron Oxides And O.M

Analysis	Min.	Mean	Max.	C.V%
		Free Fe_2O_3/Total		
All	1.7	2.7	4.2	20.5
Surface	2.1	2.7	3.4	13.3
Subsurface	1.7	2.7	4.2	22.3
l.Stone	1.9	2.9	4.2	18.9
Basalt	1.7	2.3	3.4	18.5
Rcod-1	1.7	2.3	3.1	17.4
Rcod-2	2.5	3.2	4.2	18.2
Rcod-3	1.9	2.7	3.4	16.4
		Free Fe_2O_3/clay		
All	2.2	4.6	6.6	19.8
Surface	3.7	5.0	6.6	15.3
Subsurface	2.2	4.5	6.5	20.6
L.Stone	3.1	4.6	6.6	20.1
basalt	2.2	4.6	5.8	19.7
Rcod-1	2.2	4.3	5.8	25.7
Rcod-2	3.7	4.4	4.9	9.9
Rcod-3	3.1	4.9	6.6	18.3
		Organic Matter		
Alll	0.1	0.4	1.2	50.2
Surface	0.4	0.7	1.2	35.8
Subsyrface	0.1	0.3	0.7	41.2
L.Stone	0.1	0.4	1.2	51.9
Basalt	0.1	0.5	1.0	48.7
Rcod-1	0.3	0.6	1.0	35.0
Rcod-2	0.2	0.4	1.2	71.2
Rcod-3	0.1	0.4	0.7	41.4

Table 27 - Statistical Analysis For Bulk Density And COLE

Analysis	Min.	Mean	Max.	C.v%
		B.Density/dry		
All	1.6	1.8	1.9	5.6
Subsurface	1.6	1.7	1.9	6.7
Subsurface	1.7	1.8	1.9	3.9
L.Stone	1.6	1.8	1.9	5.3
Basalt	1.6	1.8	1.9	5.5
Rcod-1	1.6	1.8	1.9	5.5
Rcod-2	1.7	1.8	1.9	5.8
Rcod-3	1.6	1.8	1.9	5.0
		B.Density/moist		
All	1.2	1.4	1.5	5.3
Surface	1.2	1.3	1.5	6.5
Subsurface	1.3	1.41	1.5	4.2
L.Stone	1.2	1.4	1.5	5.7
Basalt	1.3	1.4	1.5	3.7
Rcod-1	1.3	1.4	1.4	4.2
Rcod-2	1.2	1.3	1.4	4.2
Rcod-3	1.2	1.4	1.5	5.0
		COLE		
All	0.07	0.10	0.12	14.7
Surface	0.07	0.09	0.12	20.7
Subsurface	0.07	0.09	0.12	12.5
L.stone	0.07	0.09	0.11	15.5
Basalt	0.07	0.09	0.11	11.9
Rcod-1	0.07	0.09	0.11	12.8
Rcod-2	0.09	0.11	0.12	10.3
Rcod-3	0.07	0.09	0.12	14.3

Table 28 - Statistical Analysis For Carbonates and pH

Analysis	Min.	Mean	Max.	C.V%
		CO_3-rest		
All	0.1	0.2	0.4	54.1
Surface	0.1	0.2	0.4	53.8
Subsurface	0.1	0.2	0.4	54.4
L.Stone	0.1	0.2	0.4	48.1
Basalt	0.1	0.1	0.4	57.5
Rcod-1	0.1	0.2	0.4	63.4
Rcod-2	0.1	0.2	0.3	47.0
Rcod-3	0.1	0.2	0.4	52.8
	CO	CO_3-VFS		
All	0.1	0.3	0.7	59.9
Surface	0.1	0.3	0.7	61.3
Subsurface	0.1	0.3	0.6	58.1
L.Stone	0.1	0.3	0.7	59.2
Basalt	0.1	0.3	0.5	63.7
Rcod-1	0.1	0.1	0.3	49.6
Rcod-2	0.1	0.2	0.4	52.4
Rcod-3	0.1	0.4	0.7	40.2
		CO_3-Silt		
All	0.5	7.3	17.3	61.3
Surface	0.5	8.1	17.3	62.9
Subsurface	0.6	7.0	15.6	61.1
L.Stone	0.5	7.7	15.8	54.0
Basalt	1.1	6.4	17.3	78.0
Rcod-1	0.5	1.7	3.1	55.8
Rcod-2	1.9	8.1	12.1	44.0
Rcod-3	4.9	9.6	17.3	34.7

Table 29 - Statistical Analysis For Carbonates And pH

Analysis	Min.	Mean	Max.	C.V%
		CO_3-Clay		
All	1.9	6.9	15.4	53.7
Surface	3.1	5.7	12.6	49.6
Subsurface	1.9	7.3	15.4	53.7
L.Stone	1.9	7.8	15.4	50.3
Basalt	3.3	5.2	12.5	49.8
Rcod-1	1.9	3.6	5.7	30.5
Rcod-2	4.2	11.1	15.4	30.8
Rcod-3	3.5	6.9	14.8	43.2
		CO_3-Total		
All	2.4	14.8	24.4	45.8
Surface	3.7	14.4	23.2	48.3
Subsurface	2.4	14.9	24.4	45.7
L.Stone	2.4	16.1	24.4	39.5
Basalt	4.9	12.2	23.2	57.4
Rcod-1	2.4	5.3	7.3	31.4
Rcod-2	14.6	19.9	24.4	15.1
Rcod-3	11.0	17,2	24.4	26.4
		pH		
All	7.5	8.0	8.2	1.9
Surface	7.5	7.8	8.0	1.9
Subsurface	7.7	8.0	8.2	1.6
L.Stone	7.5	8.0	8.2	2.2
Basalt	7.8	8.0	8.2	1.4
Rcod-1	7.5	7.8	8.0	16.6
Rcod-2	7.6	8.0	8.3	2.5
Rcod-3	7.8	8.0	8.2	1.3

Table 30 - Statistical Analysis For Extractable Cations

Analysis	Min.	Mean	Max.	C.V%
		Calcium		
All	39.1	46.7	55.4	6.8
Surface	44.9	47.7	55.2	7.0
Subsurface	39.1	46.6	55.4	6.7
L.Stone	39.1	45.9	48.0	4.9
Basalt	44.6	48.8	55.4	7.9
Rcod-1	46.1	49.9	55.4	7.8
Rcod-2	46.2	46.7	47.3	0.8
Rcod-3	39.1	45.4	47.4	5.2
		Magnesium		
All	5.7	8.9	15.9	22.7
Surface	5.7	8.7	14.8	27.4
Subsurface	6.1	8.9	15.9	21.5
L.Stone	5.7	8.7	11.8	19.7
Basalt	6.1	9.2	15.9	27.5
Rcod-1	6.3	9.6	15.9	29.4
Rcod-2	8.4	10.1	11.8	11.2
Rcod-3	5.7	8.1	10.6	18.2
		Potassium		
All	0.2	0.8	3.6	84.3
Surface	0.4	1.3	3.6	72.9
Subsurface	0.2	0.6	1.0	38.2
L.Stone	0.3	0.8	3.6	74.0
Basalt	0.2	0.6	1.5	51.8
Rcod-1	0.2	0.5	1.5	67.0
Rcod-2	0.5	1.1	3.6	81.1
Rcod-3	0.4	0.7	1.9	48.9

Table 31- Statistical Analysis For Ext. Sodium And E.C

Analysis	Min.	Mean	Max.	C.V%
		Sodium		
All	0.3	1.4	5.5	97.1
Surface	0.3	0.5	0.8	33.4
Subsurface	0.4	1.6	5.5	86.2
L.Stone	0.3	1.5	5.5	106.1
Basalt	0.4	1.2	2.5	55.3
Rcod-1	0.4	1.0	2.5	64.0
Rcod-2	0.4	2.8	5.5	79.2
Rcod-3	0.3	1.0	2.3	60.0
		Electical Conductivity		
All	0.13	0.23	0.64	44.9
Surface	0.13	0.21	0.44	41.0
Subsurface	0.15	0.24	0.64	45.6
L.Stone	0.13	0.24	0.64	52.9
Basalt	0.16	0.22	0.30	14.8
Rcod-1	0.16	0.22	0.25	11.9
Rcod-2	0.15	0.35	0.64	49.9
Rcod-3	0.13	0.19	0.30	20.1

* Rcod-1 : 400-500mm rainfall,
Rcod-2 : 350-400mm rainfall,
Reod-3 : 250-350mm rainfall.

وتبين ايضا ان كمية الكربونات كانت اعلى في تلك الاراضي المتكونه من الحجر الجيرى من تلك الاراضي المتكونه من البازلت، وتتناقص بازدياد كميات الامطار.

يتميز قوام هذه الاراضي بنسبه عاليه من الطين (٣٠ - ٧٢٪) ، ويسود معدن طين السمكتيت والذى يعزى اليه تشقق الاراضي في فصل الجفاف الاراضي المتكونه من الحجر الجيرى ، بينما كانت معادن الطين المتداخله على شكل السمكتيت/ فيرميكيولايت سائده في الاراضي المتكونه من البازلت بغض النظر عن كميات الامطار المختلفه.

كما وجد ايضا ان كمية اكاسيد الحديد والماده العضويه تتناسب طرديا مع كميات الامطار بغض النظر عن نوع مادة الاصل .

كانت كمية الكالسيوم اعلى في الاراضي المتكونه من الحجر الجيرى عن تلك المتكونه من البازلت، بينما كانت كمية المغنيسيوم اعلى في الاراضي المتكونه من البازلت، وتزداد كمية هذين العنصرين بازدياد كميات الامطار.

بينما كانت كمية الصوديوم والبوتاسيوم متأثره بكميات الامطار فقط بغض النظر عن نوع مادة الأصل ، حيث ازدادت كمية الصوديوم بازدياد الامطار، وقلت كمية البوتاسيوم.

سعه تبادل الايونات الموجبه كانت اعلى في الاراضي المتكونه من البازلت عن تلك في الاراضي المتكونه من الحجر الجيرى ، وتزداد بازدياد كميات الامطار.

كما وجد ايضا ان هذه الاراضي لا تتواجد في المناطق التي تقل فيها كميات الامطار عن ٣٠٠ مم / سنويا .