GEOMORPHOLOGY AND SOILS OF HARYANA STATE, INDIA

A THESIS

submitted in fulfilment of the
requirements for the award of the degree
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DOCTOR OF PHILOSOPHY
in
EARTH SCIENCES

By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **"GEOMORPHOLOGY AND SOILS OF HARYANA STATE INDIA"** in fulfilment of the requirement for the award of the Degree of Doctor of Philosophy submitted in the Department of Earth Sciences of the University is an authentic record of my own work carried out during a period from January,1986 to December, 1988 under the supervision of Prof. B.Parkash, Prof. M.L.Manchanda and Dr.A.K.Pachauri.

The matter embodied in this thesis has not been submitted by me for the award of any other degree.

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GEOMORPHOLOGY AND SOILS OF HARYANA STATE, INDIA

ABSTRACT

Haryana State (India) over its major parts, is underlain by the Indogangetic Plains and is bordered by the outer Himalayan ranges i.e. Siwalik Ranges in the northeast and by the northern tip of the Aravalli Ranges in the southwestern part. This region including the adjoining area of Panjab is known to have witnessed drastic changes in courses and discharges of the rivers like the Saraswati, Yamuna and Sutlej since Protohistoric times. The area has also been a scene of tectonic activity since Mid-Miocene time and climate changes during middle and late - Holocene and exploitation by man since Protohistoric period. All the above factors could have resulted in instability of the environment and are likely to be reflected in physiography and soils of the area. The present study aims at a detailed study of geomorphology and soils of the area and work out the effects of the above mentioned factors on them.

In the present investigations, a detailed and systematic study of regional distribution of landforms and soil has been made using Landsat imageries and CCT's, published literature and field work. Thirteen geomorphic units, with distinctive soils, identified and delineated on the map are : (a) Siwalik Hills, (b) Aravalli Hills, (c) Old Sutlej Plain, (d) Aeolian Plain, (e) Basin with Marl, (i) Older Piedmont Plain, (g) Younger Piedmont, (h) Yamuna Floodplain, (i) Ghagger Floodplain, (j) Kaithal Upland Plain, (k) Karnal Upland Plain, (l) Drishadvati Plain and

(m) Fluvio-Aeolian Plain.

In all 34 pedons well distributed over different geomorphic units have been studied for their field characters. 184 sample collected from major soil horizon of different pedons have been analysed for their grain-size distribution, pH, EC, major elements, minor elements (Cu, Mn, and Zn) and micromorphology. Silt+clay, Fe_2 O_3 and Al_2O_3 accummulation indices, presence or absence of $CaCo_3$ concretions and oxidation mottling / Fe-Mn concretions and micromorphological aspects such as degree of development of pedality, grain structure and ferri-argillans are all used in an integrated way to know the degree of development of soil profiles on different geomorphic units and to construct a soil-chronosequence for the area of study.

Soils of different geomorphic units have been classified into three members of a post incisive soil-chronosequence i.e. Q_1, 1000 B.P., Q_2, 3500 B.P.and Q_3, 5000 B.P. These members of the chronosequence include soils of different geomorphic units as follows : Q_1- Yamuna Floodplain, Q_2 - Younger Piedmont, Fluvio-Aeolian Plain (Basin with Marl, top soil only) and Ghagger Flood plain and Q_3 - Karnal Upland Plain, Kaithal Upland Plain, Basin with Marl (Palaeo-lacustrine Marl) and Older Piedmont.

Also tectonic features identified from the study-area are : Main Boundary Fault, Foothill Fault, Southern Boundary Fault, Yamuna Fault and Ghagger Fault.

The sequence of events suggested, for evolution of soils, landforms and drainage of the study area, is (i) the Yamuna debouched into Haryana plains and probably flowed through the wide Drishadvati Plain and changes to its present course about 5000 B.P. due to activity along the Yamuna Fault. (ii) Next phase includes the formation of mesohaline lakes along depression northeast of Aravalli Ranges and development of soils with calcretes (5000 B.P. to about 3500 B.P.) on the Drishadvati Plain and Karnal and Kaithal Upland Plain and Calcrete free soils on the Older Piedmont, and (iii) the last phase starts at about the time 3500 B.P., it marked by the end of lacustrine sedimentation, covering the area of units - Basin with Marl and Fluvio-Aeolian Plain with a thin cover of fluvial sands, their reworking by wind and tilting of the Older Piedmont zone in the north, start of deposition of the Younger Piedmont and northward shifting of the Sutlej river course from a tributary of the Ghagger to an independant tributary of the Indus.

In brief, emphasis throughout the study is on a closer understanding of role of tectonism in shifting of river courses and development of landforms and soils of the area.

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INTRODUCTION

1.1. RATIONALE

Major part of the Haryana State (Fig. 1.1) lies in the westernmost part of the Indogangetic plains of India and spans an area between the Aravalli Hills (northrenmost extension) and the Siwalik Hills of the Sub-Himalayas. This area has been a scene of tectonic activity since about the Mid-Miocene (Parkash and Kumar, in press). Also, parts of the Thar desert just southwest of this area witnessed significant climatic fluctuations in the middle and late Holocene period (Singh, 1971; Singh et al., 1974) and the probability of this area being affected by these environmental vicissitudes is very high. The region was drained by the mighty Saraswati and Drishadvati rivers (now extinct or represented by smaller streams) and extensively referred to in the old Vedas. This also points to significant changes in courses/discharges of rivers of the area in the late - Holocene. The area has been inhabited by man at least from the time of Pre-Harappan period and overexploitation of the region by man could also trigger instability of the environment.

The environmental changes as well as instability caused by tectonic activity should be reflected in the landforms and soils of the area. The present study attempts a detailed mapping and description of landforms and related soils and aims at reconstruction of the evolution of these two variables i.e. environment and tectonic activity in the area during the late-Holocene.

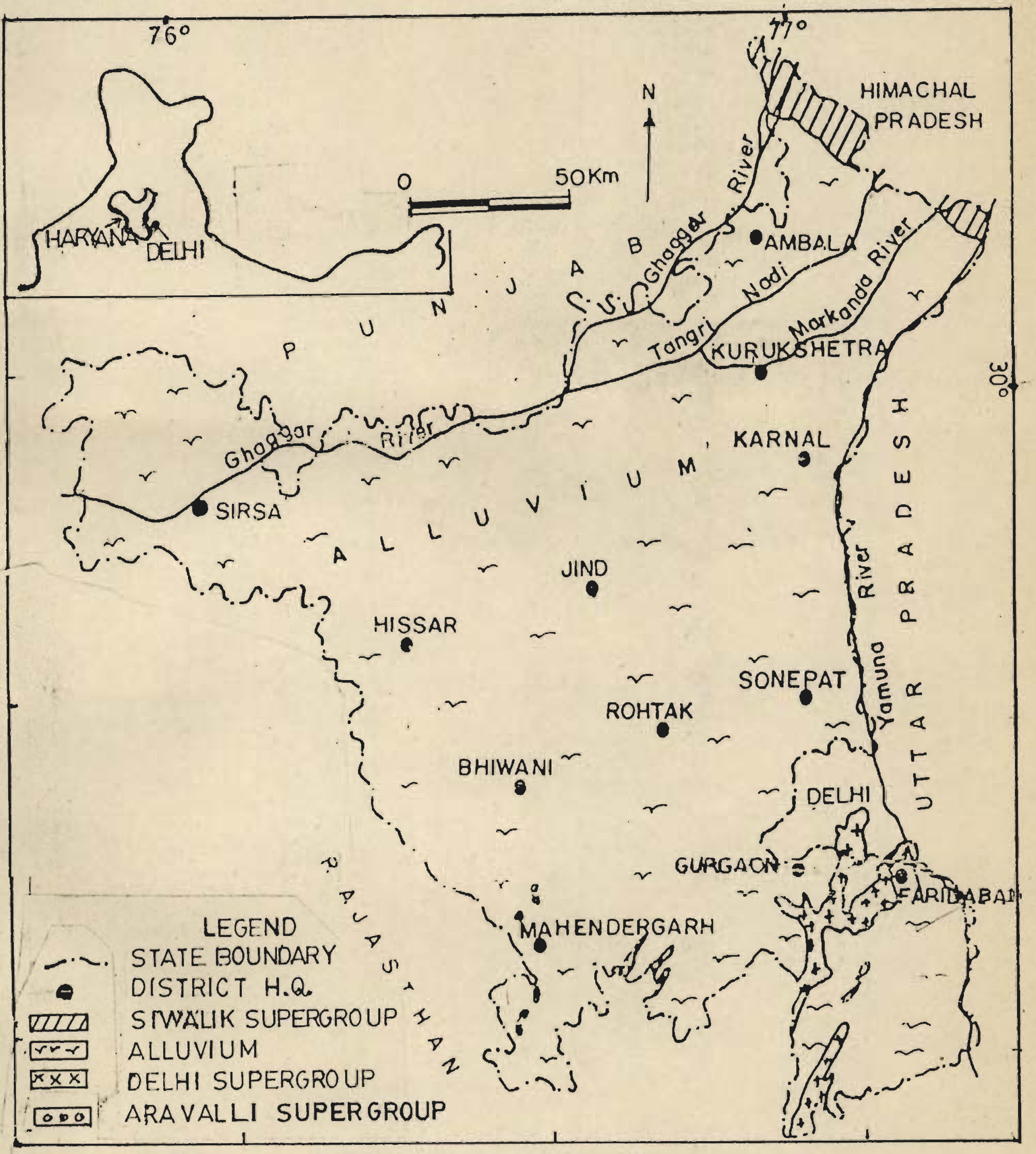

FIG 1. GEOLOGICAL MAP OF HARYANA

Table 1.1 Average monthly rainfall (mm) for the period 19 78 -83.

DISTRICTS	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	ANNUAL TOTAL
HISSAR	16.1	14.5	20.8	31.3	31.4	26.2	122.2	62.6	29.2	4.5	6.9	8.2	373.9
BHIWANI	16.2	15.1	18.6	21.3	21.0	25.1	110.0	76.9	14.0	7.6	5.7	5.6	337.1
GURGAON	17.5	15.1	23.8	21.2	44.7	69.7	213.5	159.7	49.6	8.3	8.9	7.3	639.0
GIND	14.3	21.5	15.5	31.5	35.7	22.6	121.4	94.4	48.8	0.0	5.7	6.9	418.3
MAHENDRA-GARH	15.3	17.3	20.6	13.2	42.1	44.9	156.4	123.7	16.6	6.6	14.3	7.0	478.0
AMBALA	72.6	32.4	30.2	36.1	39.1	73.5	316.9	255.7	80.0	10.3	20.6	26.4	993.8
KARNAL	35.9	15.9	45.3	33.0	22.8	41.1	252.3	94.2	39.1	6.7	11.6	13.9	611.8
ROHTAK	18.1	17.7	27.9	20.3	24.2	51.5	196.0	119.9	39.8	11.3	10.9	7.4	545.0
SONIPAT	24.8	19.4	40.9	28.8	32.1	77.5	292.7	226.8	60.2	15.0	12.5	12.7	843.7
KURUKSHETRA	33.8	17.2	37.1	32.4	21.1	45.4	214.0	104.9	51.4	4.9	14.9	12.2	589.3
FARIDABAD	14.4	10.4	18.8	28.2	25.5	64.9	170.1	148.9	58.9	13.0	3.2	6.6	562.9
SIRSA	8.5	20.0	18.9	20.5	23.7	12.0	95.2	47.7	20.0	3.0	16.0	4.7	290.2

SOURCES : Directorate of Land Records, Haryana.
Statistical Abstract of Haryana, 1984-85

Table 1.1

NORMAL MONTHLY MEAN TEMPERATURE (AT SELECTED STATIONS) IN DEGREE CENTIGRADE

DISTRICTS	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
HISSAR (1984)	12.3	13.7	22.1	27.3	34	32.5	29.4	29.5	27.3	23.9	18.6	14.8
BHIWANI (1971-81)	12.5	14.9	19.9	27.4	31.27	32.97	30.78	30.97	28.62	25.3	17.9	13.86
GURGAON (1969-80)	13.8	15.2	20.3	27.5	31.4	32.6	30.4	28.9	28.1	25.9	21.1	15.4
JIND	13.6	16.4	22.3	28.4	33.2	32	32.5	30.8	31.1	25.1	18.7	15.2
AMBALA (1884)	12.3	13.7	22.1	27.3	34	32.5	29.4	29.5	27.3	23.9	18.6	14.8
KARNAL	14.2	15.6	21.3	27.1	30	31.4	30.1	28.7	27.4	24.1	18.9	15.6
ROHTAK (1976-79)	13.5	14.6	19.6	26.2	31	31.2	29.8	28.6	28	25.3	21.6	15.1

SOURCE: 1. Statistical Abstract of Haryana (1984-85)
2.Depty Commissioners office,Rohtak
3.Soil Survey Report, Part of Yamuna Alluvial plain, Near Assandh, Karnal by D.K.Verma, et al.(9182)

1.2 GENERAL FEATURES

1.2.1 Location and Extent of the Study Area

Haryana State is located in the northwest part of India between 27^0 39′ to 30^0 55′ N and 74^0 27.8′ to 77^0 36.5′ E (Fig.1.1). The total area of about 44,000 sq km, mainly forms a part of of the Indogangetic plains. It has a steeper slope in the northeast in the alluvial piedmont (locally called 'Bhabar') and the rest of the plain is almost flat with a slope from northeast to southwest. General height varies from 212 to 273 m above mean sea level.

1.2.2. Climatic Conditions

The Himalaya in the northeast and the Thar desert in the southwest of Haryana state determine its climatic conditions. It receives much needed rain bearing depression during rainy monsoon season, which lasts from July to September (Table 1.1). 80 % of the annual rainfall is received in these three months. Generally dry conditions prevail from October to the end of June next, except for a few light showers received from the westerly depression coming from the Middle East and yielding a little moisture on being lifted against the Himalaya. The climate of the area can be broadly referred to as sub-tropical and semi-arid with average annual rainfalls of 993.8 mm in northeast and 290.2 mm in the southwest respectively.

A considerable variation exists between the normal mean, maximum (June) and normal mean, minimum (January) temperatures for the study area (Table 1.2). The mean monthy temperature is as high as 40^0 C during the hottest months i.e. May and June in the plains and 30^0 C in hilly areas, while the mean monthly

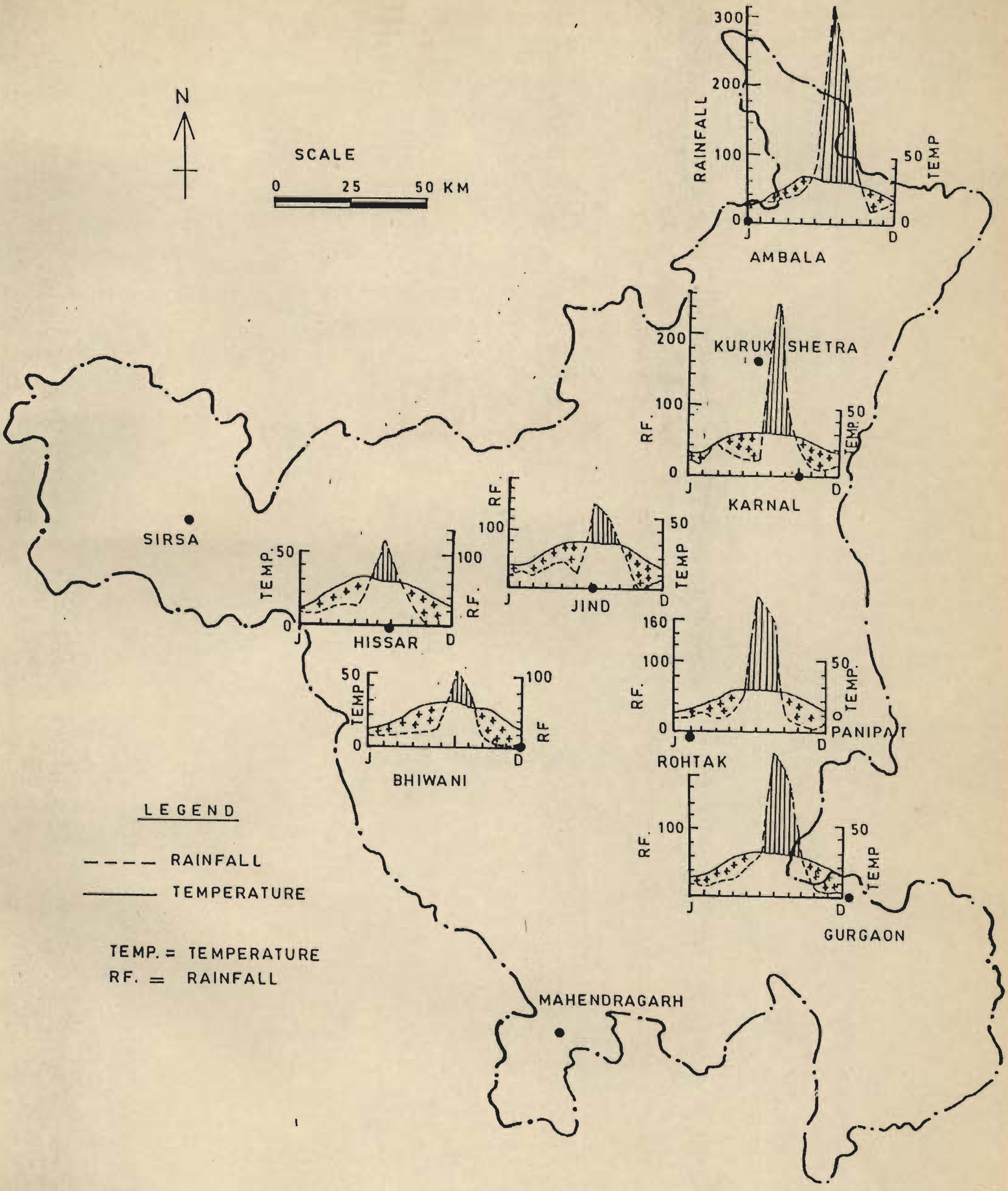

Fig. 1·2 – Temperature-Precipitation diagrams for different stations in Haryana.

temperature is as low as 1^0 to 3^0 C in plains and + / - 2^0 C in hilly areas in coldest months. The temperature variation is greater in dry season than in rainy season. The temperature follows an upward trend from February until the maximum is reached in the month of June. During these intense summer months high velocity dust storms are also experienced. With the onset of monsoon, although temperature tends to drop, fairly high temperature prevails till October, beyond which the monthy minimum is reached in the month of January.

In general, summers are extremely hot and winters cool. The presence of mountains in the northeastern region greatly modifies the temperature. Temperature increases and rainfall decreases as the distance from the Himalaya increases.

1.2.3 . Soil Moisture

Temperature and rainfall being the two basic components of climate, other parameters like relative humidity, potential evapotranspiration (PET) follow nearly similar trends in the area. It is seen that PET - demands record steep rise with rising temperature and decreasing relative humidity from February to May (Fig. 1.2). The increased relative humidity during monsoon months results in low evaporative demands, whereas prevailing temperature conditions are responsible for low PET during winter months.

In south to southwestern parts of the State (Hissar, Bhiwani, Mahendergarh districts), there is practically no period when water supply is more or even equal to water need. Since water need is much more than rainfall, whatever, amount of moisture is received (as rainfall), is utilized as evapotranspiration. An invariably long and continuous dry period from January till December is experienced. The dryness is more pronounced from March to June. The soil moisture regime of these parts is aridic.

In most of Haryana State, except the areas mentioned above, the variations in soil moisture regime are still great. However, one may find two dry periods (March to June and October to November), wherein water need exceeds water supply and the need is much more pronounced during the former period. This necessitates a withdrawal of moisture from the reservoir. Water supply from the reservoir may in some cases be sufficient to meet the need of second dry period (October to November), but it is not enough to meet the need of the first dry period at all places, thus rendering the soil dry for about 80-100 days consecutivly and 100-180 days cumulative in a year. Also as temperature is more than 22^0C, soil moisture regime of the area is classified as Ustic.

1.2.4. Natural Vegetation

The plains consituting about 80% of the area of the Haryana state are mostly under cultivation. In general, the area bears scarce natural vegetation, except in badly dissected areas of the piedmont zone, where thin forest may exist. Important vegetation species found in the area are Ak (Calotropics procera), Bhakra (Tribulus terrestris). Pohli (Carthamus oxycantha), Dub (Cynodon dactylon) and Sarkanda (Sacchrum sp.) among grasses and weeds; Babul (Acacia arabica), Khair (Acacia catactin), Neem (Azadirecta indica) and Beri (Zizyphus jujuba) among trees.

1.2.5. Agriculture and Landuse

As mentioned above, most of the plains are being used for agriculure, which forms the backbone of economy of the area. With improved technology in the field of agriculture including release of high yielding varities of wheat and rice, use of fertilizers and other management practices, intensive cropping is being increasingly adopted in these areas. paddy-wheat is the most common rotation, where soil and water facilities are favorable. Besides sugarcane, potatos, oilseeds and cotton are also importnat cash crops grown. The main cropping patterns being adopted in the areas are :

	Kharif (Summer)	Rabi (Winter)
Rainfed	maize, guar	gram, wheat, oilseeds
Irrigated	paddy, cotton	wheat, sugarcane

Some parts of the plains in the State are barren, because of being affected by salinity and/or alkalinity. However, these areas are also being reclaimed and put under cultivation due to increasing pressure for agriculture on land. Northeastern parts of the plains are well irrigated and are extensively irrigated and use of farm machines is made in these areas on a moderate scale. Southwestern parts of the state have scanty irrigation facilities and soils in these areas are also light textured.

1.2.6 Drainage

The major rivers flowing in the area are the Yamuna, Ghaggar, Markanda, Saraswati, Chatuang, Sahibi, Kalinadi and

Dohan nadi. The Yamuna and Ghaggar are the major rivers and have perennial flow. These have their source in the Himalaya. They form the northern and eastern boundaries of the major of the study area. All other streams are seasonal rivers. The Markanda and Chatuang are the minor streams. After emerging from the Siwalik Hills, they flow southwestwards to get lost in the sandy semiaridic tract or are able to join the Ghaggar. Dohan, Sahibi and Kalinadi originate in the Aravalli Ranges, flow northwards and they loose their waters around 28^0 30′ N latitude.

1.2.7 Irrigation

Haryana state has extensive facilities for cananl irrigation in general. The oldest Yamuna Canal commissioned in 1883 and entering the area from northeast, caters to major irrigation needs of the State. After travelling for 100 km distance, it birfurcates into Hansi and Delhi branches. Other canals irrigating the area, especially the north-western region, are Birendra Narayan Chakravarti canal, Indira Gandhi Canal and Jui Canal with lift irrigation systems.

1.2.8 Communication

Most of the study area is well connected by roads and railway line, except northern hilly parts and southwestern semi-desertic tract, which is because of low population and problem of construction and maintenance of roads in these areas.

1.3. GEOLOGY OF THE STUDY AREA

Geomorpgolocially and geolgically the study area can be divided into three zones:

i. Siwalik Hills

ii. Indogangetic Alluvial Plain, and

iii.Aravalli Hills

A brief description of these zones is given below.

1.3.1 Siwalik Hills

Northeastern part of Haryana is bordered by the Siwalik Hills. These are comprised of rocks of Siwalik Supergoup of Paleocene to Lower Pleistocene in age, which have been moderately to intensely folded and faulted. The Tertiary sequence of the Siwalik Hills consist of about 10,000m of mainly clastic sediments. The Siwalik Supergroup of rocks are in contact with the unfossiliferous rocks of the Lesser Himalaya in the north along the Main Boundary Fault (MBF) and also has a faulted contact with the sediments of the Indogangetic Plain to the south. The later fault has been named as foothill fault in a later section (2.4).

1.3.2 Indogangetic Plains

The Indogangetic plains cover the major part of the study area. Geophysical and borehole studies by the Oil and Natural Gas Commission indicates that in this area, in general, the Siwalik Supergroup of rocks overlie unconformably the basement of the Aravalli and Delhi Supergroups of rocks. The Siwaliks are little deformed and are almost flat lying. The thickness of the Siwalik Supergroup along with the overlying Pleistocene alluvium in this area is between 1000 m and 3000 m, the maximum being close to the Siwalik Hills and it decreases towards the Aravalli Hills to the southwest.

1.3.3 Aravalli Hills

Southern part of Haryana state is covered by Aravalli Hills, extending as hillock and ridges, and comprising rocks of the Aravalli Supergroup overlain by Delhi Supergoup rcoks. Lithologically, the rocks of the Aravalli Hills are mainly quartzite, phyllite, schist and crystalline limestone. The rocks are traversed by basic intrusives, granites, pegmatites and quartz veins. These rocks act as alomost dividing screen between areas with high and low aeolian activity.

1.3.4 Geological History of the Area

Parkash and Kumar (in press) have provided a good rerview of the evolution of the Indogagetic Basin. Their study suggests that the Siwalik Hills represent deformed portion and the Indogangetic plains consititute the undeformed portion of the Indogangetic Molasse Basin. This basin with about 10.000 m thick sediments, develped as a result of the collision of the India and China continental plates during the Paleocene. Collision resulted in intraplate subduction along the Main Central Thrust, raising the Higher Himalaya to form source rocks and "popping through" of the more southerly part of the India plate to form the basin. With time, more southerly areas were raised and by Mid-Pliocene subduction also started along the MBF. A mainly clastic sequence with coarsening-up nature was deposited. Folding of the northern edge of the basin during the Early Pleistocene formed the Siwalik Ranges.

The Indogangetic Basin had a east-west elongated shape and started with a shallow marine environment, which changed to estuarine and deltaic one with time. By Mid-Miocene, continental sedimendation marked by fluvial enviroment dominated the scene and this setup has continued to the Present with minor modifications.

1.4. PREVIOUS WORK

Soil scientists have studied soils of Haryana mainly from the agricultural point of view. Most of these studies are limited to investigation of soil profiles, their particle-size analysis, chemical analysis for small areas of the State. Some workers have studied morphology in relation to soil for the region, and micromorphology and clay mineralogy of some pedons in the state as well. Major effort has been made in respect of classification of soils from the agricultural point of view.

The physiographic-soil relationship has been studied in different parts of the alluvial plain by using aerial photographs and/or landsat imageries (Bhandari et al., 1976; Khanna et al., 1977; Ahuja et al., 1978; Sangwan, 1978; Garalapuri et al., 1978, Manchanda and Khanna, 1979; Goyal, 1981). A report on geomorphology, soil and landuse of Haryana has been brought out by Dhankar et al. (1983).

Ahuja and Khanna (1983) have subdivided the Ghaggar river basin into i. relict channel course, ii. levees and bars, ii. relict channels. iv. undifferentiated plain, and v. old basin. Shanwal (1984) and Shanwal et al. (1985) have classified the Yamuna alluvial plain into: i. recent flood plain, ii. young meander plain, iii. old meander plain and iv. old alluvial plain.

Role of fluvial and aeolian proceses in development of various soil groups has been emphasized in western Rajasthan (Roy et al., 1967) and in northern Indian plains (Shankarnarayana and Hirekerur, 1972). Statigraphy of the Ghaggar-Hakra river basins in Rajasthan exhibits alternate layers of aeolian and fluvial origin indicating that these processes have been acting in this region for fairly long period (Gupta et al., 1976).

Salinity of soils of plains of Haryana and other similar areas of the Indogangetic plains has been attracting the attention of scientists for over a century. Medlicott (1878), Voelcker (1897), Center (1880) and Leather (1897) were the early workers who studied this problem. Leather (1897), Desigmon (1927) and Sen (1958) discuss the climatic factors influencing the salinization of Indian soils and find that rainfall has a greater effect than annual temperature in determining the salinity of soils. More recently, notable studies have been those of Govindrajan et al. (1970), Bhargva et al. (1972) and Kaushik and Shukla (1977), who observe that a poor drainage and high water table lead to the soil salinization in Haryana. Manchanda (1978) finds a strong relationship between certain landform units and salinity-akalinity. Bhargava et al. (1980) attempt to correlate salinization and alkalinization with precipitation, topography, hydrology and hydrogeochemical factors and find salinity to be restricted to rainfall zone of 500-600 mm.

Manchanda and Khanna (1980) have observed mechanical illiviation of clay in the soils of Upland area, where soils are impregnated with salts. In case of undifferentiated Aeolian Plain, soil texture is uniformly coarse and there is no development of argillic horizon. Manchanda et al. (1983) have pointed out that a mere increase in clay content and shining ped faces as obseved in the field for recognition of an argillic horizon are sufficient most of time, especially for alluvial soils, but confirmation by thin sction studies is essential. Bhargava et al., (1985) report clay illuviation in sodic soils from Haryana and other northwestern parts of the Indogangetic plains.

Calcium carbonate accumulation in the soils of Haryana has been investigated by some workers. Sen (1953) observe that the saline-alkaline soils of Karnal are characterised by a zone of accumulation of calcium carbonate in the form of nodules. Roychaudhary (1963) and Kanwar and Sehgal (1964) report that the accumulation of calcium carbonate and development of kankar in the B horizons of almost all the salt affects soils of Karnal district. Sehgal and Stoops (1972) have observed the accumulation of pedogenic calcite in soils of arid and semiarid plain regions of erstwhile Panjab (that included Haryana) and find that all types of calcite formations seem to be of secondary origin. Some bedded marls of lacustrine origin have been reported from Bhiwani district and two carbon dates from these marls are 5363 +/- 110 B.P. and 3640 B.P. (Bhatia and Singh, in press).

Investigations of the coarse fraction mineralogy of alluvial soils of Haryana (Ahuja et al., 1978; Garalapuri and Goyal, 1974; Sidhu et al., 1976; Shanwal, 1984; Manchanda, 1978) show that in fine sand, major constituents are quartz, muscovite and albite, and minor constituents are tourmaline, hornbelnde, biotite, chlorite etc. Other accessory minerals in soils of Haryana are zircon, garnet, rutile and apatite. Secondary calcite is also present in many cases.

Distribution of clay minerals in soils of different moisture regimes of Panjab and Haryana has been studied by Sehgal and Coninck (1971) and Sehgal (1974) and they report that in addition to dominant mineral illite, some kaolinite and intergrade minerals such as chloritised vermiculite in place of chlorite are present in these soils. Their observation regarding chlorite is, however, discounted by Sidhu and Gilkes (1977), who contend that the true chlorite is of wider occurrence in northwestern India. Pundeer et al. (1978) report illite (37-66%), kaolinite (10-26%), chlorite (4-18%), smectitie (2-13%) in clay fractions of Panjab soils. Recently Kapoor et al. (1982) find that in addition to illite (23-34%) and chlorite (10-20%), appreciable amounts of smectitie (10-40%) and mixed layer minerals of the type illite-chlorite and illite-smectite (15-30%) are present in clay fraction of soils of Hissar, Tohana, Suniarheri and Bhauri soil series of Haryana and Panjab.

Total elemental analysis of Haryana soils has been carried out by Ahuja (1978), Manchanda (1978) and Goyal (1981). They used these data for computing molar ratios like SiO_2 / Al_2O_3, Al_2O_3 / Fe_2O_3 etc. for working out weathering intensity of soils in the area. Total trace elements as well as trace elements available to plants (micronutrients) have also been studied by some workers. Bhumble et al. (1964) and Zandhawa and Kumar, (1964) have reported total trace elements and available micronutrients from alluvial soils of Panjab and Haryana. They find that copper and zinc contents increase with increasing contents of silt+clay in the soils whereas manganese content increases with depth.

Limited studies of micromorphology of soils of Haryana have been made by Kooistra (1982) and Manchanda and Hilwig (1983). Kooistra has investigated two soil profiles micromorphologically i.e Zarifa Viran series (Central Soil Salinity Research Institute Farm, Gudah, Karnal) and Ladwa series profile (Haryaan Agricultural University Farm, Hissar) as a part of study of micromorphology of Seventy Benchmark Soils of India. He has reported the presence of cutans and common infillings of voids, composed of clay (e.g. argillans) in the soils of Zarifa Viran series.

Courty and Fedoroff (1985) have described in detail micromorphology of four recent soils and eleven buried soils under archaeological sites of Proto-historic period (5000 BP) down to 1500 AD in plain areas of districts of Hissar, Sirsa and Hansi. Major micromorphological features of both buried and recent soils are attributed to biological activity. Local distrbution of clay, silt and carbonates indicate translocation of these components and evidence of biological activity as expressed in characteristics of the soils. Proportions of mica flakes in sands becoming smaller are taken as evidence of lack of alluvial sedimentation and greater aeolian activity since the Protohistoric period . As soils are comparatively young , influence of parent material on pedogenesis is found to be significant. They have also proposed a model of formation of dense kanakar in these soils.

Surfacial sediments of the Indogangetic Plains have been divided into the Older Alluvium and Younger Alluvium and locally called as Bhangar and Khadar respectively. The Bhangar occurs in elevated areas and contained calcite concretions (called 'kankar') and generally assigned the Pleistocene age (Wadia, 1966 P.394). The Khadar occurs in lower terrains adjacent to river channels. Manchanda (1981) has assigned the plain around Rohtak as Khadar. However, no such detailed distinctions have been made on a regional scale for soils of Haryana.

Ostracoda from lacustrine kankar deposits from Haryana and other parts of the Indogangetic plains have been described by Bhatia and his students and these have been dated to be 5363 +110 to 3640 yr BP by radiometric methods and have been thought to represent a humid phase in the area (Bhatia and Khosla, 1967, 1977; Bhatia, 1982, 1983, 1985, Bhatia and Singh, in press).

Haryana and adjoining area of Panjab have witnessed changes in the river courses/ discharges since Protohistoric Period. The palaeodrainage of the area has been discussed by a number of workers (Oldham, 1874, 1893; Cunninghan, 1877; Rapson, 1914; Keith, 1922; Dey, 1927; Stein, 1942; Singh, 1952; Krishnan, 1952; Indras, 1957; Vashista, 1962; Wadia, 1966; Sharma, 1974; Kar and Ghose, 1984). One of the intresting papers on the subject has been of Pal et al. (1980). They have attributed the change in course/discharge of rivers under consideration due to tectonism. Kar and Ghose (1984) find that climatic change is the major cause and to some extent tectonism is also a factor. Also, shifting of the Yamuna alternately to the Indus and Ganga river systems has been assigned as a major factor in the observed changes.

Role of tectonism has been invoked by Manchanda (1981) to explain the distribution of salinity in Panjab and Haryana areas. He suggests the presence of two faults, one fault being roughly along the topographic depresion on the western side of the Aravalli Hills and is thought to extend into Panjab across the Ghaggar and the other trending roughly along Jind-Karnal towns. Movements along these faults leads to ponding of the area and results in the observed salinity distribution.

From the brief review of literature on soils of Haryana, it is evident that no detailed correlation between landscape and soils is available and time factor/environmental changes with time have not been taken into consideration in explaining the characters and degree of development of soils of Haryana. Also, the role of tectonic activity in development of landforms and soils in conjunction with shifting of river courses needs to be appreciated.

1.5. OBJECTIVES AND SCOPE OF THE WORK.

The present study attempts to reconstruct changes in environment and tectonic activity during the late Holocene Period in Haryana State. Keeping the above in view, different geomorphological units with distinctive landforms/soils have been recognised and delineated using published lieterature, topographic maps and Landsat imageries, FCC's, CCTs and computer assisted analysis of CCT's. Extensive field work has been carried out to groundcheck the ideas obtained through application of remote sensing. Also 34 typical soil profiles, fairly distributed over different geomorphic units, have been studied for their field characters. In all 184 representative soil samples from different soil horizons of various pedons have been collected.

Also, oriented soil samples have been collected for micromorpholgical studies. These samples have been analysed in the laboratory for their grain-size distribution, for semi-quantitative estimation of clay mineral contents by x-ray diffraction method and total major and minor elements and micromorphology. The work has been presented in the form of five chapters.

Chapter 1 entitled <u>INTRODUCTION</u> provides a brief summary of objectives of the present study, a general background of climatic and soil moisture conditions, natural vegetation, drainage and geology of the area. An overview of literature on soils of Haryana is also included.

Chapter 2 with the title '<u>MORPHOLOGY OF THE STUDY AREA</u>' deals with the various remote sensing techniques used in mapping of soil-morphological units of the area. Also a brief description of major soil-morphological units is included.

Chapter 3 entitled <u>"FIELD AND LABORATORY STUDIES'</u> describes methologies of field and laboratory analyses employed and discusses data on grain size distribution, semiquatitative analyses of clays and major and trace elements of 184 soil samples collected from major horizons of pedons studied. Statistical analysis of field and laboratory analyses is also presented.

Chapter 4 entitled <u>MICROMORPHOLOGY'</u>describes major microscopic features of soils of major pedons and attempts to rank soils of different geomorphic units from the points of soil profile development.

The last chapter 5 with the title 'SUMMARY, SYNTHESIS AND CONCLUSIONS' summarizes the major aspects of the present study and provides synthesis in the form of soil-chronosequene and evolution of soils, morphology and drainage of the area. Also major conclusions are presented separately.

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CHAPTER - 2

2. MORPHOLOGY OF THE STUDY AREA

2.1 INTRODUCTION

The present chapter describes the different remote sensing techniques used to distinguished different landform units marked by characteristic soils and compare their utility in distinction of different units. It also discusses morphological and typical soil of different soil-landform units.

2.2 SOILS AND REMOTE SENSING

2.2.1 General Methodolgy

Over fifty years back, soil scientists started using aerial photographs systematically as an aid to soil mapping. A comprehensive review of the history and development of methodology of soil survey has been compiled by U.S. Conservation Service and Goosen (1967). More recently remote sensing of the surface of the earth for soils and other resources by satellites has become into vogue. Data of Landsat series of satellites of the U.S. are most easily accessible. Data from satellites like SPOTS (France) and MAMS (West Germany) has also become available in recent years. In near future, it may be possible to use data from the Indian satellite ERS-1A launched in March, 1988.

Important techniques for identifying and mapping of soils with satellites and other air-borne platforms are side-looking airborne radar (SLAR or SLR), synthetic aperture radar (SAR), infra-red line scanner, multispectral photography and scanner, infra-red and panchromatic black and white aerial photography. In the present study, we have used mainly products of Lansat MSS.

Use of multispectral remote sensing and computer processing technique in soil studies was first reported by Kristaf and Zachary (1971) and they have shown that this technique can be used to map soil surface conditions over small areas with a reasonable degree of accuracy. Since then, a number of workers have used this technique. At ITS, Enchede, scientists have used computer for picture processing rather than for automatic classification and to get insight into the huge amount of data available. In the present study, visual examination of the False Colour Composites and analysis of digital data for picture processing as done at ITC has been used.

2.2.2 Choice of Imagery

Selection of imageries for the studies related to soil/physiographic relationship is usually based on consideration of time of year, or season (climate), cropping pattern, cloud cover, image quality, side lap, and moisture conditions (Hilwig, 1978). Hilwig (1976) found that November and December Imageries were good for landuse and salinity studies for Haryana. Keeping this in view, imagries and and digital data from MSS CCT's for the months of November and December were selected for use. Table 2.1 gives detailes of products used.

2.2.3 Computer-Assisted Analysis

MSS data on CCT's have been analysed on the VAX/11/780, Super Minicomputer at the Regional Remote Sensing Service Centre (RRSSC), Dehradun for processing of the above imageries. VIP-32 pericolor camera attached with video display of images on the video screen was used to get pericolor photographs of the processed pictures.

A set of programs available with RRSSC for classification purposes, i.e. for calculation of brightness values, soils brightness index (SBI), greeness vegetation index (GVI) were used and processd pictures were obtained and stretching has been performed to get best results. The alogrithms used were:

$$BI = ((MSS\ 2)^2 + (MSS\ 4)^2)^{1/2}$$

$$SBI = o.406\ MSS4 + 0.660\ MSS5 + 0.645\ MSS6 + 0.243\ MSS7$$

$$GVI = -0.283\ MSS4 - 0.660\ MSS5 + 0.577\ MSS6 + 0.388\ MSS7$$

Also an FCC from all three bands 4, 2 and 1 and a hybrid FCC for GVI, SBI and band 7 has been obtained by image processing.

A multivariate technique for mathematical simplification of data from different bands called Principal Component Analysis (PCA), has also used to produce a picture. It has proved to be of immense value in analysis of remote sensed digital data. It transforms the corrected set of mutispectral data into new principal components that are more intrepretable than the original data (Kaneko, 1978; Byrne et al., 1980).

2.2.4 Results

As mentioned before, use of remote sensing have been combined with field work and as a result, thirteen landform units with characteristic soils have been recognised and delineated on map. These along with symbols used them in (Fig 2.1 - 2.9) are:

i.	Siwalik Hills	(S)
ii.	Aravalli Hills	
iii.	Old Sutlej Plain	

iv.	Aeolian Plain	(A)
v.	Basin with Marl	
vi.	Older Piedmont	(OP)
vii.	Younger Piedmont	(YP)
viii	Yamuna Floodplain	(Y)
ix.	Ghagger Floodplain	(G)
x.	Kaithal Upland Plain	(K)
xi.	Karnal Upland Plain	(R)
xii.	Drishadvati Plain	(D)
xiii.	Fluvio-Aeolian Plain	(F)

In this section, we will discuss the usefulness of different methods in identifying and mapping these large landforms. For this purpose, a simple ranking system by into five classes for usefulness of a particular method for interpretibility of a morphogenic unit as given below is used and results are listed in Table 2.1.

Class	Rating
1	very good
2	good
3	fair
4	poor
5	very poor

Computer analysis helps in identifying the Younger Piedmont Plain very well. Brightness index and soil brightness index are very good to good for recognising this unit, (Fig- 2.1 - 2.3). These later imageries are also good to very good for characterising different units except for units ii, iv, v, x, xi

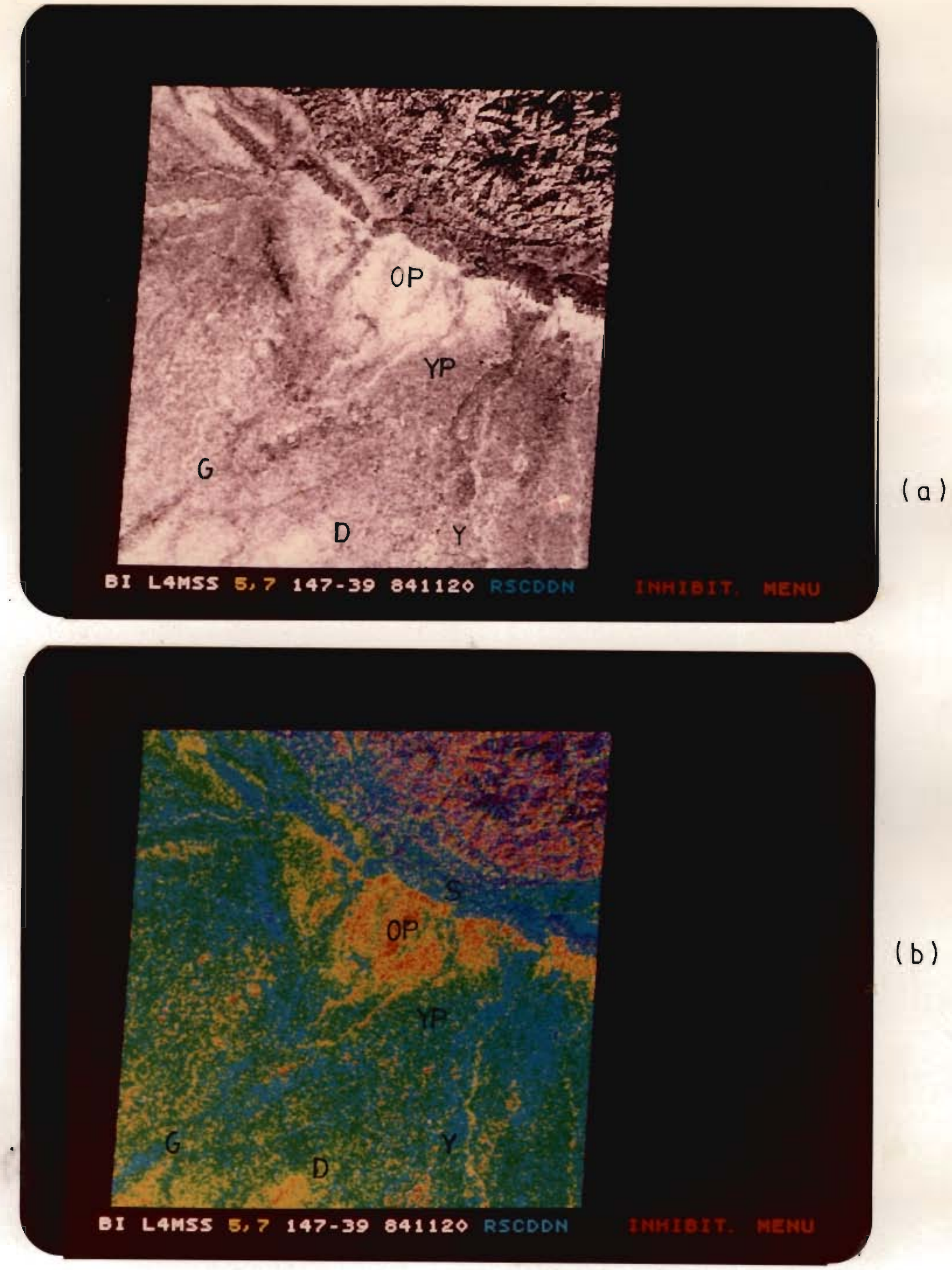


Fig. 2.1 Birghtness index (BI) B & W (a) and pericolour (b) images. The response for the Lesser Himalaya is very good; the response for the Siwaliks (s), Ghagger Floodplain (G), Younger Piedmont (YP), Yamuna Floodplain (Y) are good, Older Piedmont (OP) and Drishadvati Plain (D) shows poor response.

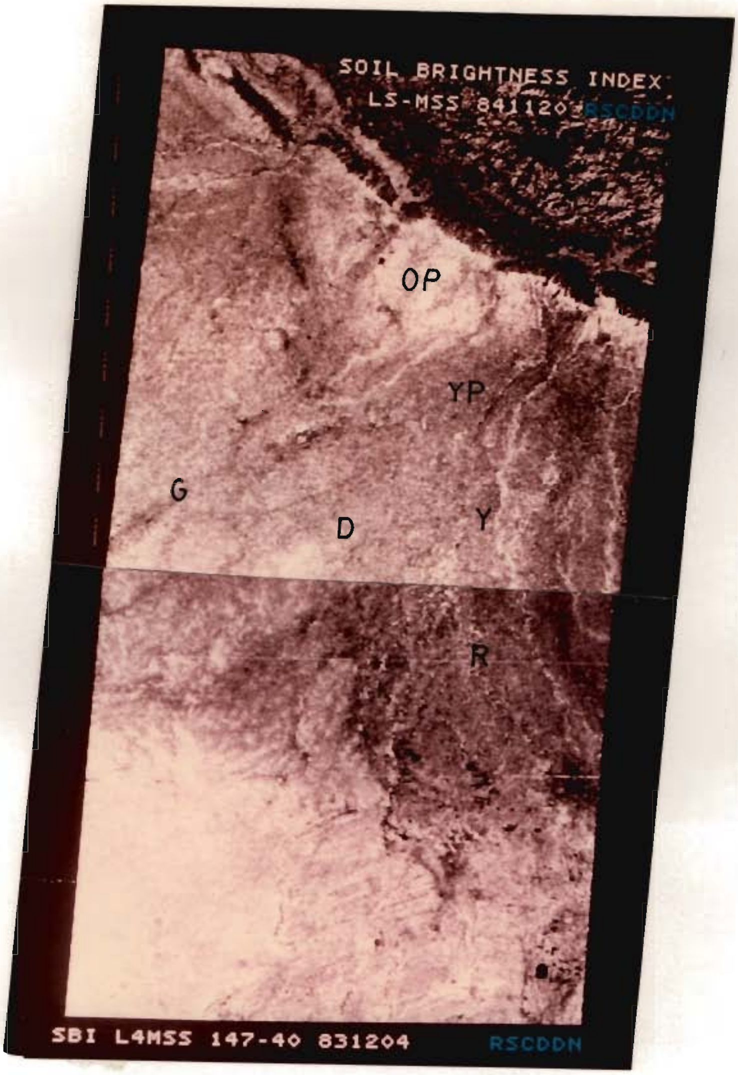


Fig. 2.2 Soil Brightness Index (SBI), Imagery mosaic distinguishes, the Siwalik Hills (S), Older Piedmont (GP), Yamuna Floodplain (Y) and Karnal Upland Plain (R) with good results.

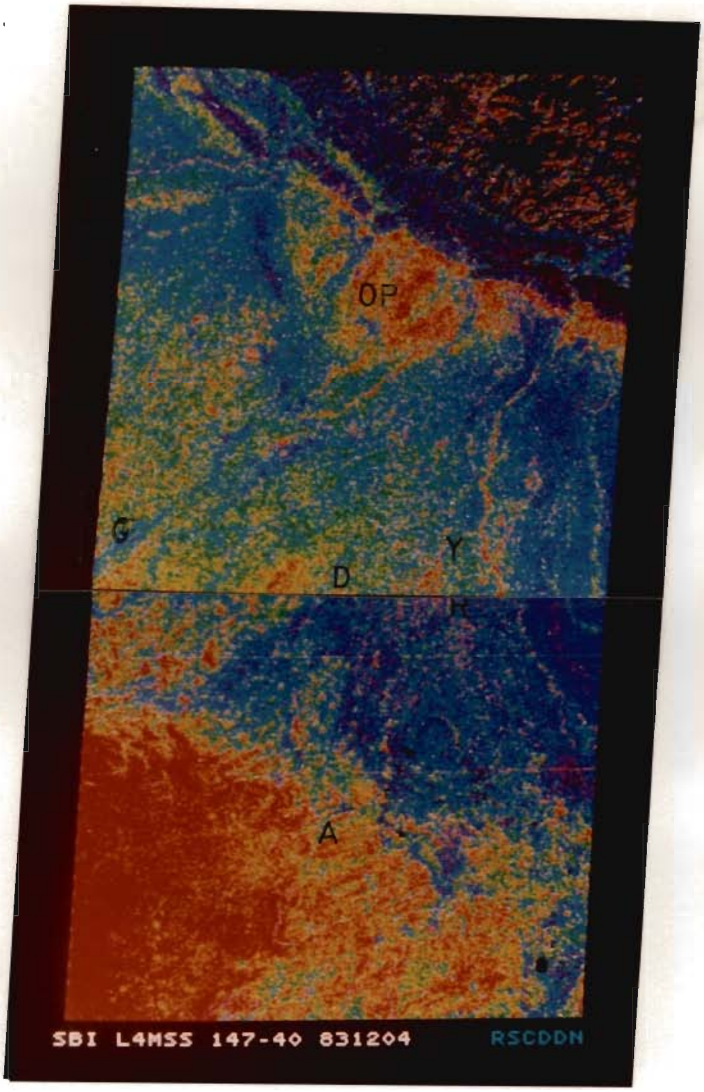


Fig. 2.3 Pericolour image mosaic of Soil Brightness Index (SBI) disinguishes, the Older Piedmont (OP), Ghagger Floodplain (G), Yamuna Floodplain (Y), Drishadvati Plain (D) and brings out southern boundary of the Siwalik Hill (S) and northern boundary of Aeolian Plain (A) more clearly as compared to B & W imageries (Fig. 2.2).

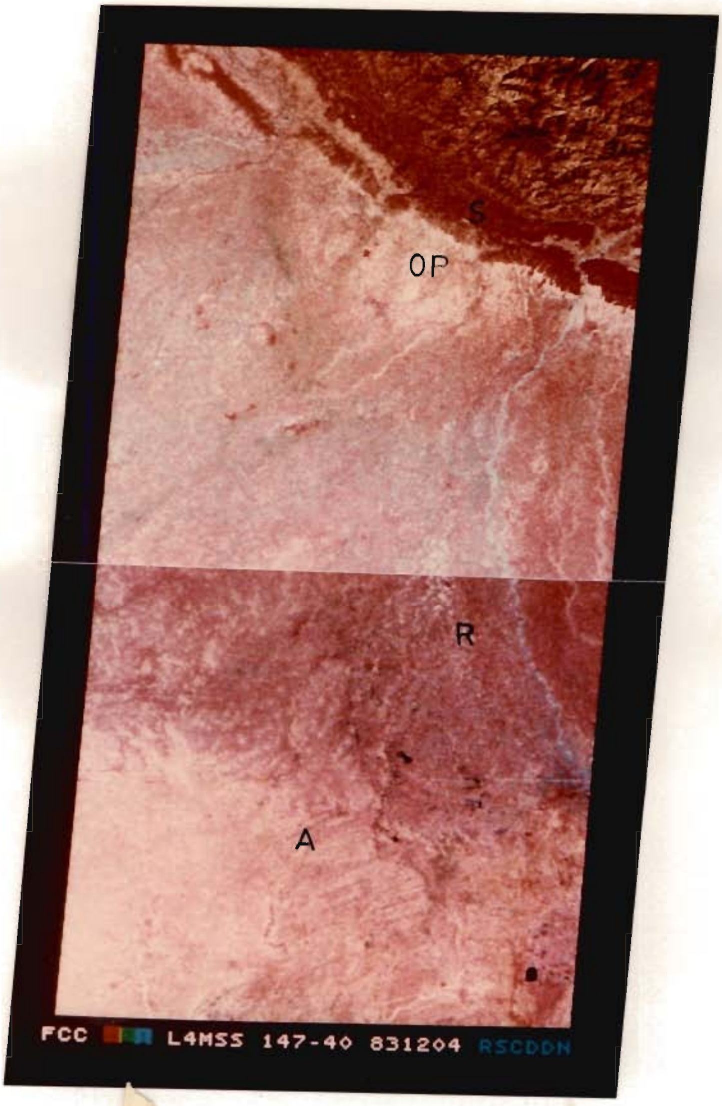


Fig. 2.4 FCC mosaic of L4 MSS images is fairly helpful in distinguishing Aeolian Plain (A), Siwalik Hill (S) and Karnal Upland Plain (R), Good Contrast between the Older Piedmont (OP) and Siwalik Hill (S) is clearly visible.

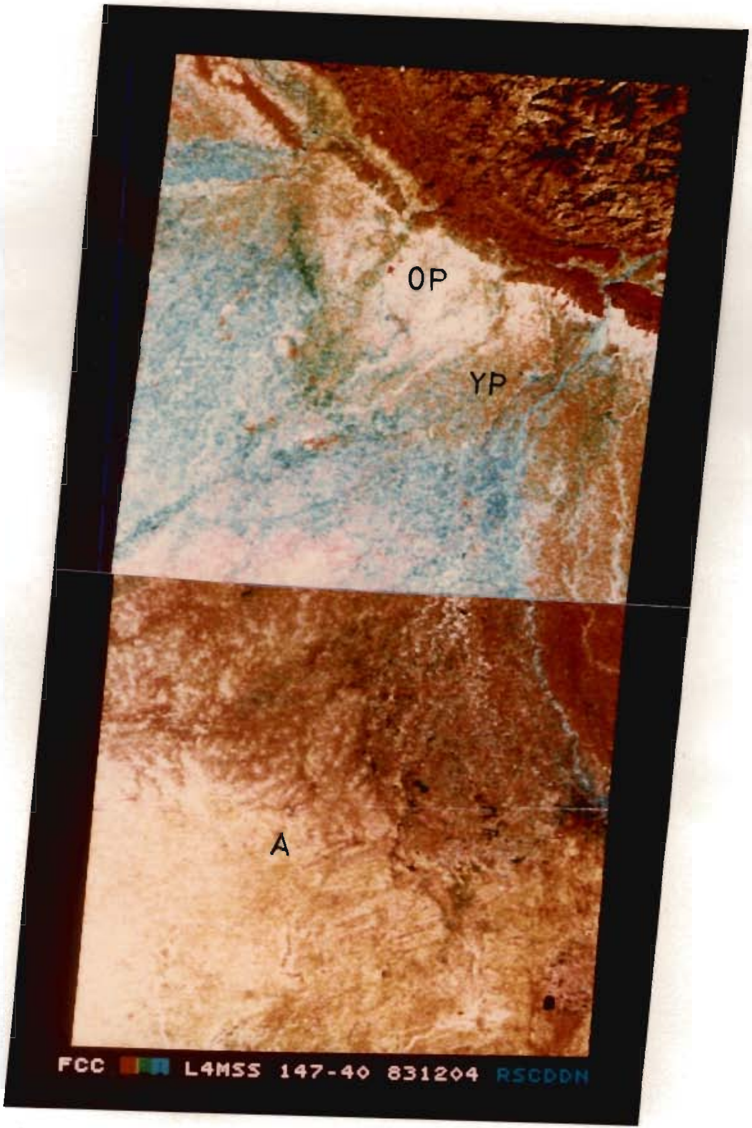


Fig. 2.5 FCC Pericolour imagery mosaic with stretching is better than Fig. 2.4 (unstretched imagery for distinguishing) the Older (OP) and Younger Piedmont (YP) and aeolian sediments on the Aeolian Plain (A) and adjoining areas.

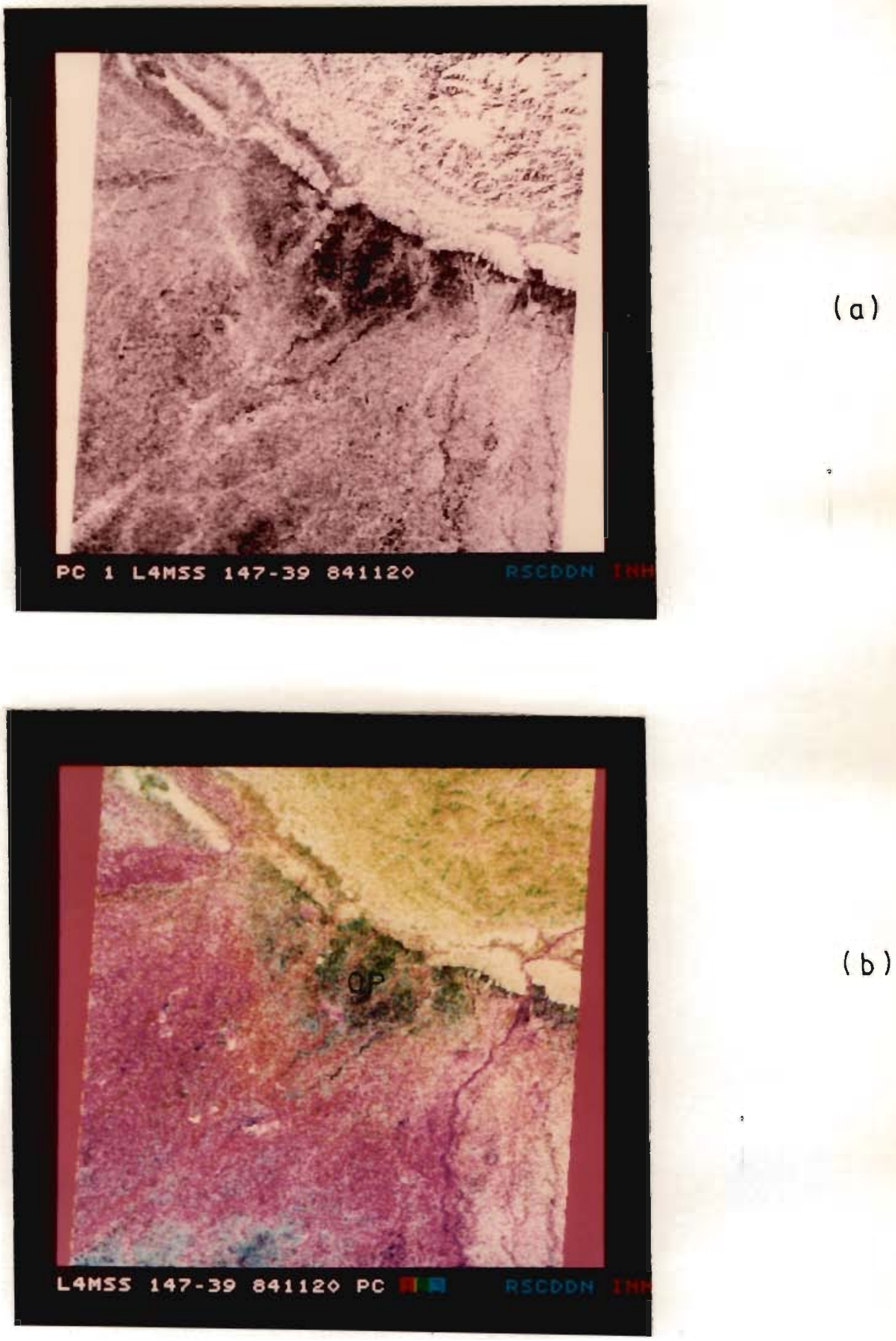


Fig. 2.8 B & W (a) and Peri-colour (b) imageries for L4 MSS 147-39. The B & W imagery brings out the Old Piedmont (OP) and older channels of ephemeral streams well. The pericolour image is excellent in nowing out the Lesser Himalayas from the other units.

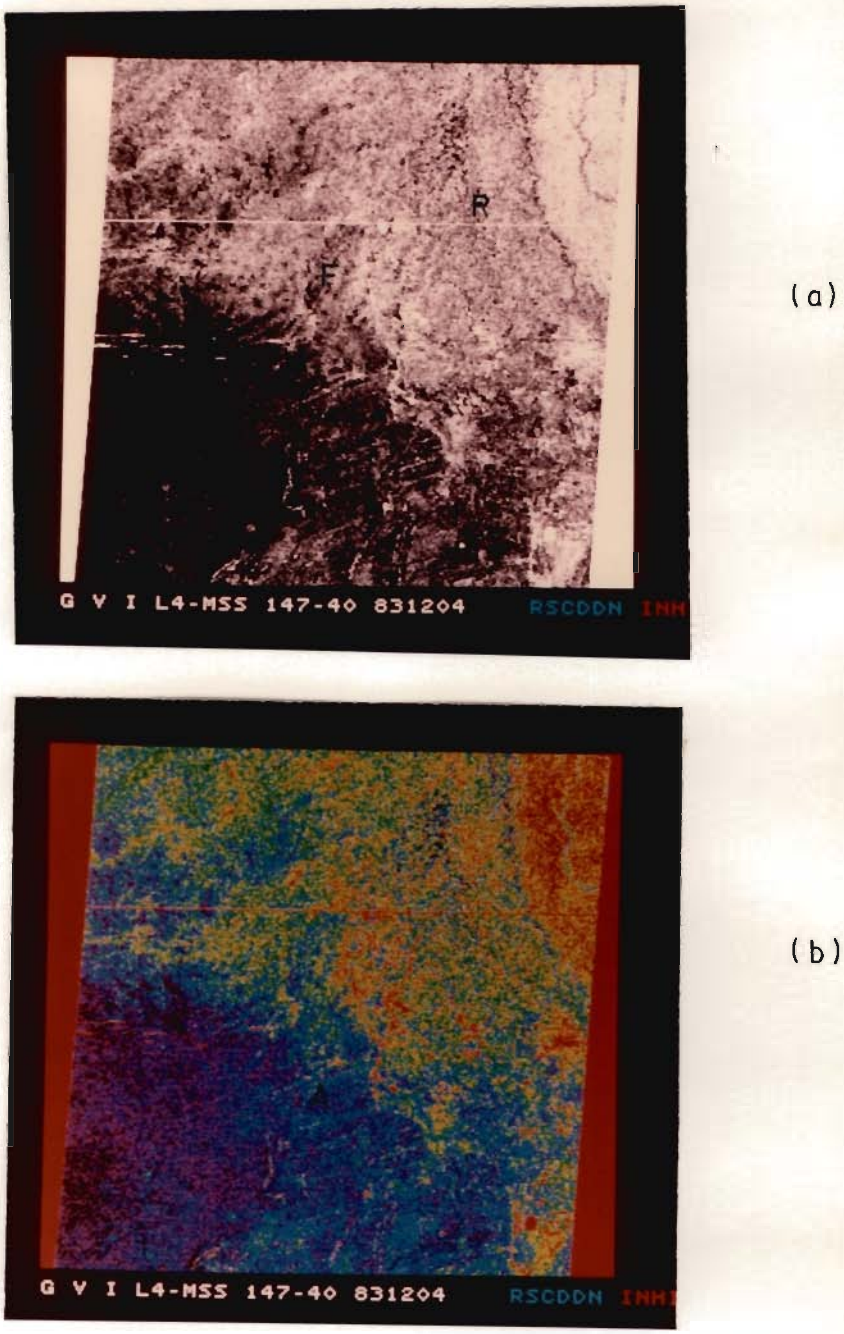


Fig. 2.9 Greenness Vegetation Image in B & W (a) and pericolour (b) for L4, 147-40 frame, boundaries are better in B & W than pericolour imagery. The Aeolian Plain (A) and Aravali Hills are not distinguished from each other, their northern boundaries are well marked in both the imageries. B & W imagery brings out the finer texture of Fluvio-aeolian Plain (F), Karnal Upland Plain (R) very well.

Table 2.1 - Visual comparision of Landsat Imageries/FCC/Computo r assialysis Vs Geomorphic units

S.No	Morphogenic Units	Landsat Imagery	Brightness Index(BI)		Soil Brightness Index(SBI)		Principal Component Analysis		F.C.C.		Hy-brid F.C.C	Greenness Vegetation Index		
		B & W	B & W	Colour	B & W	Colour	B & W	Colour	Orig-nal	Stret-ched		(GVI)	Row&Path Nos	
1	Siwalik Hills	1	1	1	2	2	4	4	2	x	x	x	147	39
2	Older Piedmont Plain	3	2	2	1	1	1	1	3	3	x	x	147	39
3	Younger Piedmont Plain	5	2	2	2	1	3	3	4	3	x	x	147	39
4	Yamuna Floodplain	1	1	1	1	1	1	1	3	3	x	x	147	39
5	Ghagger Floodplain	2	2	2	2	2	3	3	3	3	x	x	147	39
6	Drishadavati Plain	1	4	4	2	2	2	2	3	2	5	5	147	40
7	Kaithal Uplandplain	1	x	x	1	1	x	x	3	3	4	5	147	40
8	Rohtak Uplandplain	2	x	x	1	2	x	x	2	1	5	4	147	40
9	Fluvi-Aeolian Plain	x	x	x	x	x	x	x	1	x	x	x	147	40
10	Basin with Kankar and Plain with Aeolian-activity	2	x	x	2	3	x	x	1	1	2	1	147	40
11	Aravalli Hills	1	x	x	1	1	x	x	2	2	3	2	147	40
	Fig Nos -	2.1	2.1	2.2	2.3	2.4	2.4	2.5	2.6	2.7	2.8	2.9		

INDEX -
Class and Rating: 1=Very good, 2=Good, 3=Fair, 4=Poor and 5=Very poor.

Table 2.2: Output of PCA program run for CCT (147-39), dated; 7/12/19 at Regionl Remote Sensing service Centre, Dehradun.

```
COMMAND KLOEVE
VARIANCE MATRIX
       329.7103           280.5734           357.6754           233.63
       280.5734           278.5561           340.8481           225.19
       357.6754           340.8481           630.2795            475.9
       233.6347           225.1968            475.978           389.7
OUTPUT CHANNEL                   1
EIGEN VALUE  =            1418.557
PERCENTAGE OF INFORMATION=                    87.12081
COFFICIENTS OF EIGEN VECTOR
      -0.421543
      -0.3957125
      -0.6556284
      -0.4856591
OUTPUT CHANNEL                              2
EIGEN VALUE=               178.706
PERCENTAGE OF INFORMATION=                    10.97525
COFFICIENTS OF EIGEN VECTOR
      -0.6168852
      -0.4951637
       0.3009451
       0.5326328
OUTPUT CHANNEL                              3
EIGEN VALUE=              22.02746
PERCENTAGE OF INFORMATION=                    1.352819
COFFICIENT OF EIGEN VECTOR
       0.6587579
      -0.7448375
  -4.5122676E-02
   9.6014991E-02
OUTPUT CHANNEL                              4
EIGEN VALUE=             0.5511436
COFFICIENTS OF EIGEN VECTOR
   8.8274531E-02
       0.2084258
      -0.6910483
       0.6864536
```

and xii for which these methods were not used. Black and white imageries for bands 2 and 4 are found to be equally useful, except that the Older and Younger Piedmonts were marked with difficulty (fair to very poor rating).

FCC's (Fig-2.4 - 2.7) for the bands 4, 2 and 1, are found to give good to fair results for almost all units except for the Younger Piedmont, which is recognised with difficulty. Boundaries for the Karnal Upland Plain, Aeolian plain and Fluvio-aleolian Plain has been transferred from the FCC to the map. Stretching of the data improves the interpretation of FCC in some cases (Fig-2.5 - 2.6).

Results of PCA are listed in Table 2.2. Fist principal component explains for 87.12 % of the variance and is the most informative. Imagery obtained through this component (Fig-2.8) is as good as obtained by BI and SBI. However, cost of PCA is extremely high in terms of computer time (Central Procesing Unit Time) without any additonal information to that given by the above indices. Greeness vegetation index imagery (Fig - 2.9) is not very helpful in the present study, as expected, as during the months of November and December, differences in vegetation are not supposed to be significant.

In summary, combinations of black and white imageries for bands 2 and 4, soil brightness image, brightness image and FCC give very good results for identifying and mapping soil-geomorphic units in the study area. Of course, imageries should be for months of October and November for good results.

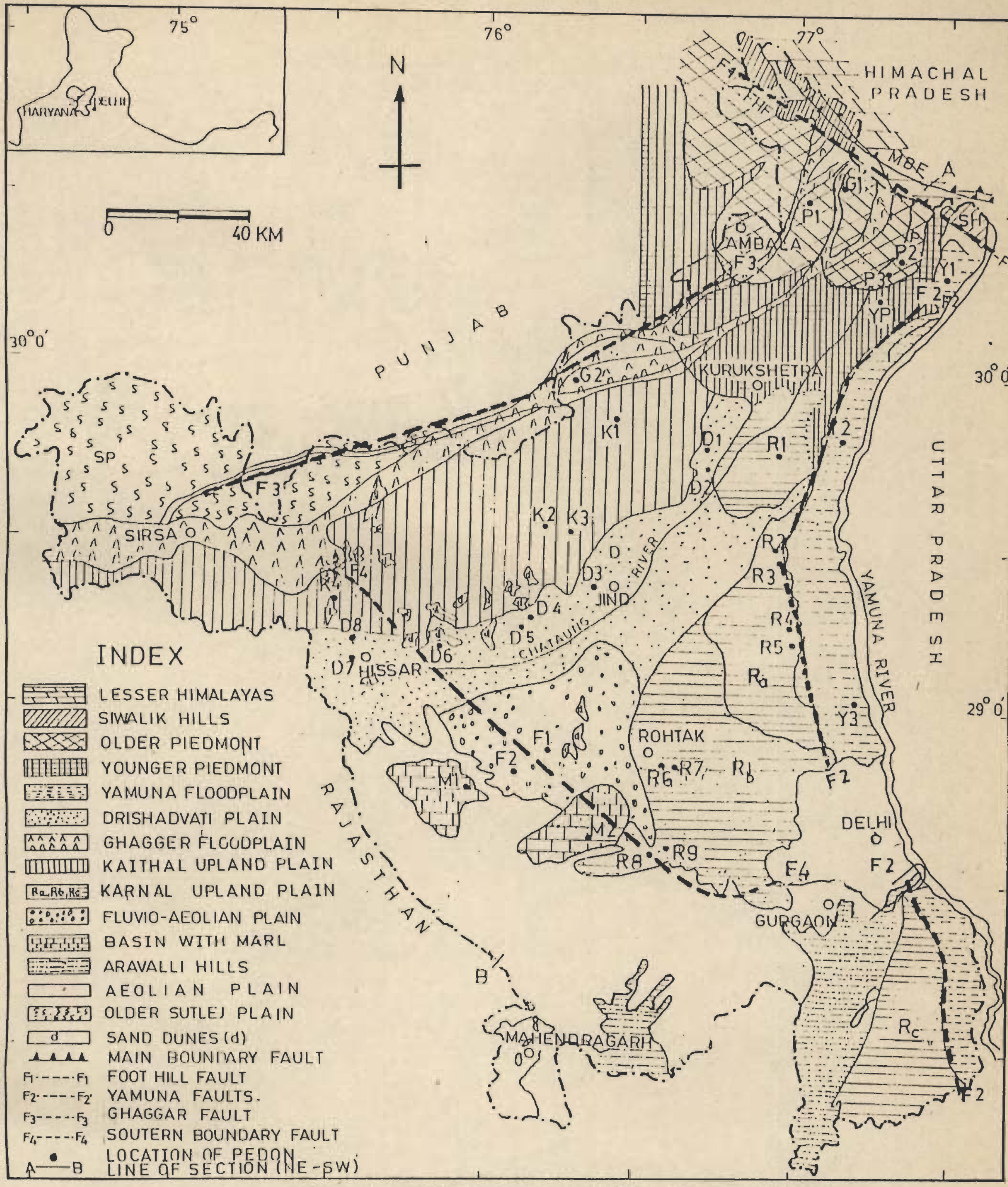


FIG.2.10 -SOIL-PHYSIOGRAPHIC UNITS OF HARYANA

2.3 DESCRIPTION OF SOIL-MORPHOLOGICAL UNITS

A brief description of different soil-morphological units is given below. (Fig - 2.10)

2.3.1 Siwalik Hills

The Siwalik Hills have heights in the range of about 350m-700m and they end to the south in an undulating sub-montane tract of the older Piedmont. These are underlain by a great thickness of clays, sands and conlomerates. They are badly dissected and are being eroded on a large scale. Streams like the Saraswati, Markanda and Chautang originate in these hills. The soils are shallow and show the presence of boulders. The soils are loamy sand to fine sandy loam, well drained, non-saline, non-alkaline, without calcium carbonate concretions. Deciduous and Sal forestations are present.

2.3.2 Aravalli Hills

This unit lies in the southwestern region of the study area and covers parts of districts of Bhiwani, Mahendergarh and Gurgaon. The unit consists of low altitude (<775 m) ridges in the southwestern part and extends northwards into the Bhiwani district in the form of isolated rounded hills. This hilly terrain acts a as divide between the plain with extensive aeolian activity to the west and the area with little sand dune activity to the east.

The Aravalli Hills are underlain by rocks of Aravalli and Delhi Supergroups. The Aravalli Supergroup is composed of mainly ferruginous quartzite, slate, schist and crysalline limestone. The overlying Delhi Supergroup consists typically of quartzites and schists. This area is subjected to severe wind erosion. The Aravalli Hills are usually naked or with little soil on them. Dominant soils are Typic Ustipsamments, Typic Ustochrepts and Lithic Ustorthents.

Within the Aravalli Hills, a few small basins may with impeded drainage occur. At places, soils in these basins contain a large amount of salts. Major soils in these areas are Typic Ustochrepts, Aquic Ustochrepts and Haplaquepts.

2.3.3 Old Sutlej Plain

This unit occurs north of the Ghaggar floodplain, in the northwestern part of the area of study. This unit is a part of a large plain lying betwen the present course of Ghaggar and Sutlej rivers and covering major part of the state of Panjab (India). It is basically an alluvial plain formed due to shifting of the river Sutlej northward and consists of sand, silt and clay, with coarser material occurring along paleochannels and silt and clay covering the intervening areas between the palaeochannels. The alluvium is marked by abundance of disseminated impure calcareous matter in the form of irregular concretions i.e 'kankar'. In the western part of this Old Sutlej Plain (including the region under under consideration), wind has reworked older deposits and has heaped sand in the form of dunal ridges along the paleochannels. Between the dunal ridges, almost flat plains are observed. In these areas salt afflorescence is also common. Soils have weak to moderately developed profiles and diagnostic horizons observed in the area are :cambic, salic, calcic and argillic, natric etc. (Sehgal et al., 1968; Sehgal, 1974; Sidhu et al., 1976; Anand et al., 1977; Sharma et al.; 1978). Major soils are Ustochrepts, Ustipsamments, Haplaquepts and Natrustalfs.

2.3.4 Aeolian Plain

This unit is a part of the aeolian accumulation of the great Thar desert of India. Parts of Sirsa, Hissar and Bhiwani districts, bordering Rajasthan are characterised by aeolian cover stabilised longitudinal dunes and active barchans. In Dadri and Tosham blocks, some outcrops of the Aravalli Supergroup are also present, which diversify the landscape and soil characteristics.This unit also includes pedimental part of the Aravalli Ranges. Because of a thin cover sand on pediments, these can not be distinguished from the adjoining Aeolian Plain in the Landsat imagery. The unit is recognised by uniform light pale brown to light yellowish brown image tone in the FCC and boundaries are transferred accordingly. Climate is semi-arid to arid. Aridity and evapotranspiration increase from northeast to southwest in the area. This unit can be further divided into sub-units: (i) Plain with sand dunes, (ii) Aeolian Plain with varied landforms (a) moderately vegetated/cultivated and has a thin sand cover (less than 50 cm), (b) plain with high wind activity and thick sand cover (c) Plain with aeolian cover and sand hummocks and (d) desert area or sand dunes. (iii) flood Plains of Dohan, Kalinadi and Sahibi.

Soils in this unit are sandy to fine loamy. The sub-soil water is brackish. Dohan, Kalinadi and Sahabi are monsoonal rivers flows from south to north-east and come from the Precambrian Aravalli Hills of Rajasthan. The rivers loose their waters around 28 30 N latitude. Almost all the sediments brought in by the streams are reworked by aeolian activity during dry months. Calcium carbonate nodules are found at a depth between one to two meters depending upon the thickness of the sand cover. The soils are classified as Typic Camborthids, Typic Torripsamments, Typic Torrifluents, Typic Paleorthids and Typic Aplaquepts.

2.3.5 Basin with Marl

This unit covers a part of the topographic low (basin) in district of Bhiwani. This unit is marked by a few cms to 2 m of marl layer covered by aeolian sediments of variable thickness (1-2m) . This unit cannot be distinguished from the Aeolian unit in the Landsat imagery and it has been delineated with the help of soil profiles. Because of its significience in reconstruction of events in the evolution of soils and geomorphology of the area, it has been identified as seperate unit. This unit occurs in two seperate patches. (Fig- 2.10).The marl contains numerous animal shells. Soils are sandy loam to loam in texture. Soils of the unit are classified as Typic Torripsamments, Typic Paleoorthids and Typic Camborthids.

Ostracods from marls of this unit have been studied by Bhatia and his coworkers (Bhatia and Khosla, 1967, 1977; Bhatia, 1982, 1983, 1985; Bhatia and Singh, *in press*) and these have been interpreted to be of mesohaline lacustrine origin. Bhatia and Singh (*in press*) report two carbon dates from the marls i.e. 5363 + / - 110 B.P. and 3640 B.P.

2.3.6 Older Piedmont

South of regional 'uplift of the Siwaliks' lies with an average slope of $6x10^{-3}$, semi-circular shaped Plain with its diameter along a Fault, later named as the Foothill Fault. It has its eastern boundery along the Yamuna river and extends westwards into Panjab. The maximum width is about 55 km. Major streams like the Saraswati, Markanda and Chatuang are sub-parallel to each other and have dissected deep into the plain. Smaller , low order tributaries from this plain form dendritic pattern and have removed the soil cover from their catchment areas. Non-dissected portions of the plain exhibit development of thick soil cover. Along the river beds, boulders and coarse sands are carried. Soils on the main plain are mostly sandy loam to loamy. They are classified as coarse loamy to fine loamy Udic Ustochrepts.

2.3.7 Younger Piedmont

This plain forms a 25-50 km broad ring around the Older Piedmont Plain and has a gentle slope of $4.4x10^{-3}$. Deposition in this plain is taking place as from various streams originating in the Siwaliks and Older Piedmont Plain. Iron-manganese concretions and oxidation mottling are seen in the soil profiles of the area. Soils are mainly lighter to heavier in texture i.e. sandy to clayey in nature. Lighter soils are found along the active channels and paleochannels, whereas the rest of the plain is covered by heavier soils. Depending upon the textural variation and profile development, the soils of this unit are classified as Ustipsamments, Ustorthents and Ustochrepts. Terminal fans have been decribed from this unit by Mukerji (1976) and Parkash et al. (1983).

2.3.8 Yamuna Floodplain

The river Yamuna crosses the Doon Valley and breaks through the Siwalik Range along the Paonta Fault line (Rao et al., 1974). It is a glacial-fed river and has a good discharge throughout the year. It flows east of the present area and forms the natural boundary between States of Haryana and Uttar Pradesh. After the river enters the plains from the Siwalik range, the river has braided character for a distance of 35 km. After it enters the plains from the Siwalik Range. Further downstream, it meanders through a wide valley. The width of the valley is 8 km in Ambala district. it widens to 18 km in Karnal and Sonipat districts and again it narrows to 6 km in Gurgaon distrct. The floodplain of the Yamuna has entrenched character and entrechment increases downstream of the present area. The whole floodplain is prone to flooding due to heavy monsoons. The landscape aspects are related to channel remnants of the former river courses and related features like levees, basins, channel bars and channels. Pedogenesis is at quite an initial stage. The soils are marked by A/C, A/B/C profiles with weakly developed B-horizons. The soils have mostly sandy to coarse loamy texture with none to high salinity and calcium carbonate concretions in distal parts of the present area. Dominant soils are Udic Ustochrepts, Aquic Ustochrepts, Typic Ustochrepts, Typic Ustifluvents and Aeric Haplequents.

2.3.9 Ghaggar Floodplain

The river Ghaggar originates in the Siwalik Hills (Morni

Hills) and flows in the northeast-southwest direction. It forms the border between Haryana and Panjab. The average annual flow of the Ghaggar is 2.159 m.m^3 (Duggal, 1977). The floodplain is narrow in the northeast (Ambala district), it widens gradually to the south, through Kurukshetra and Hissar distrcits (13 km) of Haryana and it loses itself in sands of the Thar Desert in the adjoining state of Rajasthan near Hanumangarh. The river travesres climatic regime of monsoonic in the source area, to subtropical in Ambala district, and semi-aridic in Sirsa district and Rajasthan area. The Ghaggar river also acts as a drain as smaller seasonal rivers the Tangri, Markanda and Sarasvati join it. Gradient of the river varies from 1.0-1.9m /km in Ambala distirct and to less than 0.4 m/km in in Hissar and further downstream and here it follows local surface topography.Two distinct subdivisions of the Ghagger Floodplain i.e. active, narrow floodplain and the older 8-13 km, abandoned floodplain can be recognised from the Landsat imagery (Fig-2.10)

Manchanda (1981) has divided the Ghaggar Floodplain longitudinally into three zones i.e. upper. middle and lower. The Upper reaches lie in parts of Union Territory of Chandigarh, Ambala district and part of Kurukshetra district. The gradient is steep and as a result there is no problem of salinity-alkalinity or drainage. The soil texture is coarse loamy to fine loamy. The soiils are classified as Aquic Ustochrepts, Typic Ustochrepts and Natrustalfs.

The middle reaches of the Ghaggar Fooldplain cover parts of Kurukshetra and Hissar disricts. Due to shifting of the meandering river, a number of levees, bars and abandoned channels are met with. The unit suffers from flooding during monsoons and the area develops high groundwater conditions. Slopes are low (less than 1%) and soils have poor drianage. These conditons combine to give soils oxidation mottles over the most of the floodplain. Development of calcium carbonate concretions on a small scale and flood coatings have been reported by Ahuja (1981) from this unit. The unit is free to low in salt content. The soil textures belong mostly to coarse loamy and fine loamy families. The dominant soils are Typic Ustochrepts, Aquic Ustochrepts, and Natrustalf.

The lower reaches of the Ghaggar Floodplain lie in districts of Hissar and Sirsa. Here the floodplain boundaries not well defined and very large areas are prone to the effect of spreading of flood waters. This unit is comprised of levees, basins and plain. There is also salinity and alkalinity development in the extreme south of this unit. Soils belong to mostly coarse loamy family and soils encountered are Typic Ustochrepts, Aquic Ustochrepts and Typic Ustipsamments.

2.3.10 Kaithal Upland Plain

This plain comprises the higher ground between the rivers Ghaggar and Chautang. It acts as water divide between Ghaggar River System and old Chautang River System. To the west, it is covered with fluvial and aeolian sand. This unit is non to slightly salt affected having wind erosion hazard in the southwestern part. Soils are moderately to imperfectly drained. The topography is modified by the action of wind, as dunes of low elevation and areas with sandy sheet cover are met with in this unit. Sand cover varies from very fine to 50cm thickness. The moisture regime changes northeast to southwest from ustic to aridic one. Soils are mostly coarse loamy to fine loamy and classified as Typic Ustochrepts, Aquic Ustochrepts, Aeric Haplaquepts (in depressions), Typic Camborthids, Typic Calciorthids and Typic Torripsamments. Calcium carbonate concretions are present in soil, but it is free from oxidation and reduction mottles or iron/manganese concretions.

2.3.11 Karnal Upland Plain

This unit occupies a high ground between the Yamuna Floodplain and Old Chautang Floodplain. General slope of the area is from northeast to southwest. Surface drainage follows the regional slope. This unit is characterised by the presence of salinity because of poor drainage and large depressional areas. Water stagnates in the depressions in rainy season. Salinity is observed mostly in wastelands around villages or some small ponds. Salinity and alkalinity hazard is highest in this unit. This unit can be recognised on the landsat imagery by characteristic texture, caorse to medium pattern of salinity disribution. This unit can be subdivided into three subunits i.e. Ra, Rb and Rc (Fig.- 2.10). The first subunit Ra occur in the northern parts and shows strong salinity. The second subunit Rb adjoining to the Ra in the southern part has medium to low salinity. It is irrigated by canal on a large scale and it probably produces oxidation mottles observed in the upper 1 m of the soil profile. The third subunit Rc occur within the extreme south and lies between the Aravalli Hills and the Yamuna Floodplain. It is affected by wind activities, though it is not in geographic continuity with subunits Ra and Rb, soils in this subunit are considered to be equivalent to those of subunits Ra and Rb in respect of degree of soil sevelopment. Soils belong to mostly, coarse loamy to fine loamy family. Soils are classified as coarse loamy Typic / Udic Ustochrepts and Natrustalfs. The salinity affected areas in Ra subunit in the north lie in such a fashion that they form a dichotomic pattern (Fig - 2.4 - 2.5) (Howard, 1967). This salinity pattern is thought to result from remobilisation of salts by overflow in recent times. Interestingly the finer slope pattern of the area brought out by salinity distribution pattern suggegest that the older drainage during the deposition of sedimentation of Ra subunit was from the Yamuna river side.

2.3.12 Drishadvati Plain

This unit consists of old relict floodplain of the river Drishadvati. At present, the Chautang river, a probable descendent of the river Drishadvati (Rapson,1914; Keith,1922, Dey , 1927) flows through central part of teh unit. The river Drishadvati in the recent past might have been a major river and flowed through Jind, Hissar, Bhadra, Nohar before it met Ghaggar river in Rajasthan. In Ambala, the Chautang river still flows in the northeast-southwest direction between the Kaithal and Rohtak Upland Plains. It widens in Jind area and turns towards west abruptly more or less normal to the original course. Morphologically major landforms like bars, old levees, relict channel courses, salt affected plains, basin plains and plain with aeolian activity and sand dunes can be identified in this floodplain. Soils are mostly yellowish brown to dark yellowish brown in colour and texture varies from sandy to fine loamy class. Fine sand and very fine sand are dominant. The presence of oxidation and reduction mottles in the upper 1 m of soil profile and calcium carbonate concretions below it, are characteristic properties of these soils. Taxonomically soils are Typic Ustipsamments, Typic Natrustalfs, Typic/Udic Ustochrepts (Plains) and Aquic Ustochrepts (basins).

2.3.13 Flvio-Aeolian Plain

Soils of this unit can be recognised on the Landsat FCC by mottled tone (light yellowish brown with spots) . Large portion of the surface is covered with aeolian sands and shifting sand dunes. with level to general slopes.The area is marked by svere wind erosion, low availablity and retention of moisture. Soils are light textured and belong to coarse loamy family. soils in low lands are of heavy in texture (fine loamy). Soils are classified as Udic Ustochrepts, Typic Ustipsamments, and Natrustalfs.

2.4. STRUCTURAL FEATURES

The Tertiary rocks in the Siwalik Hills are in contact with the unfossiliferous rocks of the Lesser Himalaya in the north along the Main Boundary Fault (MBT). To the south, they are in contact with the Indogangetic plain sediments along a fault. This fault is of regional dimensionas.This fault has been called Mohand Thrust in the adjoining area in the east (Rao et al., 1974). Similar fault in eastern Nepal and in Bihar and Utter pradesh States of India has been called as the Foothill Fault by

Nakata (1982). The later name, being an approporiate one, has been retained in the present study.

Studies carried out by previous workers in Haryana and Panjab indicate that the soils on two sides of the Ghaggar Floodplain are very different. Soils on the Panjab side are basically related to shifting of the Satluj river, whose numerous paleochannels have been mapped by Pal et al. (1980) and some of these channels terminate in the Ghaggar Floodplain. (Fig.- 2.10) No such feature is observed on the Haryana side of the Ghaggar river. It indicates the presence of a fault/faults along the Ghaggar river in the study area this is named as the "Ghaggar Fault" here.(F3 - F3, Fig-2.10).

Garalapuri (1983) has recognised that the western side of the Yamuna Foodplain is a fault between Sohana nd Sonipat and it is related to downwarping of the easern block. it seems that this fault is part of a set of faults (F2 - F2, Fig-2.10) that give the western boundary of the Yamuna floodplain a convex curvature to the west. These are named here as the Yamuna Faults.

The region just west of the Yamuna river in Haryana forms the water-divide between the Ganga and Indus river systems in the plains presently and movement of the western block along the Yamuna Faults upwards is responsble for the formation of this water divide. Also the subsurface Delhi-Hardwar Ridge recognised by siesmic surveys (Eremenko and Negi, 1968) lies east of the Yamuna Floodplain and movements along this ridge have been thought to affect the course of the Yamuna by Manchanda (1981) and Garalapuri (1983). However, subsurface northward extension of this ridges is upto only Meerut (Rao, 1973) and activity alongt this ridge is not likely to affect the surface drainage.

Work by O.N.G.C. (Eremenko and Negi, 1968) in the plains indicates that the Aravalli Ridge continues in northwards surface with a thin sediment cover as Delhi-Lahore ridge. This ridge was a major drainage divide till about pleistocene, and the rivers emerging from the Himalaya were diverted northward or southward at the southern edge of the plains in this area (Parkash et al., 1980) Also the contact between the Indogangetic Plain sediments with Peninsular rocks is generally a normal fault in Uttar Pradesh and Bihar. Probably similar contact exists in this area as is thought to concide with the topographic low norteast of Aravalli outcrops.

2.5 RESUME

Combination of black and white imagery for band 2 and 4, soil brightness image, brightness image and FCC give very good results for identifying and mapping soil-landscape units. Imagery used for the study were for the month of November and December. Stretching of grey levels using computor also produces an FCC which gives satisfactory results.

In all thirteen soil-geomorphic units have been recognised and delineated. These units are (i) Siwalik Hills, (ii) Aravalli Hills, (iii) Old Sutlej plain, (iv) Aeolian plain, (v) Basin with Marl, (vi) Older Piedmont, (vii) Younger Piedmont, (viii) Yamuna Floodplain, (ix) Ghagger Floodplain, (x) Kaithal Upland plain, (xi) Karnal Upland plain, (xii) Drishadvati plain and (xiii) Fluvio-Aeolian plain. Also, a number of faults / fault systems i.e. Foothill Fault, Yamuna Fault, Southern Boundary Fault and

Main Boundary Fault have been recognised in the area of study. These faults have probably affected the landscape of the area and this aspect is discussed later in chapter 5.

CHAPTER - 3

3. FIELD AND LABORATORY STUDIES

3.1 INTRODUCTION

This chapter deals with field and laboratory investigations of soils of Haryana except laboratory micromorphological studies of soils. Micromorphology of soils constitutes a major aspect, and as such it is subject matter of another chapter. A brief description of methodologies, analysis and major inferences from the observations in the field and laboratory are described in this chapter. Laboratory studies included herein are analysis of samples for grain-size distribution, clay mineralogy and major and minor chemical elements.

3.2 FIELD INVESTIGATIONS

3.2.1 Introduction

Field traverses and spot checks have been made to confirm geomorphic units and their boundaries established from remote-sensing studies. Augering has been undertaken at a number of sites for selection of soil profiles for excavation. A total of 34 pedons from nine major geomorphic units of the area have been selected for studies, Locations of pedons and other relevant information are given in Fig. 2.10 and Appendix I.

For each pedon, informations regarding location, natural vegetation, parent material, relief, slope, erosion, drainage, depth of groundwater, permeability, moisture, the presence of salts or alkalies and stoniness are recorded. An open pit measuring 2m x 2m in plan upto 2 m depth or more is excavated at a selected site and deep auger holes are made in profiles, where buried soils are expected or C horizons are deeper. Next master horizons are distinguished, their boundaries demarcated and these are designated as A, B or C. Master horizons are divided into sub-horizons depending upon variations in colour, texture, roots etc. and named as B_1, B_2 etc. Further major soil properties are noted down in a standard soil profile description chart (U.S.D.A., 1966, p. 138) for all the sub-horizons.

3.2.2 Field Soil Properties

A brief account of soil properties, studied in the field, is given below.

3.2.2.1 Colour

Soil colours are indicated by using the appropriate Munsell notation for dry and/or wet soil. Soil colours are most conveniently measured by comparison with a Soil-Munsell colour chart. Three variables i.e. hue, value and chroma that combine to give different colour shades have been noted separately for matrix and mottles of different soil horizons.

3.2.2.2 Soil Texture

Soil texture refers to the relative proportions of the various size groups of individual soil grains i.e. clay, silt and sand, in the mass of soil below 2 mm in diameter. Soil texture class is obsrved in the field by feeling the soil with fingers. Confirmation of texture has been done in laboratory by grain size analysis, followed by plotting sand, silt and clay percentags in triangular diagrams (Figs. 3.1 to 3.4).

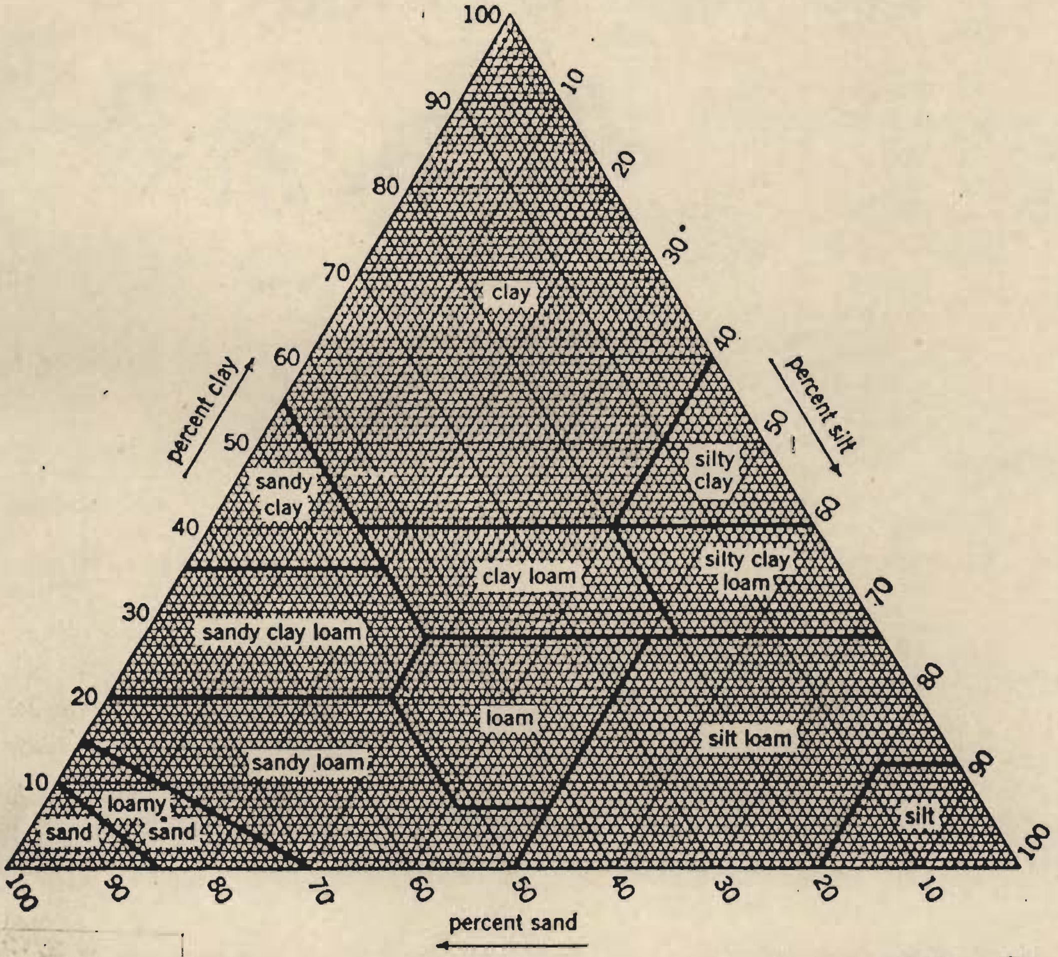
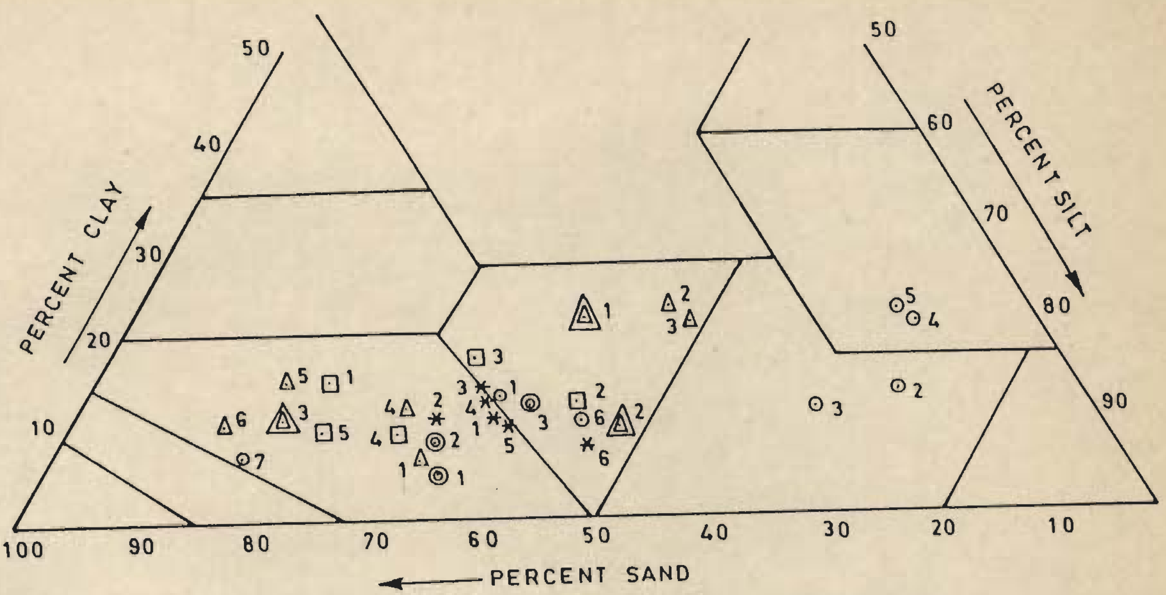
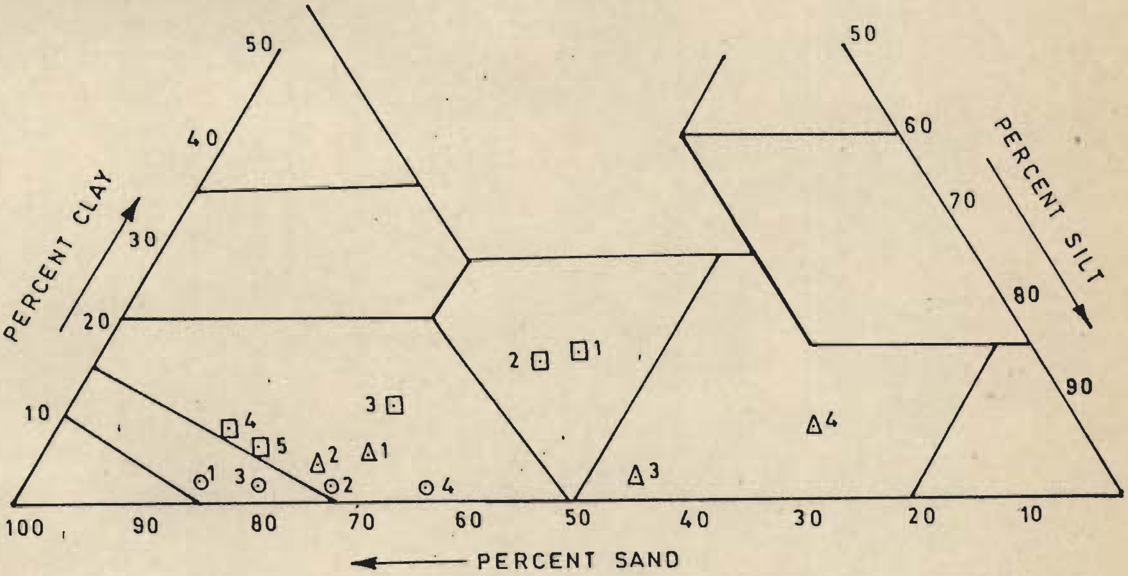


Fig. 3·1 a – Chart showing the percentages of clay (below 0.002 mm.), silt (0.002 to 0.05 mm.), and sand (0.05 to 2.0 mm.) in the basic soil textural classes.



PEDON M_1-◎, PEDON M_2-△, PEDON P_1-⊙, PEDON P_2-△,
PEDON P_3-⊡, PEDON YP_1-✱



PEDON Y_1-⊡, PEDON Y_2 — △, PEDON Y_3 — ⊙

Fig. 3.1b-Plot of soil-textures of the pedons for geomorphic units-Basin with Marl (M), Older Piedmont Plain (P), Younger Piedmont Plain (YP_1) and Yamuna Flood plain (Y).

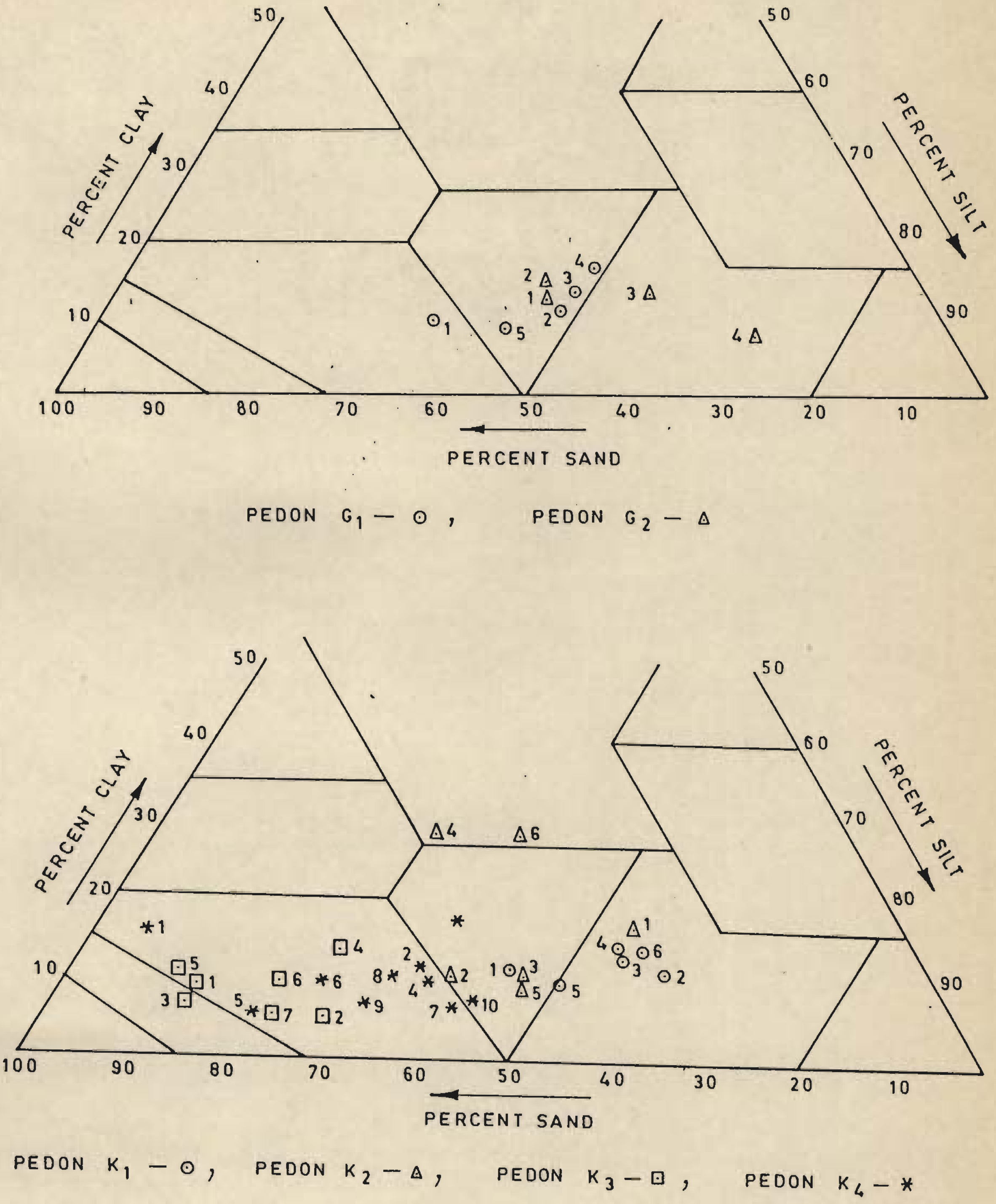


Fig. 3·2 – Plot of soil-textures of the pedons of geomorphic units – Ghagger Flood Plain (G) and Kaithal Upland Plain (K).

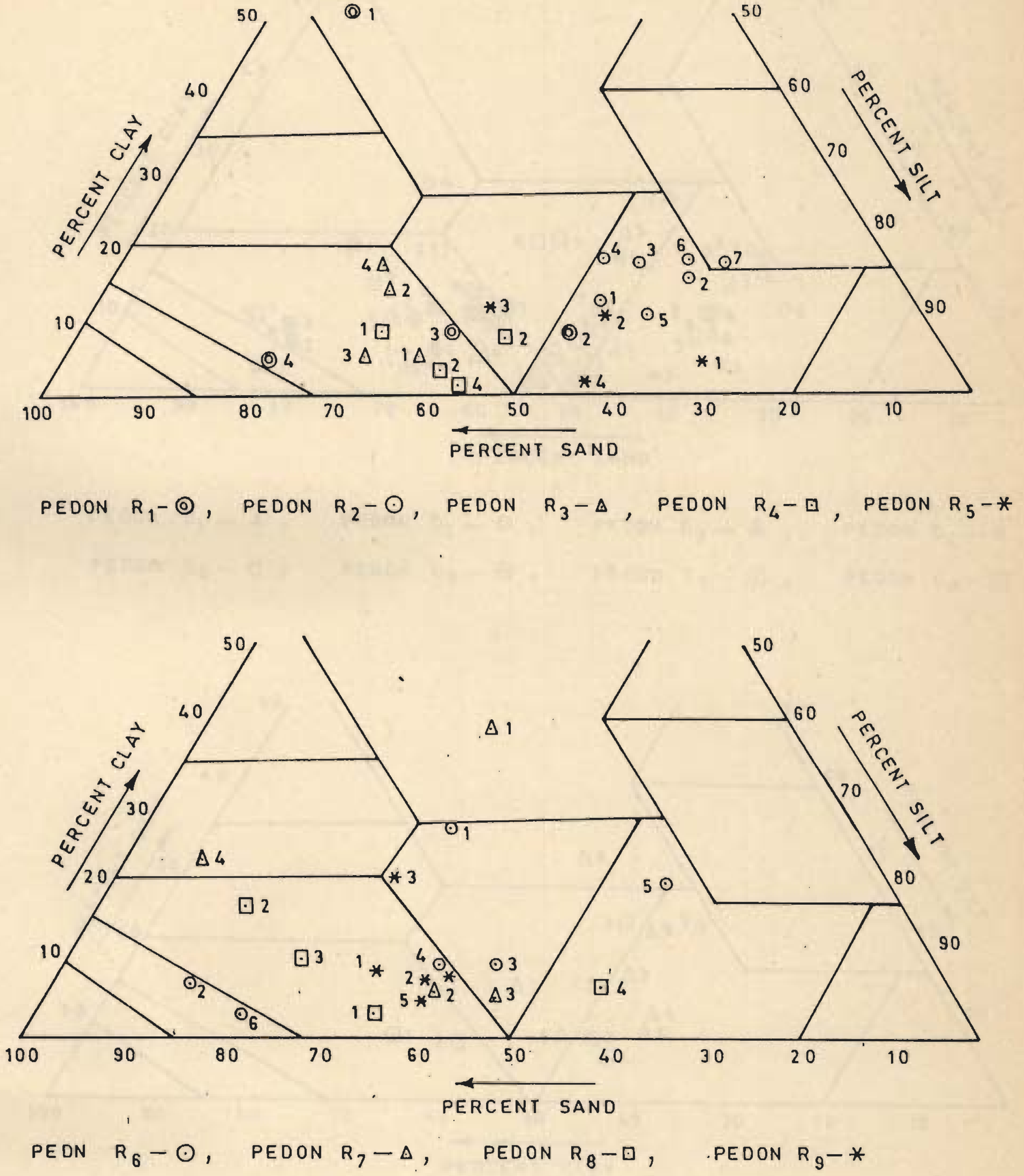


Fig. 3·3 – Plots of soil-textures of the pedons of the geomorphic unit – Karnal Upland Plain (sub-units – Ra and Rb).

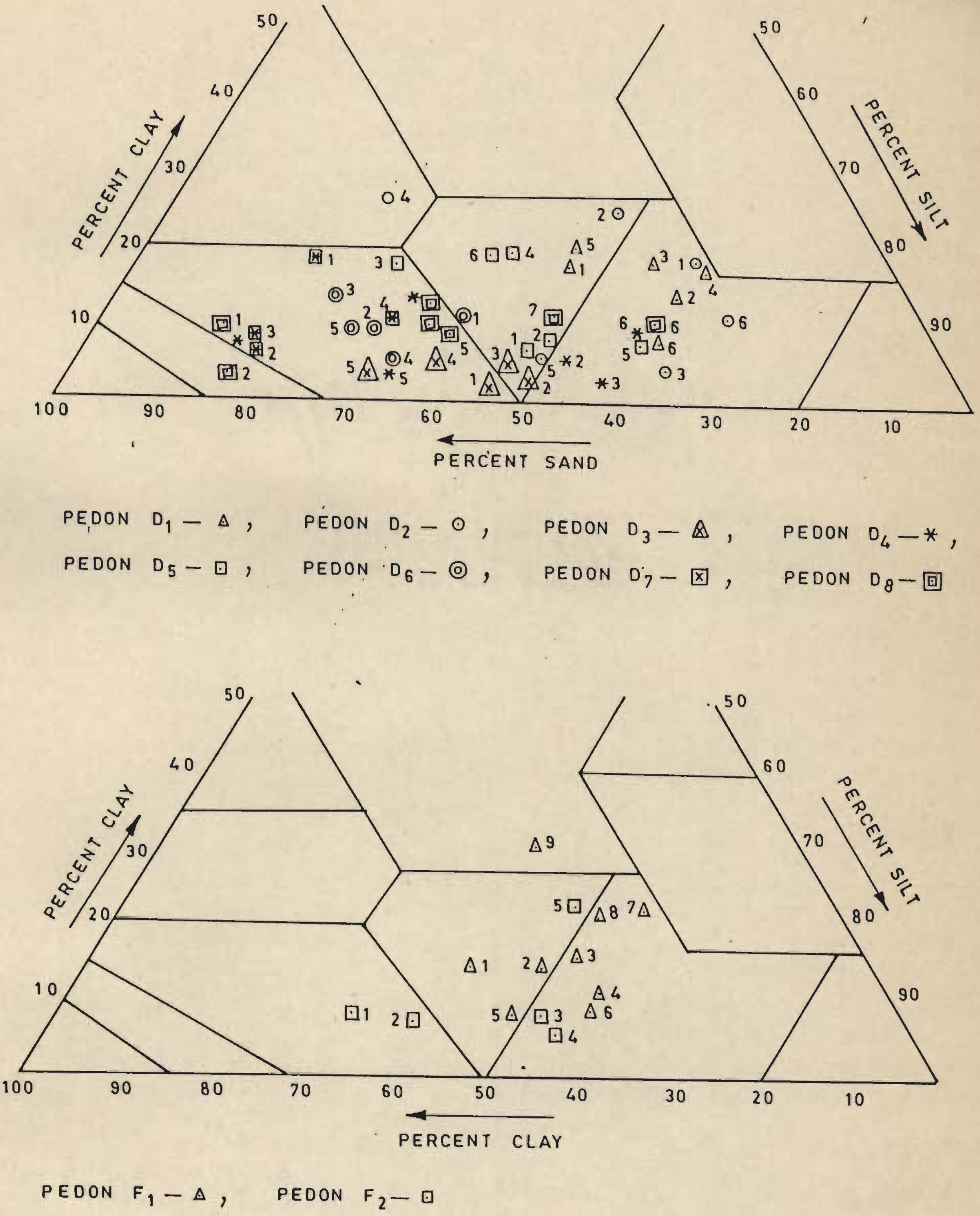


Fig. 3·4 – Plots of soil-textures of the pedons of geomorphic units - Drishadvati Plain (D) and Fluvio-Aeolian Plain (F).

3.2.2.3 Soil Structure

Soil structure refers to the aggregation of primary soil particles into compound particles, or clusters of primary particles, which are separated from the adjoining aggregates by surface of weakness. Platy, prism-like, blockwise or polyhedral (angular block and subangular block) and spheroidal are the four primary types of structures. In the field description, the shape, size, distinctiveness and durablity of visible aggregates or peds have been recorded in terms of type, class and grade of structure.

3.2.2.4 Consistence, Boundaries, Mottling, pH, Lime etc.

Consistence under wet condition has been determined in the field and recorded in terms of stickiness (non-sticky, slightly sticky, sticky, very sticky) and plasticity (non-palstic, plastic, very plastic). Consistence when moist-in terms of loose, friable, firm and very firm, and consistnce when dry-in terms of loose, slightly hard, very hard and extremely hard, have been used. No cementation has been noted in the field.

Horizon boundaries are described in terms of abrupt, clear, gradual, diffuse and according to topography, as smooth, wavy, irregular, or broken.

A desription of mottling includes a notation of colours and of the pattern. Patterns are noted according to abundance (few, common, many), size (fine, medium, coarse) and contrast from the matrix (faint, distinct and prominent). pH for 1:2 soil-water suspension is noted down with the help of pH papers. The amount of lime is indicated by degree of efferevescence with dilute HCl as slight, strong or voilent.

Special features like concretions of lime and iron-manganese are also noted.

3.2.3 Field Observations

3.2.3.1 Matrix Colour Variation

Morphological variation reveals that the matrix colour varies from light yellowish brown (10YR 6/2, moist) to brown (10YR 5/3, moist), yellowish brown (10YR, moist) to brown/dark brown (10YR 3/3) in general in individual pedons. However, light whitish gray (10YR 7/3) to whitish gray (10Yr 6/1) colour is observed in the upper horizons of pedons in saline tracts. Grayish white colour (10YR 8/2) and whitish gray colour (10YR 7/2) are common in the Aeolian plain due to the presence of high percentage (upto 50%) of the kanakar. Thus in general the variation in colours in different pedons is very limited.

Colour of soils has been used in determining relative ages in some soil Holocene-Pleistocene chronosequences (Ruhe, 1965, 1968; Harden, 1982; Rockwell et al., 1985). Keeping the above in view, colour index for all pedons with the development of B horizons has been obtained following a procedure described by Rockwell et al. (1985). A large air dried sample is passed through 2mm sieve, then fractioned in a mechanical splitter, moistened, hand homogenised to a putty consistencey and roled into a sphere. This is split into two halves, and colour is noted from one freshly broken surface. Colour index is obtained by adding chroma number to hue (of moist mixed sample), where 10YR= 1, 7.5YR= 2 and 5YR= 3. This index is obtained for a pedon by averaging for all B sub-horizons. Indices from different pedons on the same geomorphic surface have been averaged and listed in Table 3.1.

Table 3.1 - Colour Index values for different geomorphic units

Goemorphic Unit	Colour Index
Fluvio-aeolian Plain	3.8
Yamuna Floodplain	4.2
Kaithal Upland Plain	4.33
Drishadvati Plain	4.61
Ghaggar Floodplain	4.62
Karnal Upland Plain	4.65
Older Piedmont	4.75
Younger Piedmont	5.00

Colour index for all the geomorphic units varies between 4 and 5 except in the case of fluvio-aeolian plain, for which a low value of 3.8 (Table - 3.1) is observed. Also, the highest value of 5.0 is observed for the Younger Piedmont Plain, which is not the oldest unit, as discussed later. This high value for the mixed soil is due to the development of iron-manganese mottlings, in soils probably. due to poor drainage conditions. Thus due to a limited range of values and overshadowing effect of drainage conditions on colour index, it is difficult to use it for assigning relative ages of young soils of the present area.

It is interesting to note that soils with colour indices similar to the present ones have been found to be of age less than 5000 years by Rockwell et al. (1985).

3.2.3.2 Oxidation Mottles and Fe-Mn Concretions

Oxidation mottles and Fe-Mn concretions are present fairly abundantly in the sub-surface horizons of the undissected parts of Old Piedmont Plain, Young Piedmont Plain, Drishadvati Plain, Ghaggar Floodplain and Yamuna Floodplain. All variations from indistinct mottles through few, fine sized and soft Fe-Mn concretions to many, coarse sized and hard concretions are observed in all the different geomorphic units. These usually occur in B and C hrizons at depths of 20cm to 180cm and consititute less than 5% of the soil mass, but these form 20 to 25% of the soil mass in the exceptional case e.g.the pedon # YP1 in the Younger Piedmont Plain. Usually these mottlings/concretions have fine to medium size throughout the zone of occurrence. These are few and distinct in the upper part, become common in the middle part and decrease to few and become indisitnct in the lower part. In the exceptional case of the Younger Piedmont, only an increase in mottles/concretions with depth is observed upto the depths excavated.

The presence of mottles/Fe-Mn concretions indicates a degree of increased wetness and imperfect drainge conditions. Such reducing and oxidizing conditions have been attributed to a reasonably fluctuating groundwater table or the intermittent presence of a perched water table (Simonson and Boersma, 1972).

3.2.3.3 Soil Structure

Subangular and angular blocky soil structures have been commonly observed in most of the pedons studied from various geomorphic units. Massive structure is observed in some of the 'C' horizons of pedons and platy structure has been observed from the 'A' horizon of strongly saline soil of Karnak Upland Plain) and at an archaeological site in the Kaithal Upland Alluvial Plain.

3.2.3.3a Texture

The textural variations observed in the field have been varified by detailed grain-size analysis in the laboratory and the same has been discussed under the heading of laboratory methods and observations later.

3.2.3.4 Calcium Carbonate Concretions

Calcium carbonate concretions are present fairly abundantly in the subsurface horizons of the Drishadvati Plain, Ghaggar floodplain, Kaithal Upland Plain, Rohtak Upland Plain and Basin with Kankar. These vary from few, fine sized, soft concretions to many, coarse sized and hard concretions in pedons of the above geomorphic units. Typically these constitute 5 to 50 % of the soil mass. In the exceptional case of Basin with Marl, at places massive fossiliferous limestone bed with 40 to 75% of $CaCO_3$ is observed. Commonly these concretions occur in B and C/Ca horizons at depths of 25 to 250 cm. In the concretion bearing pedons, these concretions increase in size, hardness and number with depth.

The combined use of the presence or absence of iron-manganese concretions and kankar in different pedons provides a useful tool for differentiating between different geomorphic units. Calcium carbonate concretions are completely absent in the Old Piedmont Plain and Young Piedmont Plain. The Drishadvati

Plain, and Yamuna and Ghaggar Floodplains are marked by the presence of calcium carbonate concretions in the deeper horizons and iron-manganese mottles/concretions in the shallower horizons. Pedons from the Karnal and Kaithal Upland Plains, Fluvio-aeolian Plain and Aeolian Plain and Basin with Marl are rich in calcium carbonate concretions and completely devoid of iron-manganese oxidation mottles/concretions.

3.3 GRAIN-SIZE ANALYSIS

Grain size analysis is important to determine particle size distribution within the soil-profile, which is used to determine soil-texture and amount of pedogenic clay present. Variation in texture from horizon to horizon can be used to decipher the pedogenic and geological history of the soil. Fine grained fraction also affects many processes operating in a soil-profile.

3.3.1 Methodology

All the 184 soil-samples from 34 soil-profiles have been analysed for their grain-size distribution. A sample is first air dried and then rolled with a wooden pastle to break up the clods. The sample is throughly mixed, coned and quartered. The quarter reserved for analysis is passed through 2 mm mesh size sieve. About 50 gm of each sample is treated for the removal of carbonate material by reaction with 10% HCL, until effervescence stops (Carver, 1971). Then 6% $H_2 O_2$ (Jackson, Whitting and Pennington, 1949, p. 77-81). Further the sample is treated with oxalic acid in the presence of recoverable aluminium (a cylinder of sheet aluminium) to remove iron-oxide (Carver, 1971). Excess liquid is removed by decantation after gravity settling of insoluable material. Soluable salts are removed by washing by addition of water, stirring and decantation, a number of times. In the end the sample is dried in air or at 40 ^{0} C in an oven by spreading out in a thin layer on aluminium plate. Weight of oven dried sample has been used as the base weight for calculating percentage of various fractions.

After removal of organic matter, carbonates and iron-oxide, the sample is washeed on a 230 mesh sieve, silt and clay passing throught the sieve into a one litre graduated cylinder. Dispersion of the sample is carried out by addition of the dispersing agent i.e. alkaline sodium hexametaphosphate. (Carver, 1971). Particles above the 40 micron diameters , which are left on the sieve are dried and various fractions are obtained by sieving. Distilled water is added to the suspensionin the cylinder to make the total volume to 1 litre and particle size analysis at the half phi intervals is done by pipette method (Carver, 1971) for the fraction in the cylinder. Sand, Silt and Clay percentages are calculated according to size classification of United Stated Bureau of Soils (i.e. Sand = 2 mm to .o5 mm, silt= .o5 mm to .oo2 mm and Clay= less than .oo2 mm size).

3.3.2 Soil Texture

Soil texture refers to the relative proportions of the various size groups of the individual soil grains in a mass of soil, especially to the proportions of clay, silt and sand below 2 mm in diameter. Soil texture classes are studied in field and also determined by plotting on triangular diagrams (Fig.3.1 To

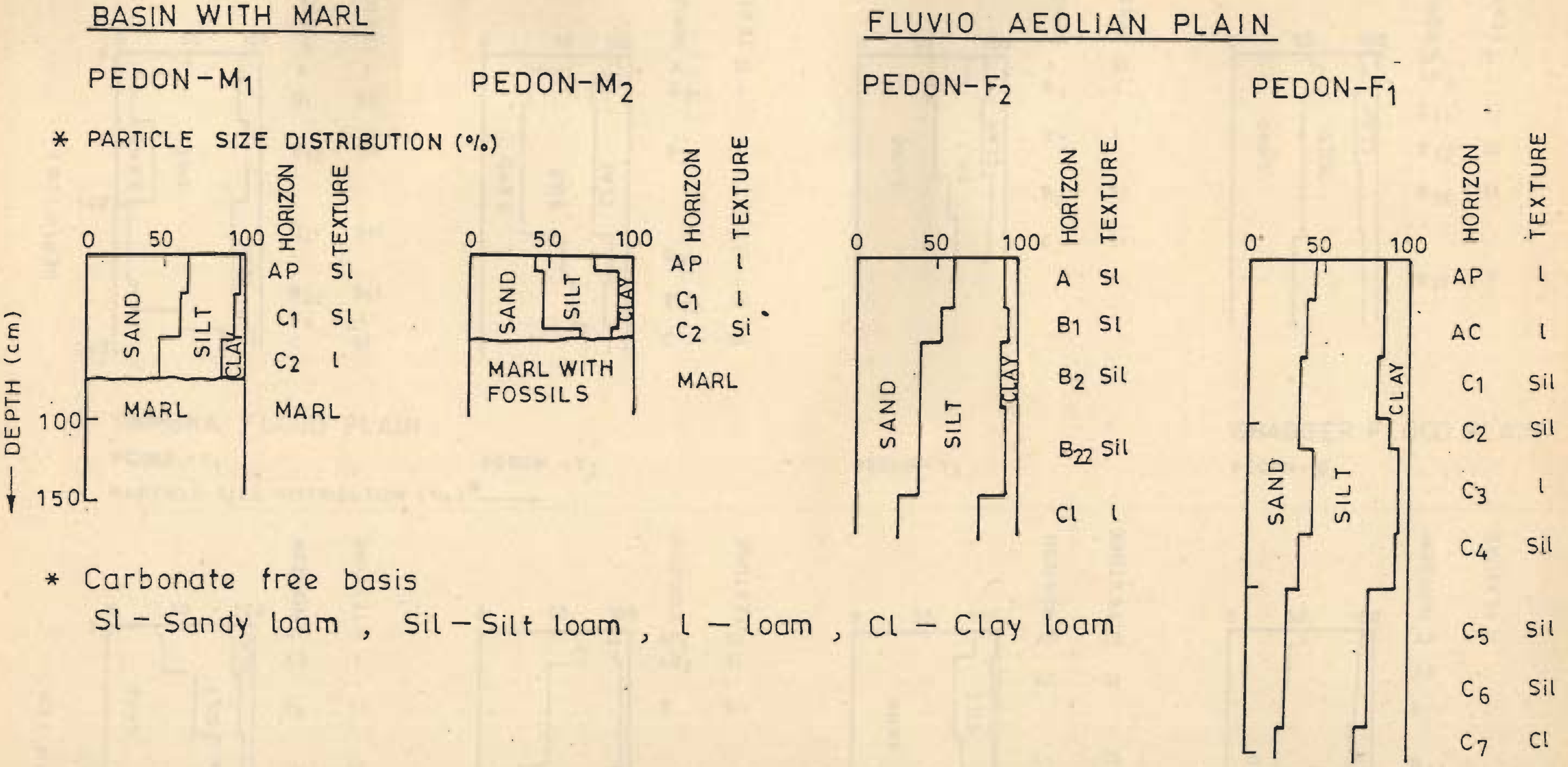
3.4.) for sand, silt and clay percentages, which have been obtained from grain size analysis, numbers 1 to 10 are used for horizon / subhorizon samples from the same pedon.

Based on the textural variations of the subsurface horizons, four catogories of soils can be recognised: (i) Sandy loam to loamy soils in the Younger Piedmont, Ghagger Floodplain, Aeolian Plain, (ii) Sandy loam to Silty clay loam soils in Older Piedmont, Karnal Upland Plain, (iii) Loamy sand to clay loam soils in Drishadvati Plain , Kaithal Upland Plain and Fluvio-Aeolian Plain and (iv) Loamy sand to silt loam in the Yamuna Floodplain.

Large variation in subsurface horizons and from pedon to pedon in different geomorphic units support the idea of their deposition from streams, which are known to be highly variable deposits.

3.3.3 Soil-profile Development Studies

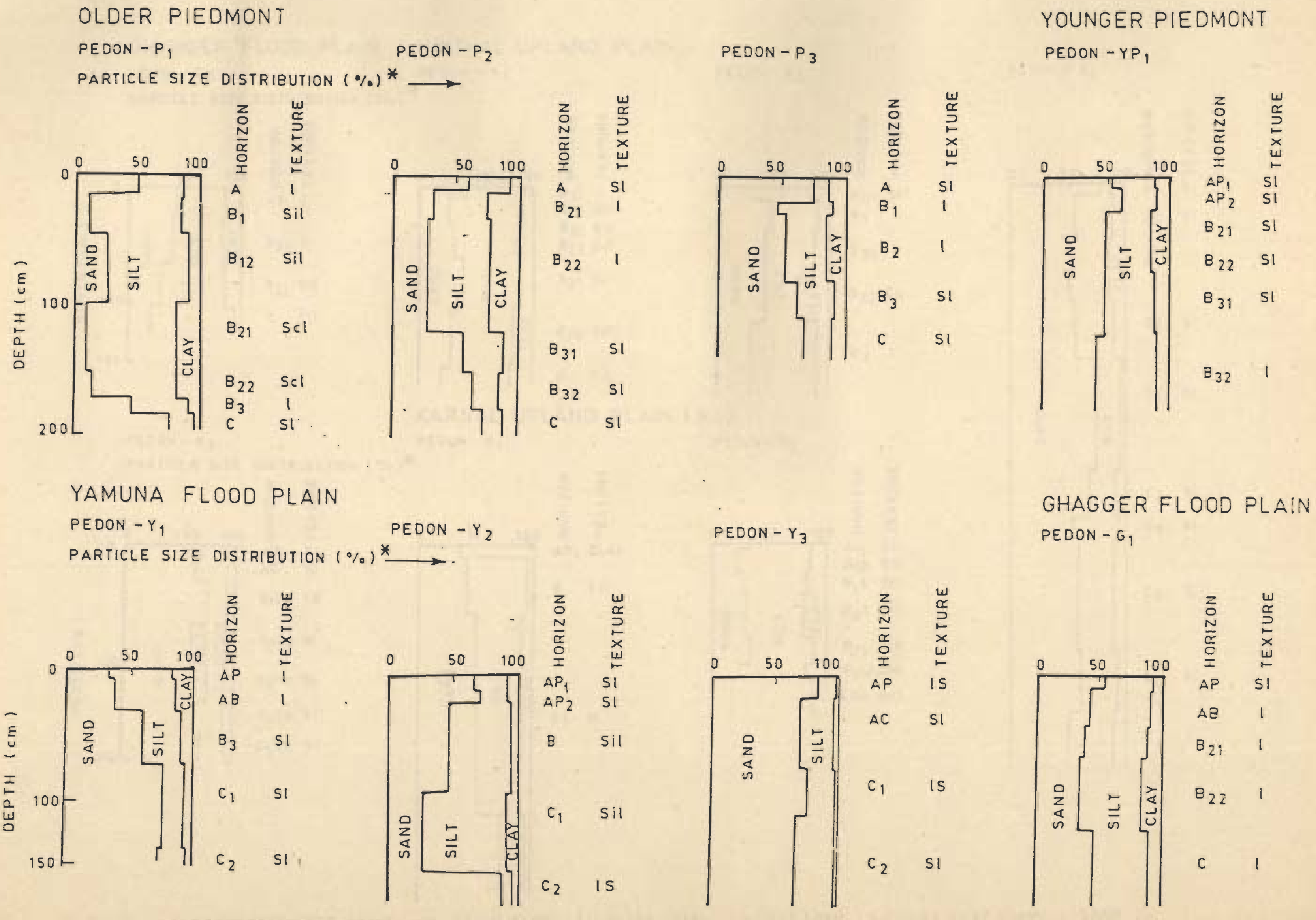
Like many other soil properties, the formation of Bt horizon that meets the argillic criteria is time-dependent because aeolian influx, weathering clay formation and translocation are relatively slow process and vertical variation in clay content may provide clues to degree of development of soil-profole (Birkland, 1984). Following Birkland (1984), variation of sand, silt and clay are shown in (Fig- 3.5 to 3.9) for different pedons. These figure bring out that clay content varies within small limits in most of the pedons and that sand and silt+clay percentages show specific trends with depth. The percentage of sand decreases and that of silt+clay increases with depth in most of the pedons upto B/B_{21}/ B_{22}/C horizons.



* Carbonate free basis

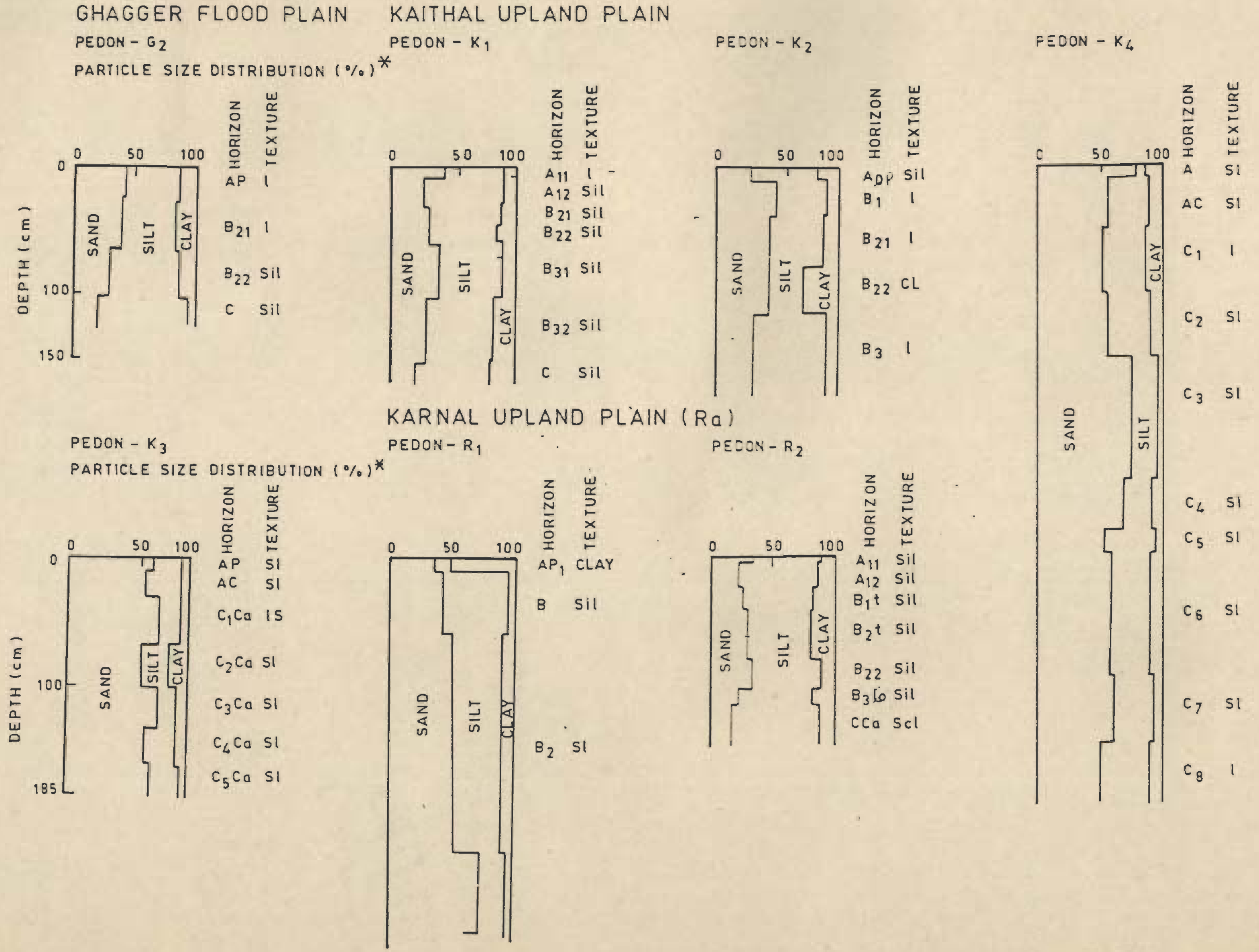
Sl – Sandy loam , Sil – Silt loam , l – loam , Cl – Clay loam

Fig. 3·5 – Variation of sand, silt and clay in different pedons.



INDEX :— * CARBONATE FREE BASIS, lS - LOAMY SAND, Sl - SANDY LOAM, l - LOAM, Sil - SILT LOAM, Scl - SANDY CLAY LOAM

Fig. 3.6 — Variation of sand, silt and clay in different pedons.



INDEX :- * CARBONATE FREE BASIS, lS - LOAMY SAND, Sl SANDY LOAM, Sil - SILT LOAM, Scl - SILT CLAY LOAM, l - LOAM

Fig. 3·7 — Variation of sand, silt and clay in different pedons.

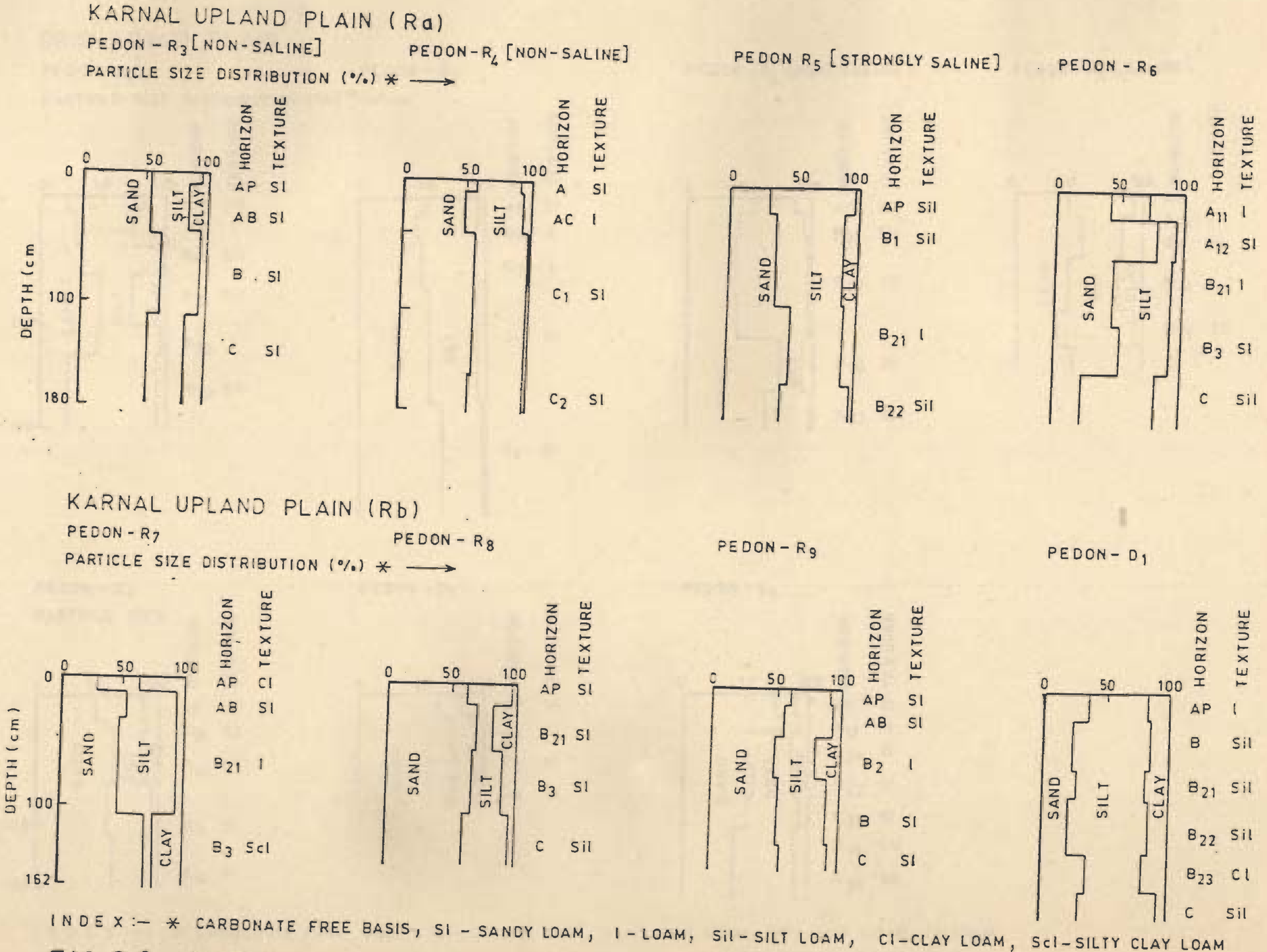
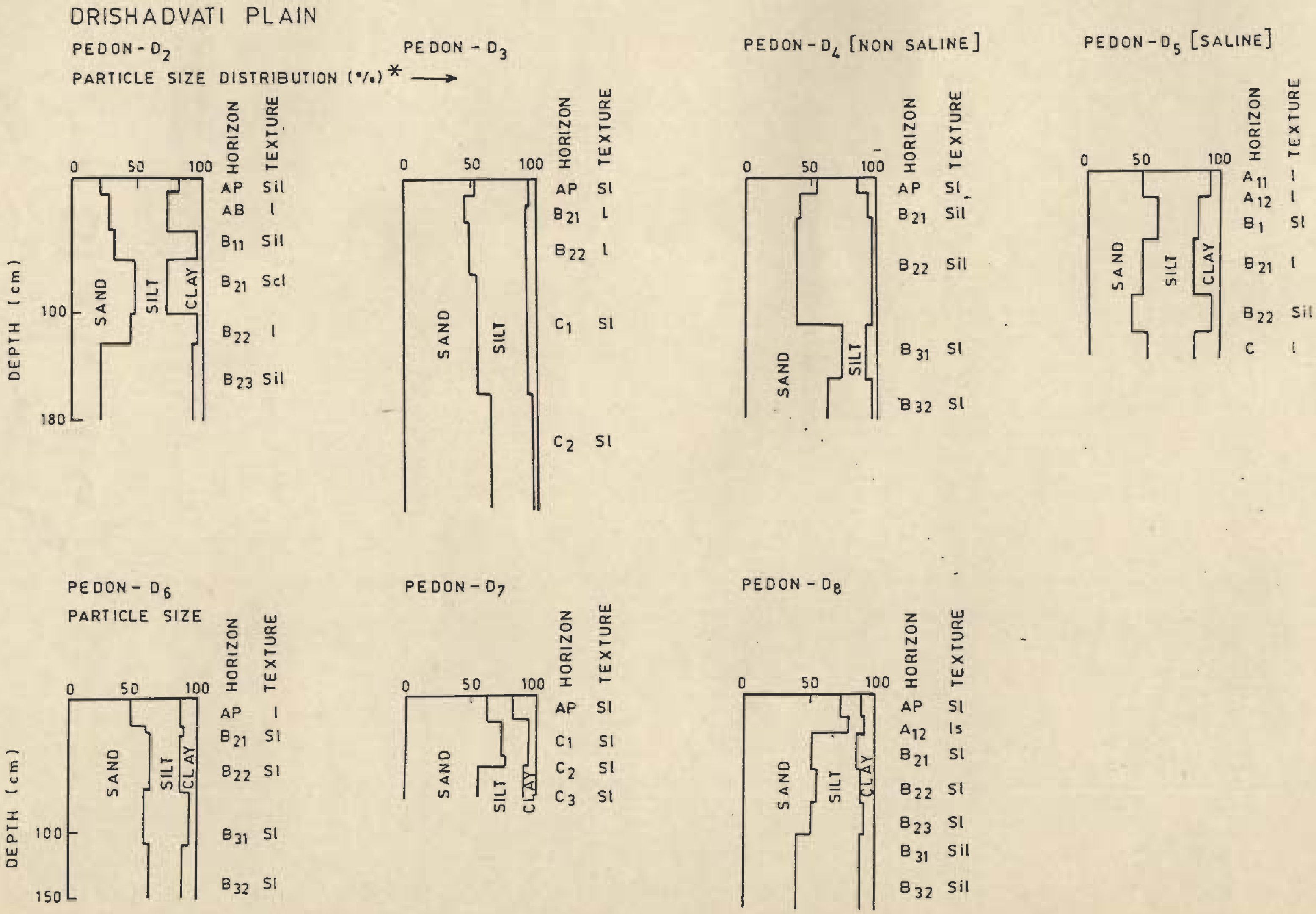


FIG. 3·8 — Variation of sand, silt and clay in different pedons.



INDEX :— * CARBONATE FREE BASIS, ls – LOAMY SAND, Sl – SANDY LOAM, Sil – SILT LOAM, l – LOAM

FIG. 3·9 — Variation of sand, silt and clay in different Pedons.

Birkland (1984) has given a clay accummulation index for B_t horizon to indicate the degree of soil profile development , as clay content in B_t horizon multiplied by its thickness. Levine and Ciolkosz (1983) have defined clay accummulation index slightly different and it is obtained by multiplying, percentages of clay in sub-horizons of B-horizon minus the percentage of clay in C or A horizon, by the thickness of sub-horizon and summing for B_2 horizon. We have calculated silt+clay accummulation index in the same manner as clay index of Levine and Ciolkosz 1983) for various pedons.

Taking into account silt+clay accummulation index of best developed pedons of different geomorphic units, their ranking is shown in table 3.2.

Table 3.2 - Ranking of different geomorphic units on the basis of silt+slay accummulation index

Geomorphic Unit	Total silt+clay accummulation Index values
Yamuna Floodplain	Nil
Fluvio-Aeolian Plain	189.1 - 457.1
Ghagger Floodplain	1144.8 - 402.5
Karnal Upland Plain	1540.0 - 88.4
Younger Piedmont	2248.7
Drishadvati Plain	2292.9 - 285.0
Kaithal Upland Plain	4048.2 -253.4
Older Piedmont	4780.9 - 552.9

The range of values of silt+clay accummulation index for different geomorphic units are given in table 3.2..and these

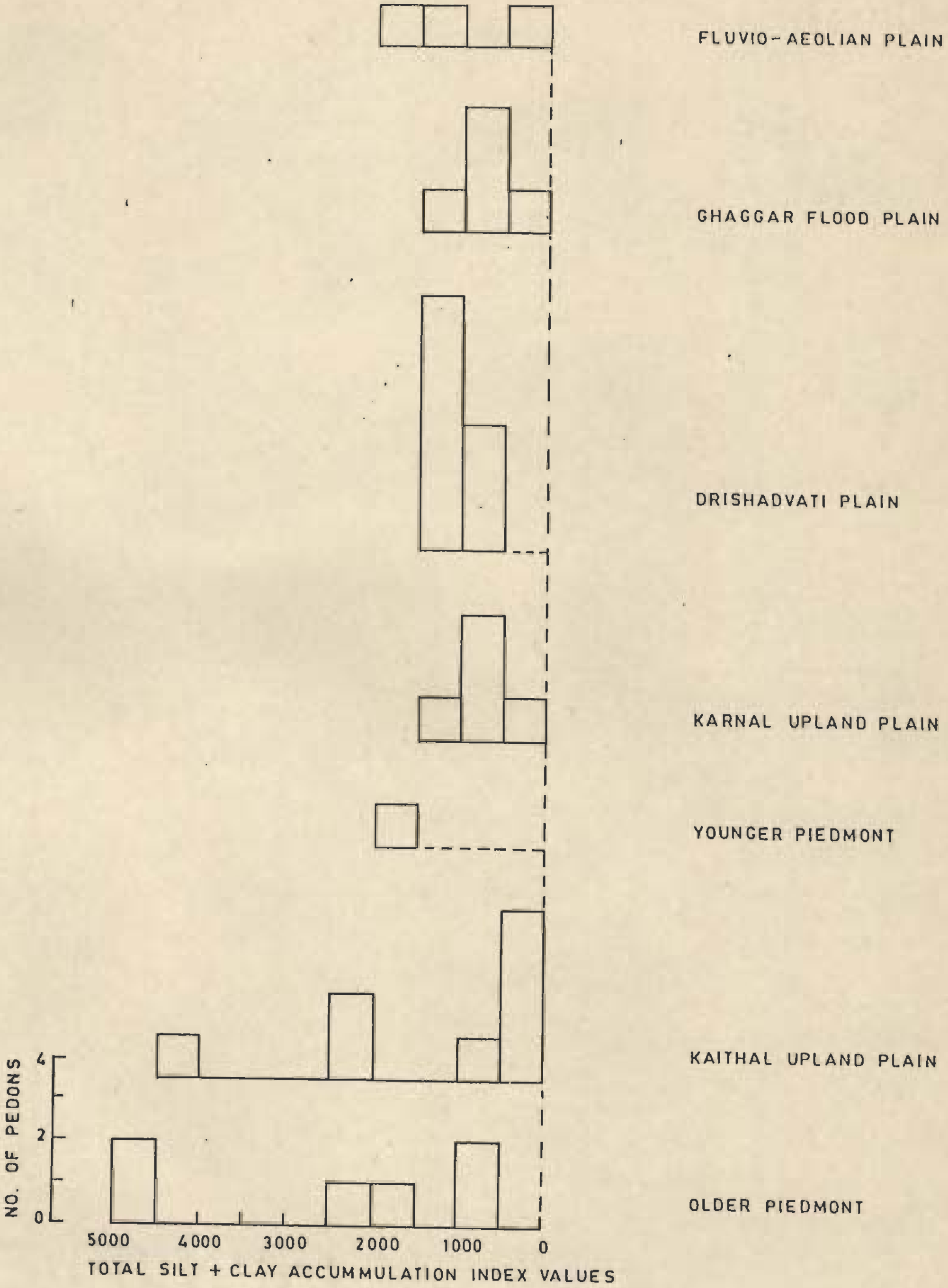


Fig. 3·10 — Bar diagram showing the range of values of silt + clay accummulation index for different geomorphic units.

values are depicted in the form of bar diagram in Fig.3.10.

These ranges vary considerably on all the geomorphic units and specially in the Kaithal Upland Plain and Older Piedmont Plain. It reflects that younger soil profiles are in the various stages of the development in the part of these geomorphic units i.e. these units have been reworked by streams at different times and younger pedons are probably from these palaeochannels. Also, Haryana State has been the cradle of civilization since about pre-Harrapan period (2300 B.C.), man has tried to plane the top surface for agriculture purposes and due to the population explosion and consequent pressure on land , this phenomenon has taken place on a large scale in recent years and has resulted in removal of top soil and exposure of lower sandy horizons (C-horizon) at places in planning operations. The above process also has produced soils showing very little profile development on some old geomorphic units.

3.4. CHEMICAL ANALYSIS

Air dried soil sample (<2mm) size is crushed upto the -100 mesh (0.127m) screen size, mixed thoroughly and split by coning and quartering method to obtain a representative sub-sample weighing about 75 gm of each sample for chemical analysis.

3.4.1.Methdology

3.4.1.1. Organic Carbon and Sulphur Determination

About 2 gm of soil sample with carbonates has been treated with 10% HCl to remove inorganic carbon, as suggested by Jackson (1967) and .5 to .999 gm of sample is placed in a porcelain crucible, specially designed for Mat-600 electric furnace, available in the Welding Research Laboratory, University of Roorkee. The dry cumbustion has been carried out in the presence of tungston as a catylist and oxygen gas. Organic carbon and sulphur are determined as CO_2 and SO_2. A print out from the instrument gives directly percentage for organic carbon and sulphur.

3.4.1.2.pH Determination

To determine pH, 1:2 soil:water suspension is prepared by using distilled water and shaking it intermittently for an hour. pH reading is taken by digital Century pH meter.

3.4.1.3. Electrical Conductivity (EC)

Soil:water (1:2) extracts are prepared by filtering the above suspension and electrical conductivity is determined by digital conductivity meter (Century, CC-601). Appropriate temperature correction for 25 degree C is made for electrical conductivity (EC) data on soil extracts to the standard temperature as described by U.S.D.A. (1954, Table 15).

3.4.1.4. Alkaline- earth Carbonates

Alkaline-earth carbonates have been determined by placing 5 to 25 gm of soil in 150 ml beaker. 50 ml of .5N HCl is added by means of pipettte. Beaker is covered by a watchglass, solution is boiled gently for 5 minutes and cooled and filtered. Soil is washed off all the acid with water. Unused acid is determined by adding 2 drops of phenophthalein indicator and back- titrating with .25N sodium hydroxide. $CaCO_3$ equivalent in percent has been calculated as (meq.HCl added-meq.NaOH used) multiplied by 5 and divided by the weight of the sample used in grams. It may be noted that this procedure gives higher values for $CaCO_3$, as soil constituents other than lime may react with the acid.

3.4.1.5. Major and Trace Elements Determination

Major and trace elemental analysis has been carried out by two solutions method, as suggested by Shapiro (1975).

Solution A: Solution A is used in the determination of SiO_2 and Al_2O_3. 50 mg of each of soil sample and standard are decomposed by fusion with NaOH at a comparatively low temperature for about five minutes. in nickel crucibles. After cooling, the melts are leached with water and solutions are acidified with 10 ml of 50% HCl and diluted to 200 ml.

Solution B: Solution B has been used in the determination of Fe_2O_3, CaO, P_2O_5, Na_2O, K_2O, and total trace elements viz. Cu, Mn and Zn. Solution has been prepared by following the procedure suggested for analysis of sediments in "Manual of Analytical Methods for Atomic Absorption Spectrophotometer" by Perkin Elmer. It is prepared by heating 200 mg of air dried soil samples in a platinum or porcelain crucible in a furnace upto 900^0C to destroy organic matter. Sample is then transferred to 100 ml special teflon beakers.

Sample expected to be high in alkaline-earths is treated with 100 ml of 1+1 HCl for one hour at 60^0C to 80^0 C. Supernatent liquid is decanted, which contains most of the alkaline metals, into a 250 ml volumetric flask and retained. The residue of this sample or the sample not expected to be high in alkaline earths is treated with 10ml of HF and 10ml of 50% HCl and evaporated to dryness. Addition of HF and HCl and evaporation to dryness is repeated till the whole of sample is digested. A few drops of $HClO_4$ (Perchloric acid) and Conc. HNO_3 (1:1, $HCLO_4$: HNO_3) mixture is used to digest the remaining organic matter, if any, and evaporated upto dryness. At the end, 5 ml of 50% HCl is added and evaporated to dryness. The residue is dissolved in a minimum amount of HCl.

The solution is transferd to a 250ml volumetric flask, combining it with the acid extract for high alkaline earth sample and diluted, so that final volume was approximately 5% (V/V)HCl.

3.4.1.6. Analytical Instruments

Na_2O and K_2O are analysed by using Toshniwal digital flamephotometer. P_2O_5 has been analysed by colourimetric method on Spectronic-20 and SiO_2, Al_2O_3, Fe_2O_3, CaO and MgO, Zn, Cu and Mn, have been estimated with the help of Perkin-Elmer-Atomic-Absorption-Spectrophotometer.

3.4.2 Chemical Analyses Data

3.4.2.1. pH, Ec, Total Sulphur and Organic Carbon

Most of the soils in the area of study are alkaline in nature. pH values for most of samples vary from 7.4 to 8.63. Higher values pH i.e. 9.02 to 10.30 in some pedons occur in association with higher concentration of soluble salts near the surface (A-horizon) in the Karnal Upland Plain.

Electrical conductivity values range from 0.013 to 20.04 mmhos/cm in most of the pedons and only one high value of 51.5 mmhos/cm is shown by the A-horizon of strongly saline soil from Rohtak Upland Plain. Older and Younger Piedmonts have EC’s less than 4.0 mmhos/cm (non-saline nature), whereas other geomorphic units have EC's more than 4.0 mmhos/cm, which indicate that they are saline in nature to varying degrees. Organic carbon varies between 0.01% to 1.03% and shows decreasing trend with depth. Total sulphur content in soils varies from .0003% to .8281% and cannot be used to establish any relationship with depth. Dil-HCl-soluable_alkaline-earth-carbonate has been determined for some selected samples for higher values of $CaCO_3$ and found that highest percentage of $CaCO_3$ is 55.60%.

Soils of Haryana have been chemically analysed by a number of workers (Kuhand, 1970; Manchanda, 1978; Ahuja, 1978, 1981; Sangwan, 1978; Rana, 1980; Bhumble and Chhabra, 1980; Kilar Singh, 1980). These studies pertain mainly to small areas for agricultural purposes. They have done analysis for pH, EC, organic carbon, CEC, soluable anions and cations, total chemical analysis, micronutrients, etc. These studies that indicate the soil pH is mainly neutral to alkaline. As the surface soils invariably contain high amount of soluable salts, EC has been recorded upto 30 mmhos/cm, these soils have been classified as saline-sodic soils (Raychoudhari, Datta and Biswas, 1954, Agarwal and Yadav, 1954, Kanwar and Sehgal, 1962). The organic carbon is generally less than one percent. These results are very similar to those obtained in the present study.

3.4.2.2. Total Elemental Analysis

Total elemental analysis has been frequently carried out by various workers and data obtained this way have been widely used for determining the amount of weathering that has taken place in a soil/rock (Birkland, 1984). In this technique, all the elements are reported as oxides because the main balancing anion ususally is oxygen and we deal with relative increase and decrease. SiO_2 is always present in the parent material, so it is always decreases, Al_2O_3 has low solubility over the usual pH range, is essential to most clay minerals, so it commonly shows a relative increase with increase in depth. Iron is present in most rock- forming minerals and after weathering in an oxidising environment converts to various Fe^{3+} bearing substances or make up a part of clay minerals. It is is reported as Fe_2O_3. More insoluable TiO_2 should show a relative increase. The major remaining elements are MnO, CaO, MgO, Na_2O, and K_2O. Among these elements, Mg is an essential part of weathering product (Mg-Chlorite), part of K is tighty held in interlayer position by illite, Mn can form bluish black mottles and Mg, Ca, K and Na are main exchangable cations. Most of the later are depleted in wet environments but in dry environments, Ca can increase at depth, if $CaCO_3$ accummulates.

Total chemical analyses have been used for inferring the degree of weathering in two ways: estimating the degree of accumulation for some selected oxides in B horizon as compared to A or C horizon and relative changes in molar ratios of some of the oxides in the B horizons of different geomorphic units.

3.4.2.3. Accumulation Indices as Indicators of Weathering

As Al_2O_3 has very low soluability and accumulates after weathering in the form of the clay minerals. In the same way iron which is the part of various rock-forming minerals, accummulates in the form of Fe^{3+} bearing substances or make up part of clay minerals. In view of the above concept accummulation of Al_2O_3 and

Fe_2O_3 is considered as time dependent. Accummulation indices for Al_2O_3 has been calculated for different pedons in a similar way as, clay accummulation index obtained by Levine and Ciolksoz (1983). The distribution of these values are shown in the form of bar diagram in Fig - 3.19a. and given below, in table.3.3 Comparision of results of the $Al_2\ _3$ and $Fe_2\ ^3$ accummulation indices with the ranking obtained from silt+clay accummulation index shows that the Ghagger Floodplain should be ranked slightly above in less developed soil profiles according to $Al^2\ O^3$ and Fe^2O^3 accummulation index

Table 3.3 - Ranking of different geomorphic units on the basis of Al^2O^3 and Fe^2O_3 accummulation indices.

Rank	Al_2O_3 accummulation Index	Fe_2O_3 accummulation Index
Yamuna Floodplain	409.6-135.8	168.0-43.40
Fluvio-aeolian Plain	287.9	264.30
Younger Piedmont	592.90	326.10
Ghagger Floodplain	528.40-500.20	197.7-40.34
Kaithal Upland Plain	680.98-616.0	680.98-506.57
Karnal Upland Plain	1387.40-517.45	648.9-4.6
Drishadvati Plain	1148.8-170.1	651.3-173.75
Older Piedmont	3121.5-380.0	1358.6-298.0

3.4.2.4. Molar Ratios Weathering Studies

For comparison of weathering intensity for different pedons from various geomorphic units, the following five ratios have been recalculated from chemical analyses.

Silics:Aiumina	SiO_2/Al_2O_3
Silica:Iron	SiO_2/Fe_2O_3
Silica:Sesquioxide	$SiO_2/Al_2O_3+Fe_2O_3$
Silica:R2O3	$SiO_2/Al_2O_3+Fe_2O_3+TiO_2$
Bases:Alumina	$(K_2O+Na_2O+CaO+MgO)/Al_2O_3$

The above ratios should decrease with time due to weathering in a leaching environment (Birkeland, 1984, p. 81). Since TiO_2 percentage is very small, $SiO_2:R_2O_3$ ratios are not very different from SiO_2:sequioxide ratios have been considered in further analysis. Trends of variation of the first three ratios with depth for various pedons are very similar and also variation of values from pedon to pedon are similar. So any of three ratios can be used for study of weathering intensity. Taking into account, silica:sesquioxide ratio values, different geomorphic units can be arranged as shown in Table 3.4.

Table 3.4 - Range of values of silica:sesqioxide ratio for different geomorphic units

Geomorphic unit	Silica:sesqioxide ratio
Younger Piedmont	5.43-4.41
Ghagger Floodplain	4.00-2.93
Yamuna Floodplain	3.09-2.71
Older Piedmont	7.53-2.16
Fluvio-Aeolian Plain	2.89-2.09
Karnal Upland Plain	4.56-1.93
Drishadvati Plain	5.15-1.74
Kaithal Upland Plain	6.04-1.11

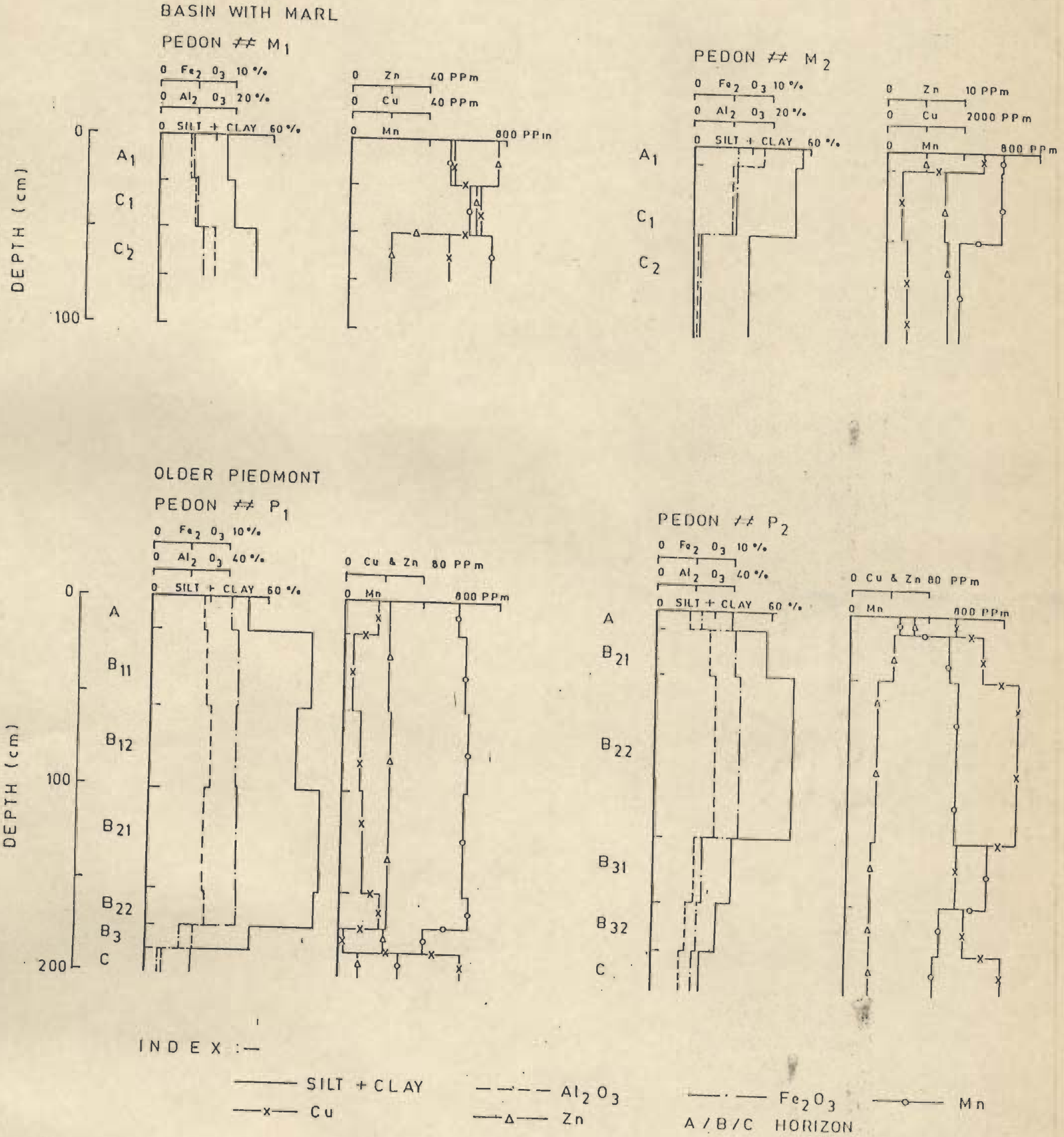


Fig. 3·11 — Variation of Al_2O_3, silt + clay, Cu, Mn and Zn with depth in different pedons, from different geomorphic units.

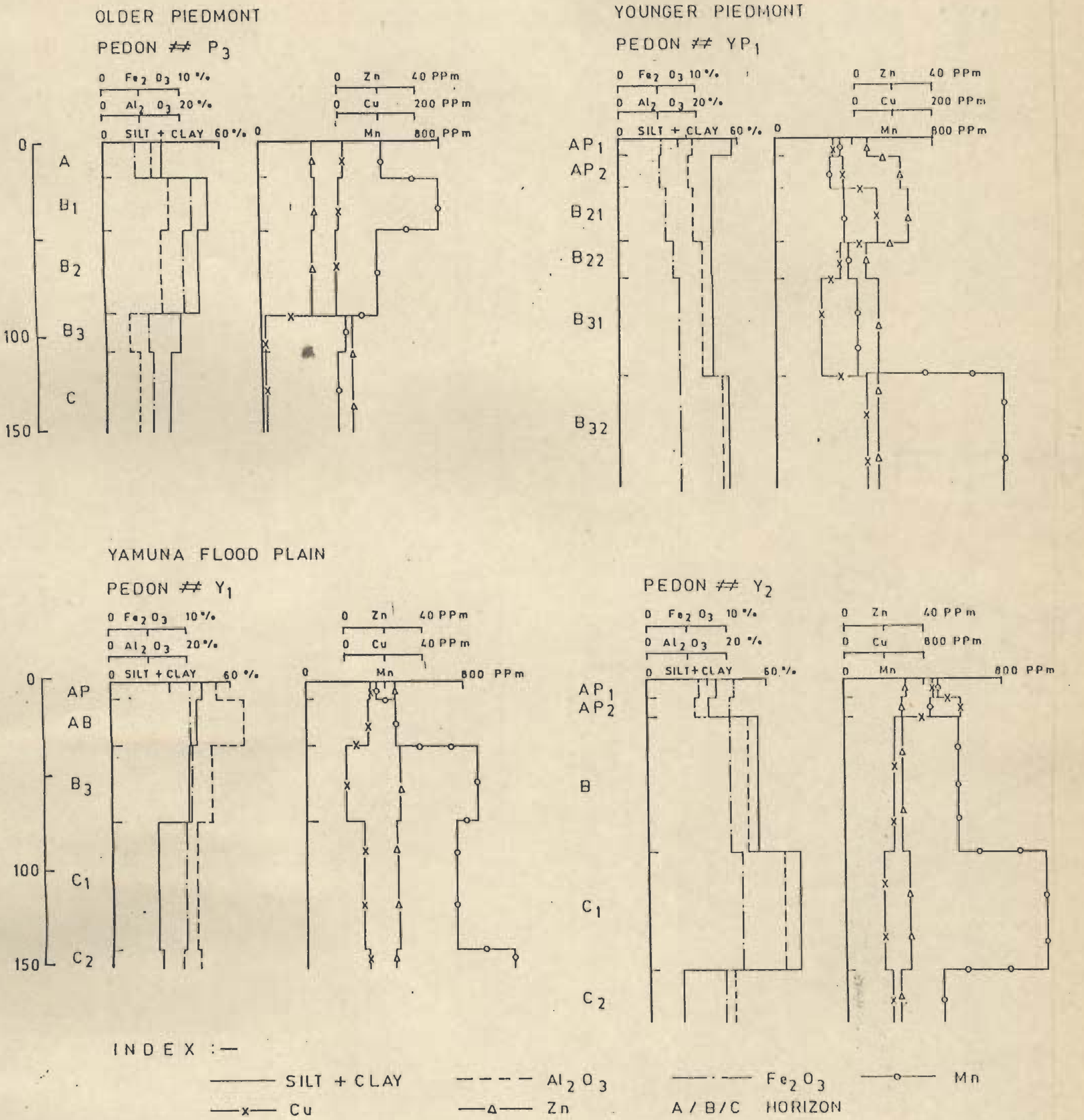


Fig. 3·12 – Variation of Al_2O_3, silt + clay, Cu, Mn and Zn with depth in different pedons, from different geomorphic units.

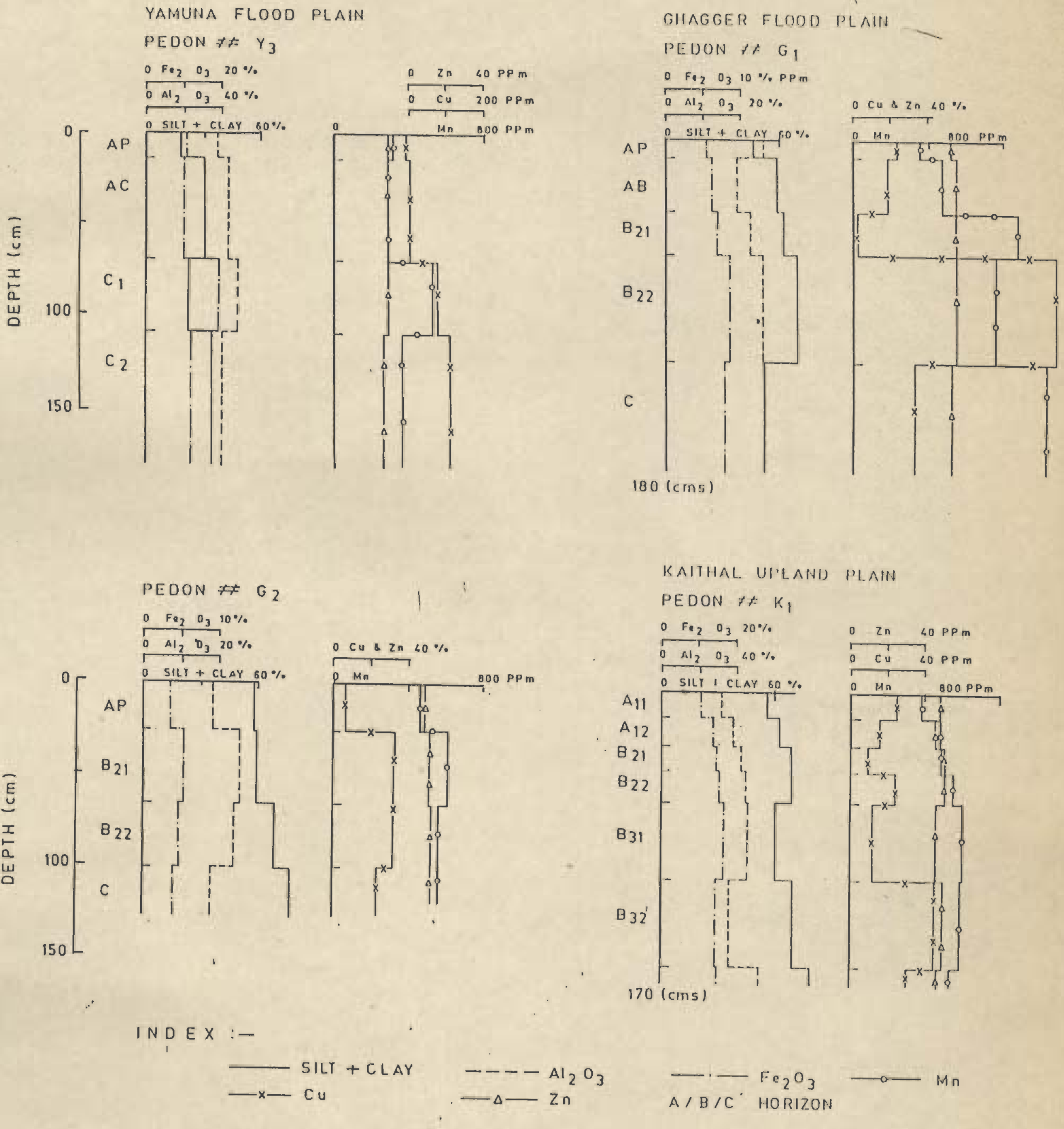


Fig. 3.13 – Variation of Al_2O_3, silt + clay, Cu, Mn and Zn with depth in different pedons, from different geomorphic units.

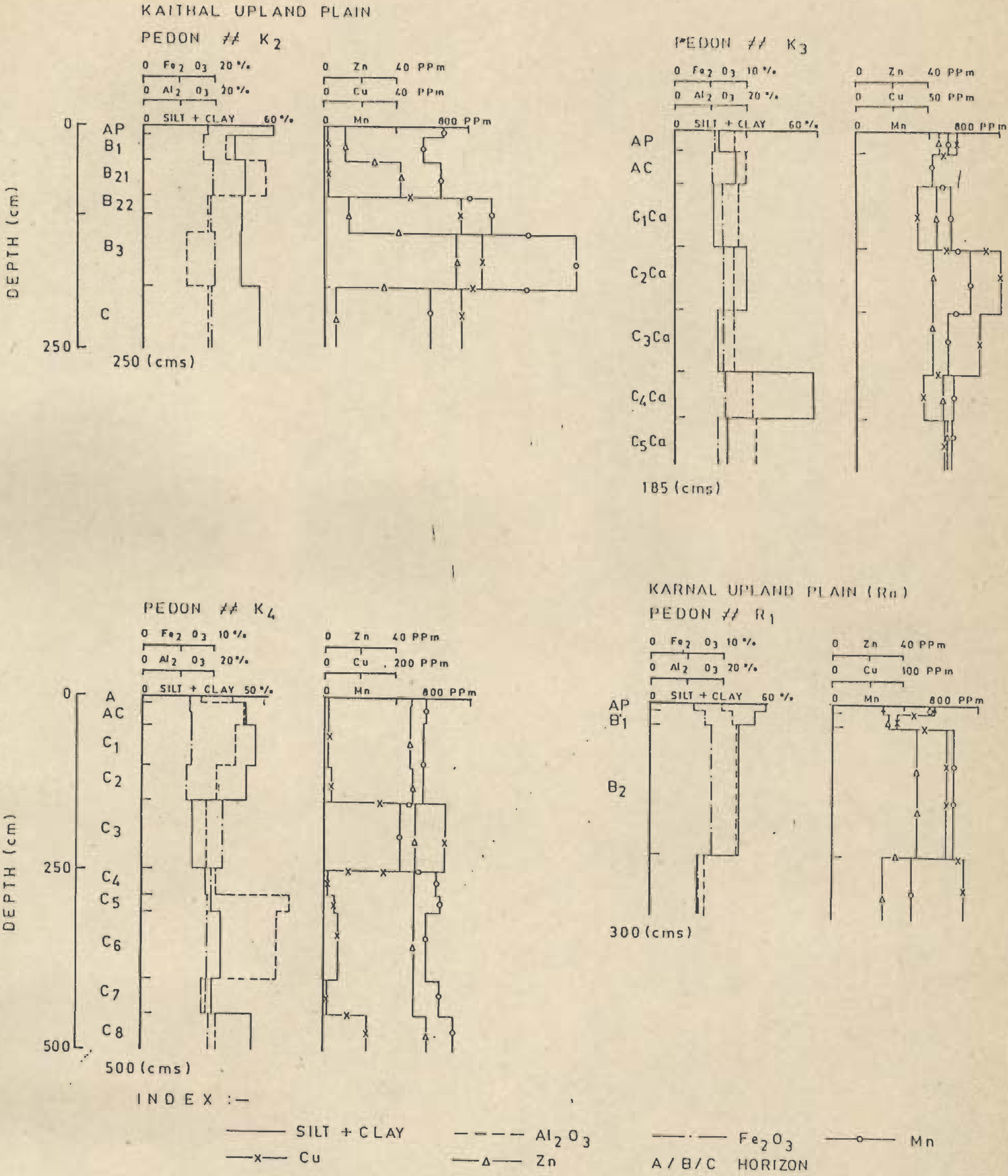


Fig. 3.14 – Variation of Al_2O_3, silt + clay, Cu, Mn and Zn with depth in different pedons, from different geomorphic units.

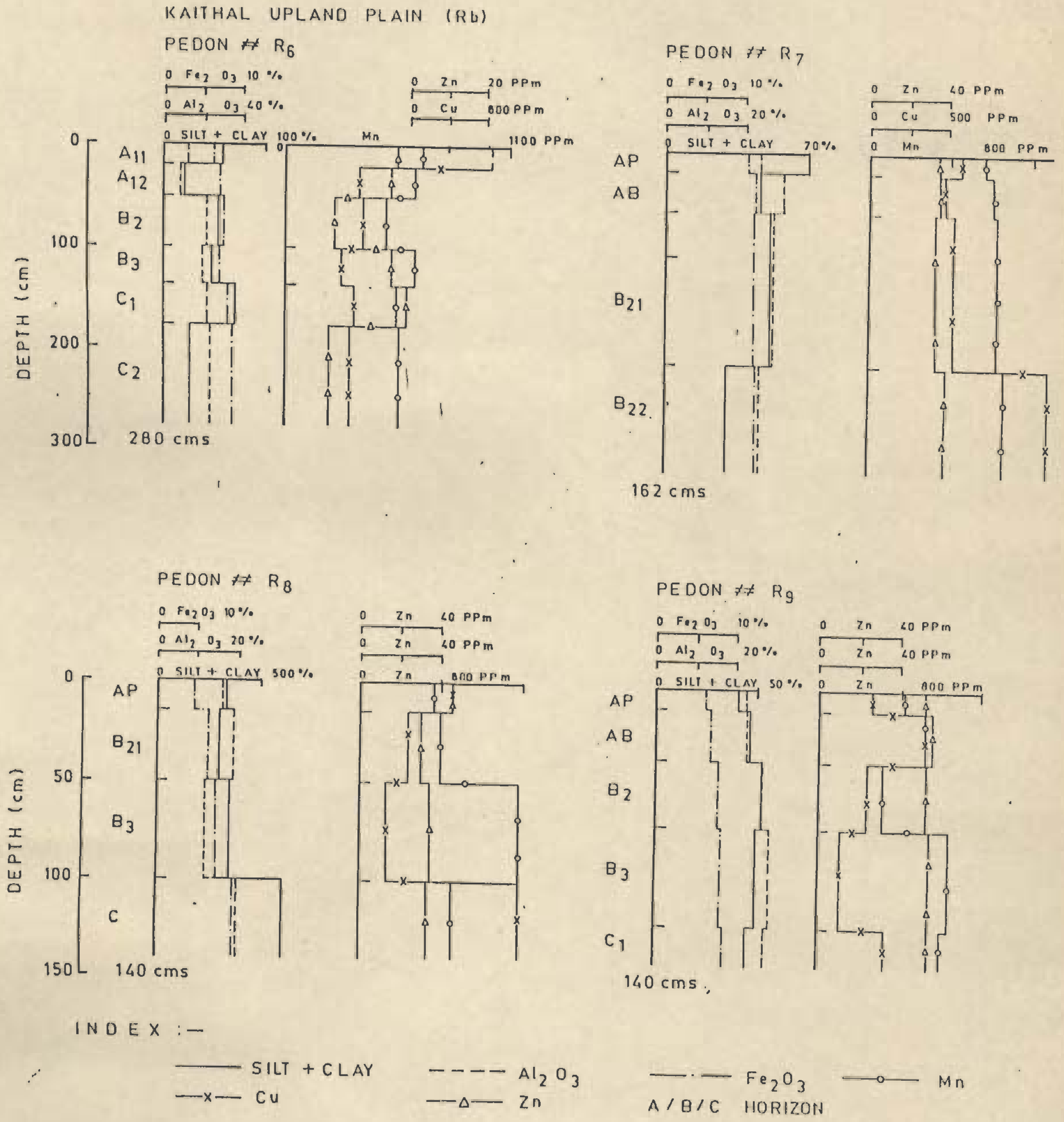


Fig. 3.15 – Variation of Al_2O_3, silt + clay, Cu, Mn and Zn with depth in different pedons, from different geomorphic units.

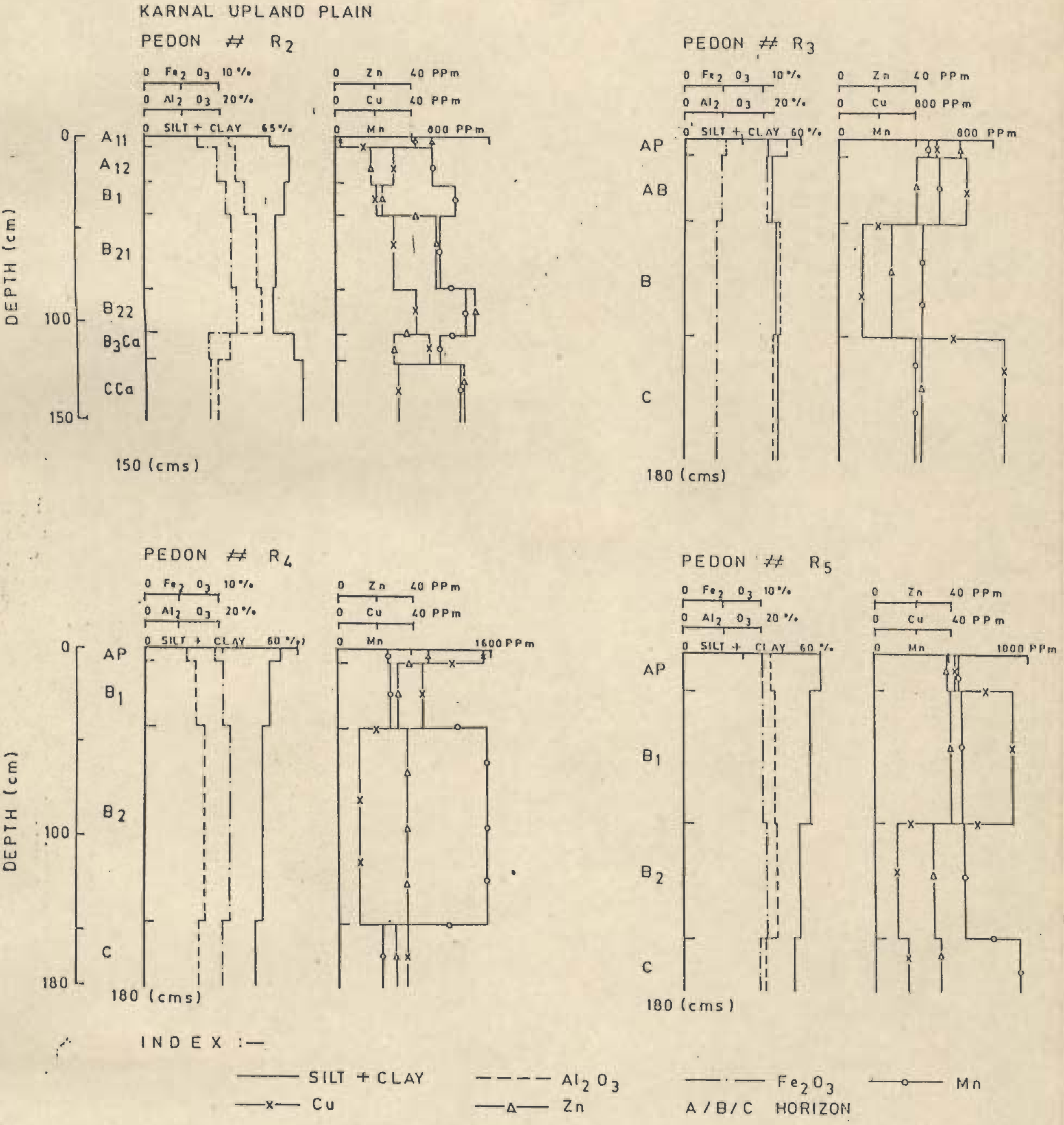


Fig. 3·16 – Variation of Al_2O_3, silt + clay, Cu, Mn and Zn with depth in different pedons, from different geomorphic units.

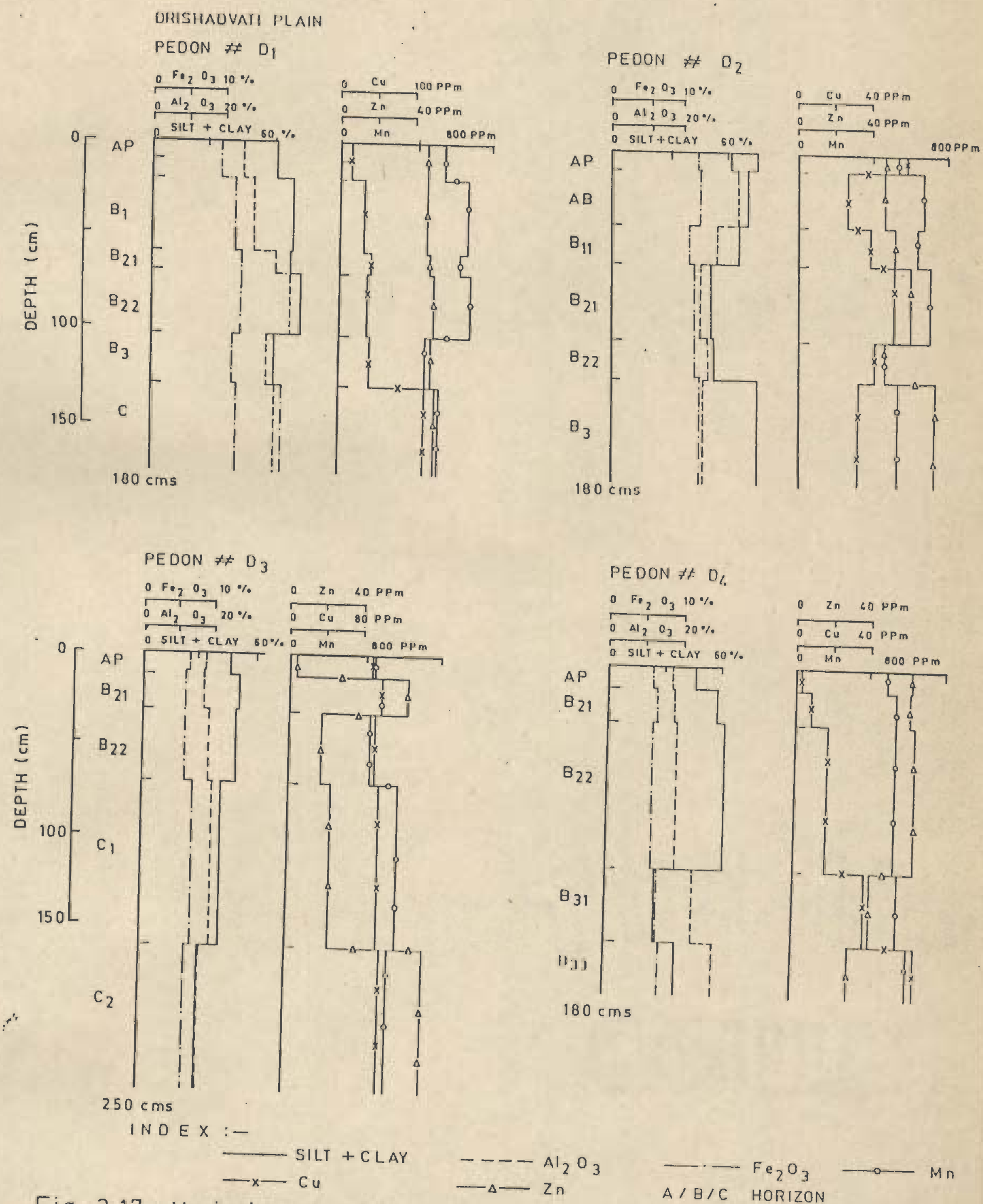


Fig. 3·17— Variation of Al_2O_3, silt + clay, Cu, Mn and Zn with depth in different pedons, from different geomorphic units.

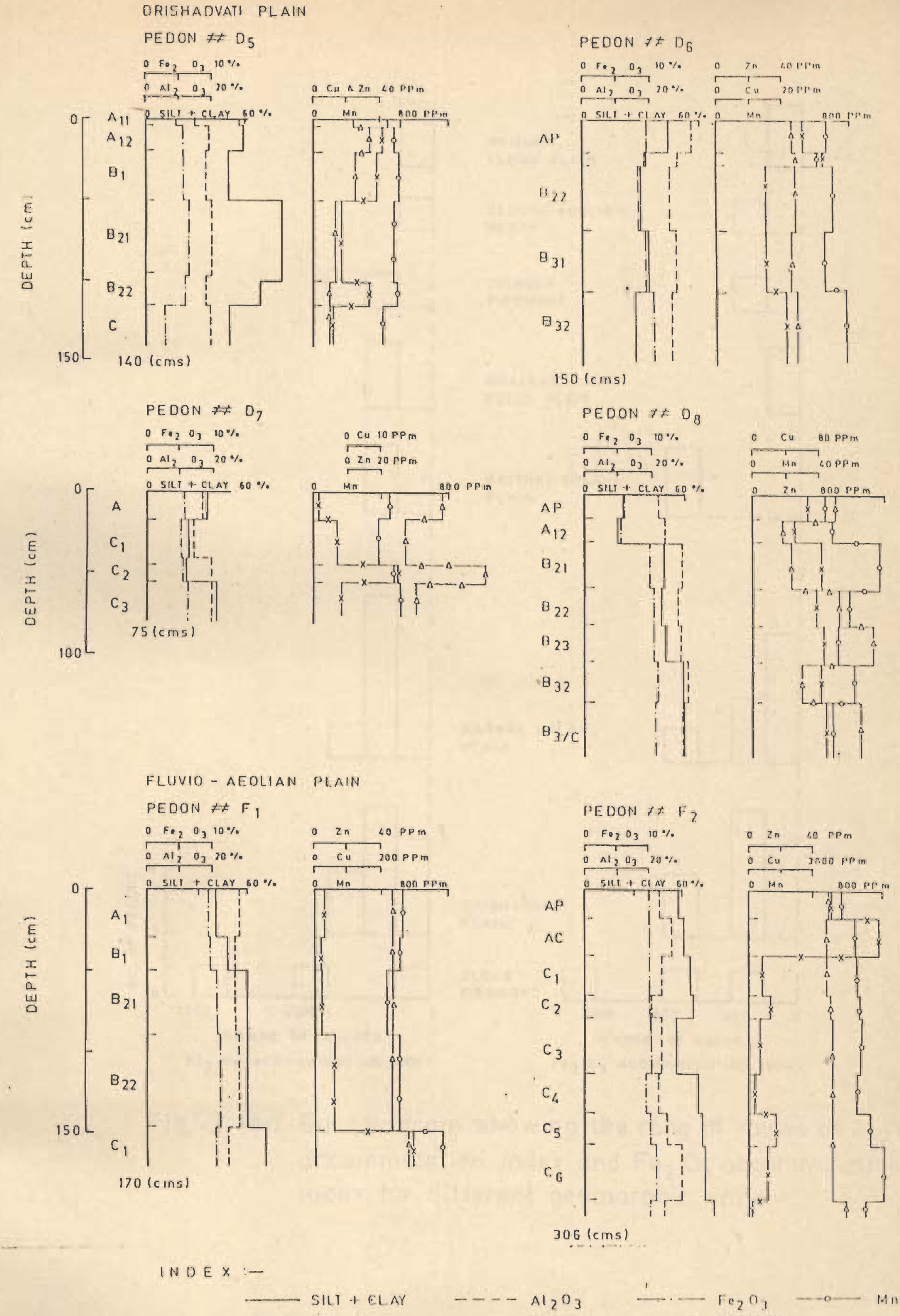


Fig. 3·18 – Variation of Al_2O_3, silt + clay, Cu, Mn and Zn with depth in different pedons, from different geomorphic units.

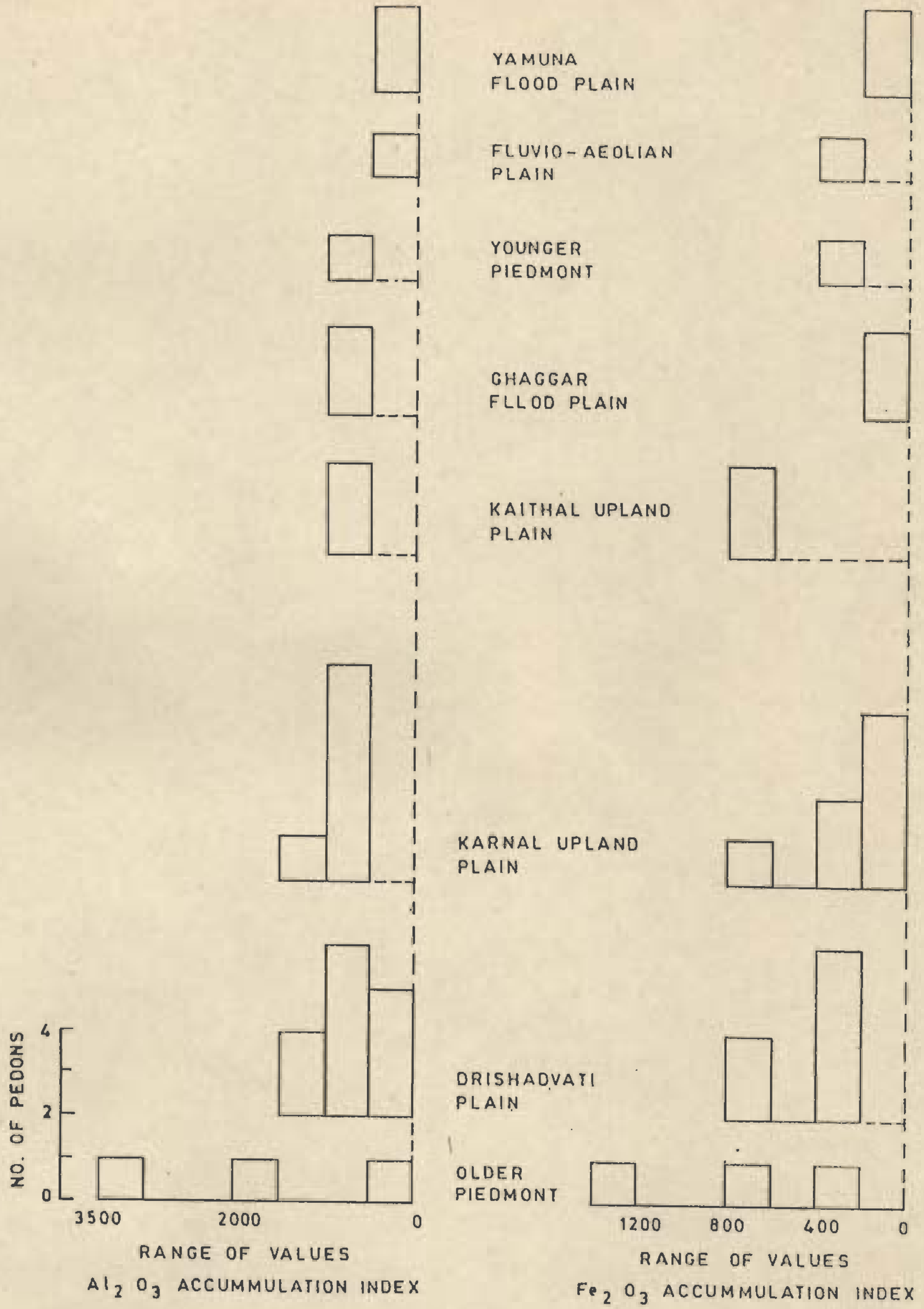


Fig. 3·19a–Bar diagram showing the rang of values of Al_2O_3 accummulation index and Fe_2O_3 accummulation index for different geomorphic units.

The molar ratio silica/sesquioxide for different geomorphic units show wide difference compared with the data of other indices mentioned above and thus given less emphasis in preparing chronosequence.

Base:alumina ratio is not found useful for infering intensity of weathering in this area as accumulation of $CaCO_3$ has been superimposed on leaching phenomenon in some of geomorphic units.

3.4.2.5. Trace elements

Mainly three trace elements Cu, Zn and Mn have been analysed for the whole soil samples. Other elements like Sn, Pb, Cr, Co, Ni, Mo, and Li were also determined for 10 representaitve soil samples and were found to be below the detection limits of the instruments (i.e .001 ppm). Study of the total trace elements contents of soils of different geomorphic units shows that Cu varies over a wide range usually from 2.5 ppm to 378.75 ppm with three exceptions ranging between 1541.25 ppm and 3906.25 ppm in sub-soil horizons of the various units and no significant trend with depth can be discerned. Total Mn varies from 258.75 ppm to 1576.25 ppm and total Zn contents varies from 10 ppm to 106.25 ppm. In general Mn increases with depth in most of the pedons, Zn varies within a small range, does not exhibit any relationship with depth.(Fig - 3.10-3.18)

Bhumbla (1964) and Zandawa (1964) have determined both micronutrients and total trace elements in soils of the adjoining area of Punjab, and reported that total Cu varies from 6.6 ppm to 36.4 ppm and copper soluable in acid reaches upto 300 ppm. Total

Zn varies from 18 ppm to 97.5 ppm (average 54.5 ppm) and total Mn varies from 350 ppm to 780 ppm. Aubert and Pinta (1977) has mentioned some ranges of about fifteen trace elements (total and micronutrients) for India and for various other countries. They mention that in India, Copper varies from 80 ppm to 250 ppm, Mn varies from 350ppm to 550 ppm and Zn content averages 50 ppm to 100 ppm. The results of the present study are comparable to the earlier studies mentioned here.

3.4.3 STATISTICAL ANALYSIS OF DATA

Many of the properties of soils are highly interrelated as brought out by study of correlation matrix (Sidhu et al., 1977) and principal component analysis (PCA) of various types of data on soils by some workers (Seward and Kantrud ,1971; Sondeim et al., 1981; Severson, 1981; and Richardson and Bigler, 1984) for analyses of various types data from soils. Studies of such relationships by using correlation matrix or PCA may provide an insight into the dependance structure of different variables and such a structure may have genetic significance.

Keeping the above in view, a computer program by Davis (1987) for calculating Pearson product correlation matrix by Davis (1987) has been used for analysing the soil data. Computations have been carried out on the University of Roorkee DEC-20 computer. Correlation matrix obtained from values of 28 variables including percentages of silt, clay, major elements, minor elemnts, depth of the various sampled horizons for 183 samples listed in Appendix III - V It indicates out that siginificant correlations ($r_{181, 0.95} \simeq 0.1$) exist between many variables and many of soil variables are highly interrelated. In

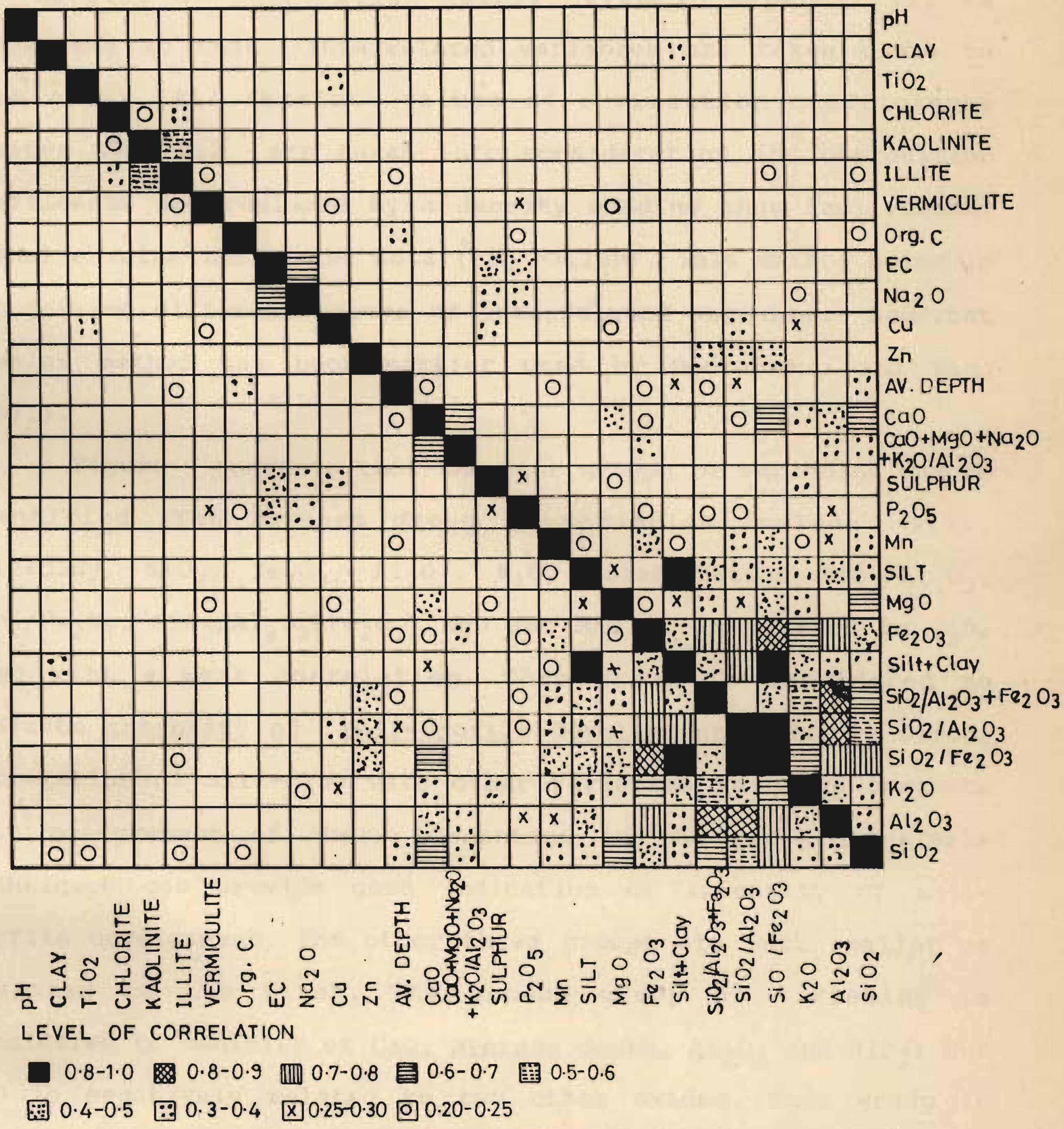


Fig. 3·19b – Representation of the correlation matrix with rearranged variables to bring out groups of interrelated variables.

the present study, the position of the the various varibale along the margins of correlation matrix given in Appendix VII is rearranged so that interrelated variables are taken close to each other. All absolute values of correlation coefficients greater than 0.2 are taken into consideration and correaltion coefficents are replaced by a density shading thus facilitating visual examination of the data (Fig -3.19b). This method helps in recognising different groups of interrelated variables. Somewhat similar method has been earlier used by Doorankamp and King (1971).

Figure suggests that the four groups of variables can be identified. The largest group of variables include silt, silt+clay, SiO_2, Fe_2O_3, Al_2O_3, K_2O, Molar ratios SiO_2/Al_2O_3, SiO_2/Fe_2O_3, $SiO_2/Al_2O_3+Fe_2O_3$, MgO and MnO It is related to P_2O_5 also with a weak correlation. This group is considered to indicate <u>intensity of soil-profile development</u>. Fairly strong correlation of silt+clay with other variables in group suggests that measurement of their percentage in the pedon by simple techniques can provide good indication of intensity of soil-profile development. The other three groups are much smaller as compared to the first. The second group of variables is considered to conisist of <u>CaO, average depth, Al_2O_3 and SiO_2</u>. But CaO is negatively related to two other oxides. This group is considered to reflect <u>$CaCO_3$</u> content, which increases with depth in some geomorphic units at the cost of SiO_2 and Al_2O_3. The third group comprises varibles like <u>EC, Na_2O, sulphur and Cu</u> and is thought to reflect mainly <u>salinity</u>. Fourth geoup consists of clay minerals. Illite is negatively related to chlorite and kaolinite and posively related with clay content suggesting that their relative proportion is basically a function of texture.

3.5 CLAY MINERAL STUDIES

3.5.1. Introduction

Most commonly observed reaction of leaching water, in the system of soil development, produces clay minerals and hydrous oxides of aluminium and iron. These products can occur alone or in combination, and their disbtribution with depth can be uniform or highly variable. Characterisation of these products probably best reflects the long term effect of the chemical and leaching environment of the soil. Keeping this in view, the present study aims at semi- quantitative analysis of different clay mineral species and their variation in soil profiles and between different geomorphic units.

3.5.2 Analytical Procedure

X-ray diffraction technique is the single most powerful tool for qualitative clay mineral analysis. This method can also be used for quantitative estmation, but many problems are encountered in this method (Brindlay, 1981). Many clay mineralogists have adopted a compromise procedure which sacrifices accuracy, but enables a rapid semi-quantitative analysis of clays to be made directly from x-ray diffraction trace (Biscaye, 1965; Griffiths, 1967). Even in the later technique, a number of precautions need to be taken for obtaining good results, as mentioned later.

3.5.2.1 Sample Preparation

A total of 183 samples, collected from 34 pedons from different major geomorphic units have been selected for semi-quantitative analysis of clay minerals. In this analysis, the first step is to separate clay fraction from the soil samples. About 20 gm of air-dried (<2 mm size) sample is admixed with distilled water in glass cylinders of 25 cm length and 5 cm diameter size. This mixture is stirred thoroughly and is kept undisturbed for 24 hours for soaking. At this stage, almost the whole of the sample settles down leaving clear water above in the cylinder. This water containing excess salts derived from the sample is thrown away and the fresh distilled water is used to resoak the sample. After 2 or 3 soaking and washings, sample gets thoroughly dispersed. After stirring the dispersed sample in distilled water in a graduated 1 L cylinder, it is left undisturbed for sufficient time to allow >2 microns size particles (as determined by Stoke's law) to settle. The upper 5cm of the dispersed sample from the cylinder is sucked out for preparation of oriented slide mounts.

Less than 2 micron size fraction is recovered from the suspension by centrifuging. Recovered clay fraction is divided into three sub-samples. One sub-sample is kept untreated and the other two sub-samples are saturated with Mg and K by mixing with 1N $MgCl_2$ and 1N KCl solutions respectively. Three washings with distilled water are given to these subsamples to remove excess salts. Slide mounts are prepared from three subsamples by pouring thin clay- water suspensions of these subsamples on to microscope slides cut to fit the diffractometer slide holder.

Clay- water suspension is allowed to dry with care to avoid excessive peeling and curling. Mg-saturated slide is placed in a dessicator containing ethylene glycol for about a day at room temperature during sunshine days and is heated on water bath at 60^0C for 16 to 24 hours on colder days, followed by cooling. Two potassium saturated slides are heated to 350^0C and 550^0C for three hours separately (Klagge and Hopper, 1982). These slides are placed in a dessicator with silica gel to prevent rehydration before exposing them to x-rays.

3.5.2.2 X-ray Diffractometer Setting

Phillips X-ray diffractometer located at the University Science Instrumentation Centre, Univeristy of Roorkee has been used under the following operating conditions:

Power supply - 20 mA
Voltage - 35 KV
Radiation - Nickel fitered copper alpha (CuK$_a$)
Range - 2 Kc/s
Goniometer setting - 1^0 (20)/minute scanning rate
Recording - Electrically controlled recorder with chart
Chart speed - 1 cm/min

The untreated, Mg-saturated glycol treated and K-saturated, heated specimens have been scanned over 4^0-30^0 of 2 0 angle.

3.5.2.3 Clay Mineral Identification

Clay minerals have been identified from basal reflections of the x-ray diffractograms using a scheme proposed by Wilson (1987) (Table 3.5).

Table 3.5- A scheme of identification of clay minerals from basal reflections of the X-ray diffractograms after Wilson, 1987.

Clay Mineral	Basal Reflection	Untreated Slides	Mg-saturated glycolated	K-saturated Heated upto 350^0C	K-saturated Heated upto 550^0C
Chlorite	001	14.1 A^0 (6.27^0)	No change	No change	No change
	002	7.05 A^0 (12.55^0)	No change	No change	No change
	003	4.73 A^0 (18.75^0)	No change	No change	No change
	004	3.54 A^0 (25.15^0)	No change	No change	No change
Vermiculite	001	14.2 A^0 (6.22^0)	14.3 A^0 (6.18^0)	Collasped	9.4-$_0$ (9.6^A)
Illite	001	10.0 A^0 (8.48^0)	No change	No change	No change
	002	5.05 A^0 (17.56^0)	No change	No change	No change
	003	3.32 A^0 (28.85^0)	No change	No change	No change
Kaolinite	001	7.14 A^0 (12.40^0)	7.2-7.3A^0 (12.29^0 -12.12^0)	No change	Complete destruction
	002	3.57 A^0	No change	No change	Complete destruction

Note: No change indicates the same as the peak of untreated slide mount.

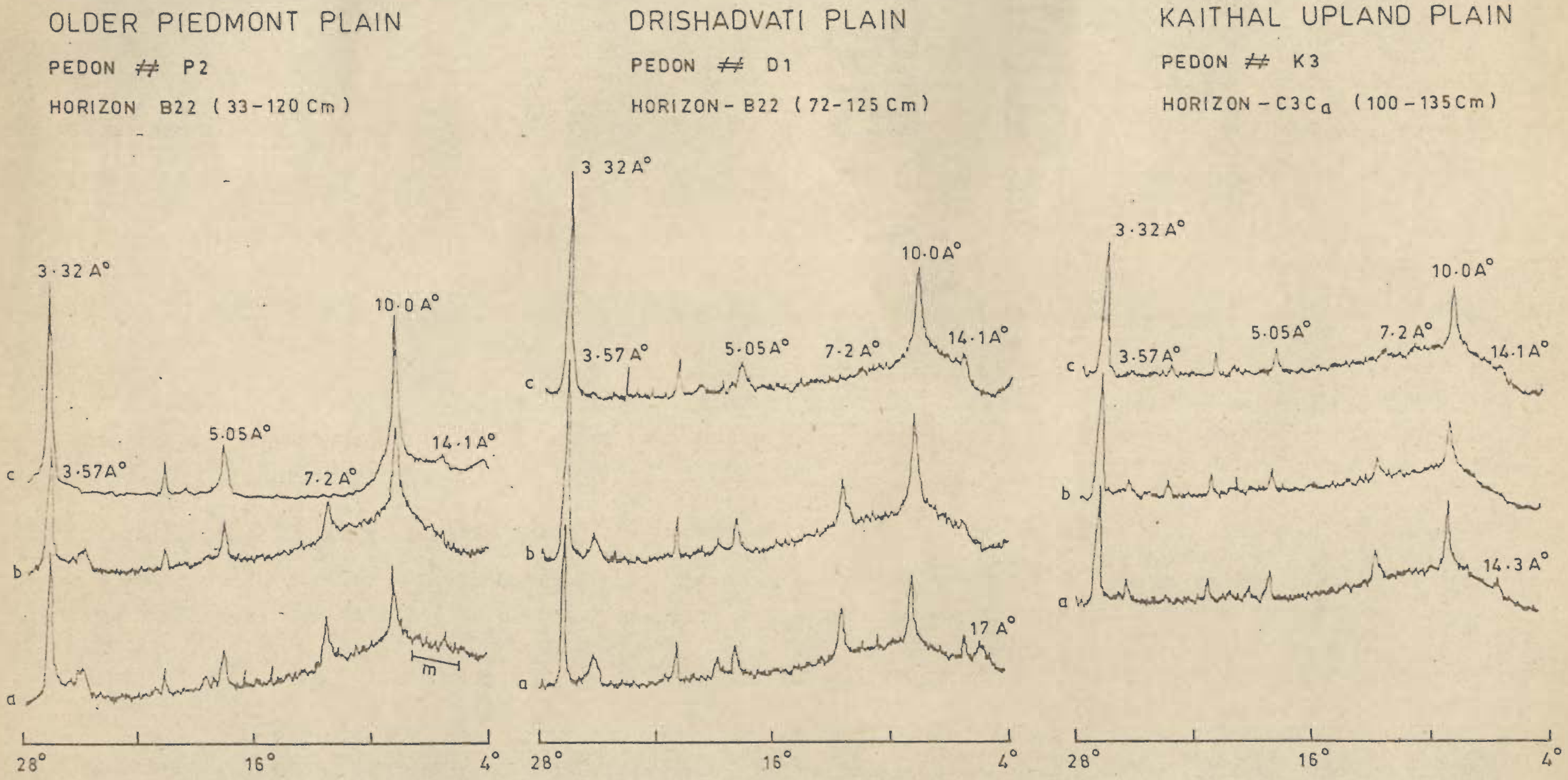
In case kaolinite is present along with chlorite in a soil sample, the 001 and 002 reflections of kaolinite and chlorite may virtually coincide and heat treatment will not give a positive identification of kaolinite. However, it is found that 002 (3.57^0A) peak of kaolinite and 004 (3.54 A^0) peak of chlorite form a distinct easily recognisable double peak system. Also the 003 reflection at ~4.73 A^0 is diagnostic for chlorite. These observations donot hold good for all chlorite/kaolinite mixtures.

3.5.2.4 Semi-qauntitative Estimation of Major Clay Minerals

Theoretically the quantitative estimation of various clay minerals concentrations is based on the principal that the intensity of x-ray diffraction by a mineral is related the amount of that mineral. But many factors such as crystallinity, composition, impurities of clay minerals, evenness and thickness of sample mounts, orientation of clay mineral grains and the irradiation set-up of x-ray machine affect such a relationship. As such the method of x-ray diffraction intensity for determining the clay mineral concentration at best, is semi-quantitative. In the present study, the sample mount conditions and the x-ray machine set-up have been kept uniform for all the samples as far as possible to minimize the error of estimation due to these factors.

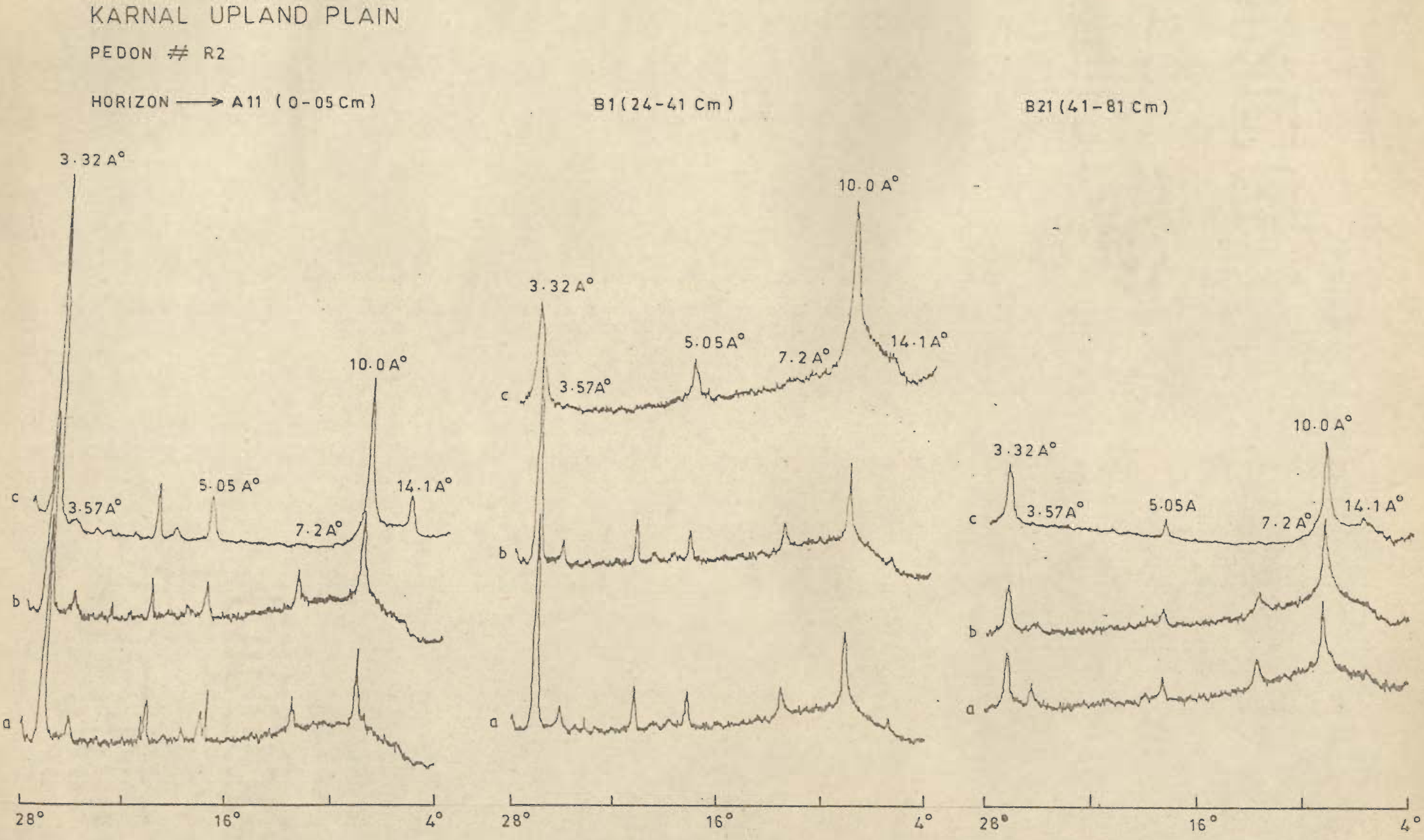
3.5.2.5 Peak Height Versus Peak Area Method of Estimation

Griffin (1962), Vemuri (1967) and Khunze and scafe (1971) advocate the use of peak heights, whereas Bridley in Brow, 1961, p. 512) and Biscaye (1965) suggest that peak areas in diffractograms give better estimates of clay mineral concentrations. However, Harley et al. (1963) and Harlan (1966) find that for estimation of relative abundance of clay minerals



INDEX :- (a) Mg-SATURATED GLYCOLATED, (b) K-SATURATED AND HEATED UPTO 350°C, (c) K-SATURATED AND HEATED UPTO 550°C

Fig. 3·20-X-ray diffractograms for soil samples for different geomorphic units showing the presence of Montmorillonite (17 A°), Chlorite (14 A°), Vermiculite (14·3 A°), Illite (10·0 A°), Kaolinite (7·2 A°) and mixed layer mineral (m) between (15 A° to 10·0 A°).



INDEX :- (a) Mg-SATURATED GLYCOLATED, (b) K-SATURATED AND HEATED UPTO 350°C, (c) K-SATURATED AND HEATED UPTO 550°C

Fig. 3·21 – X-ray diffractograms for soil samples for different horizons of pedon # R2, Karnal Upland Plain – Chlorite (14·1 A°), Illite (10·0 A°) and Kaolinite (7·2 A°) can be represented in these samples.

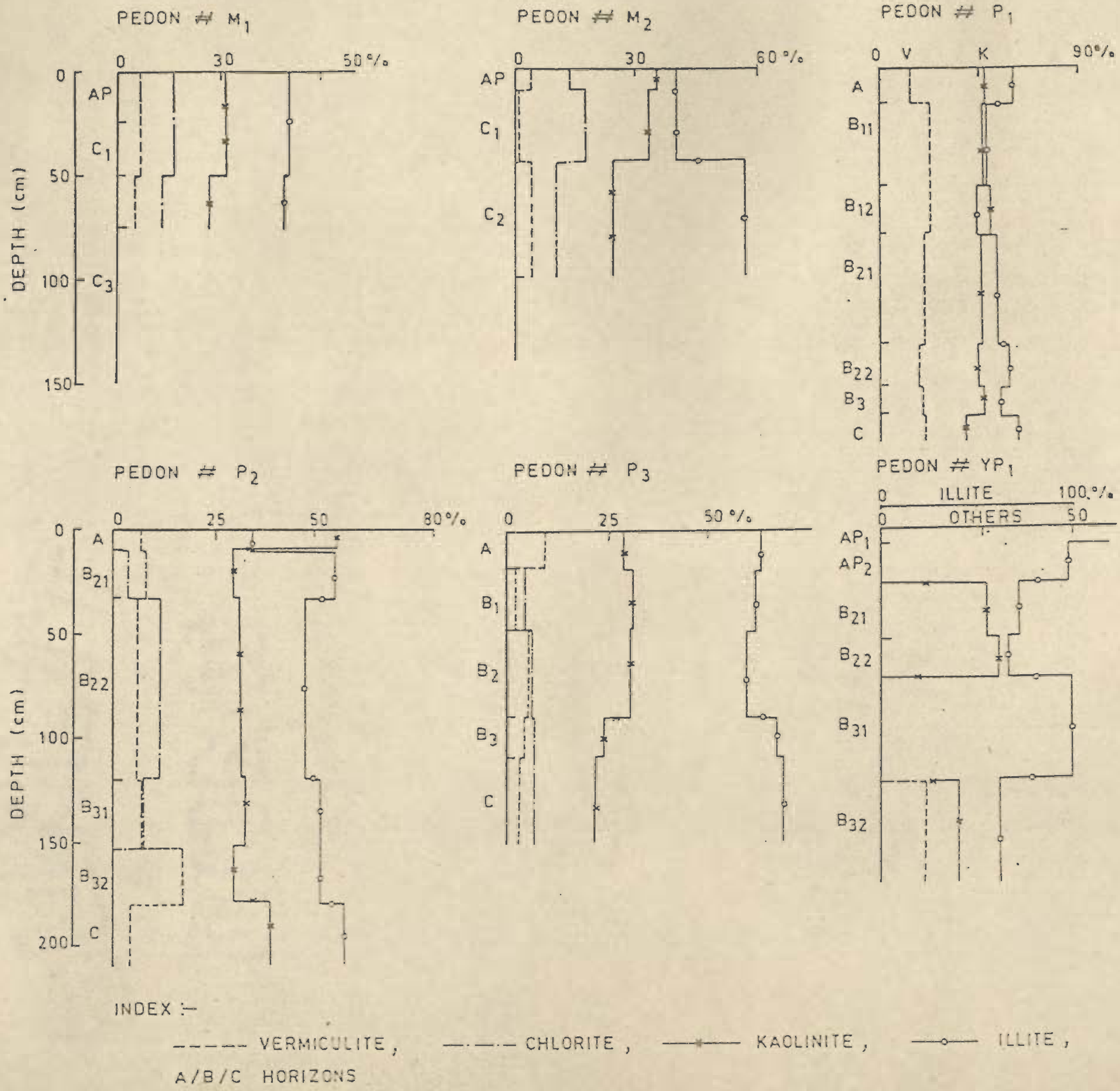


Fig. 3·22 _ Distribution of clay minerals within pedons of geomorphic units, Basin with Marl(M),older Piedmont (P) and Younger Piedmont (YP).

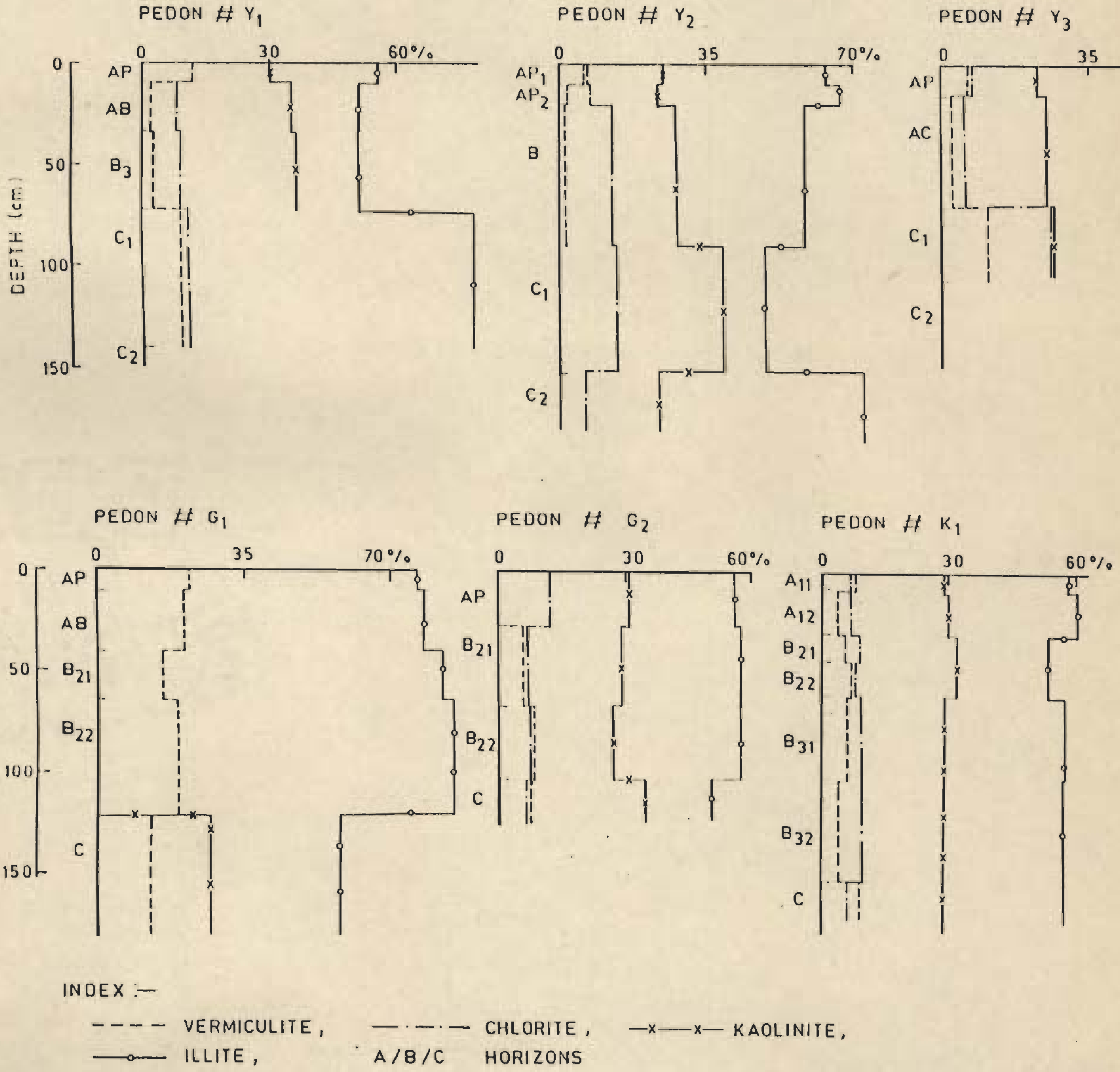


Fig. 3·23 — Variation of clay minerals within pedons of geomorphic units - Yamuna flood Plain, Ghagger flood Plain and Kaithal Upland Plain.

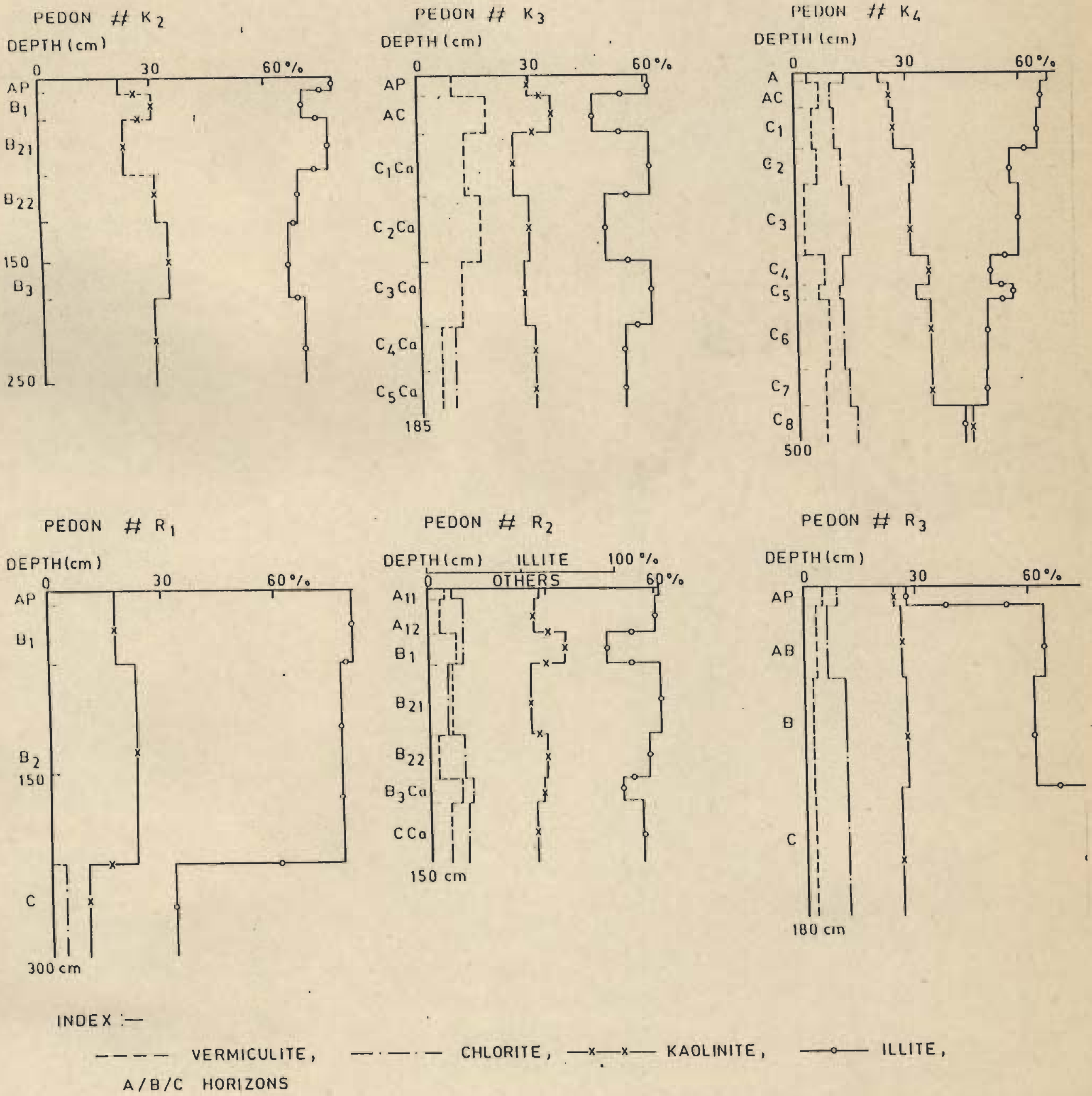


Fig. 3·24 –Variation of clay minerals within pedons of geomorphic units-Kaithal Upland Plain and Karnal Upland Plain (Ra).

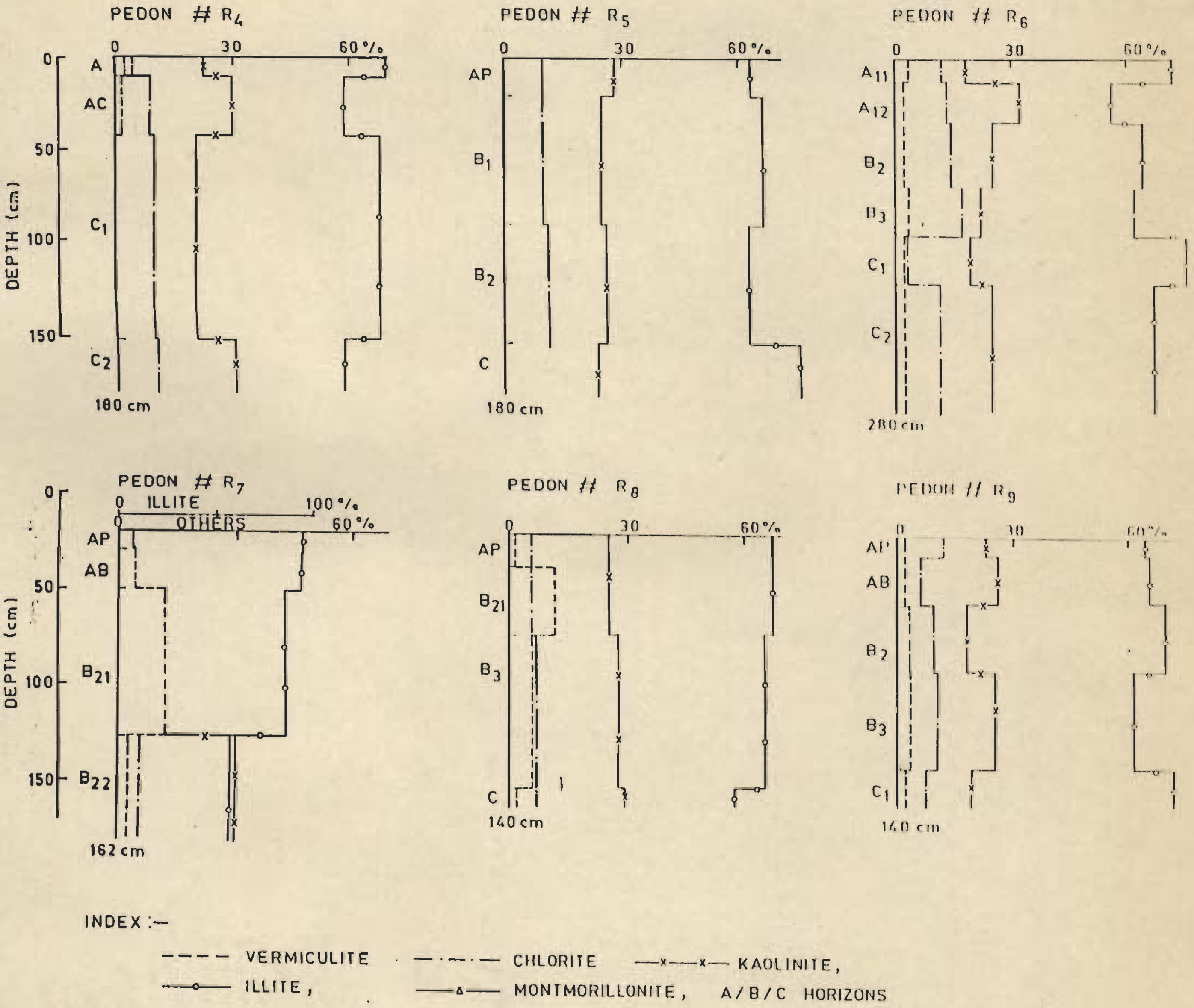


Fig. 3·25 — Variation of clay minerals within pedons of geomorphic units-Karnal Upland Plain (Ra and Rb).

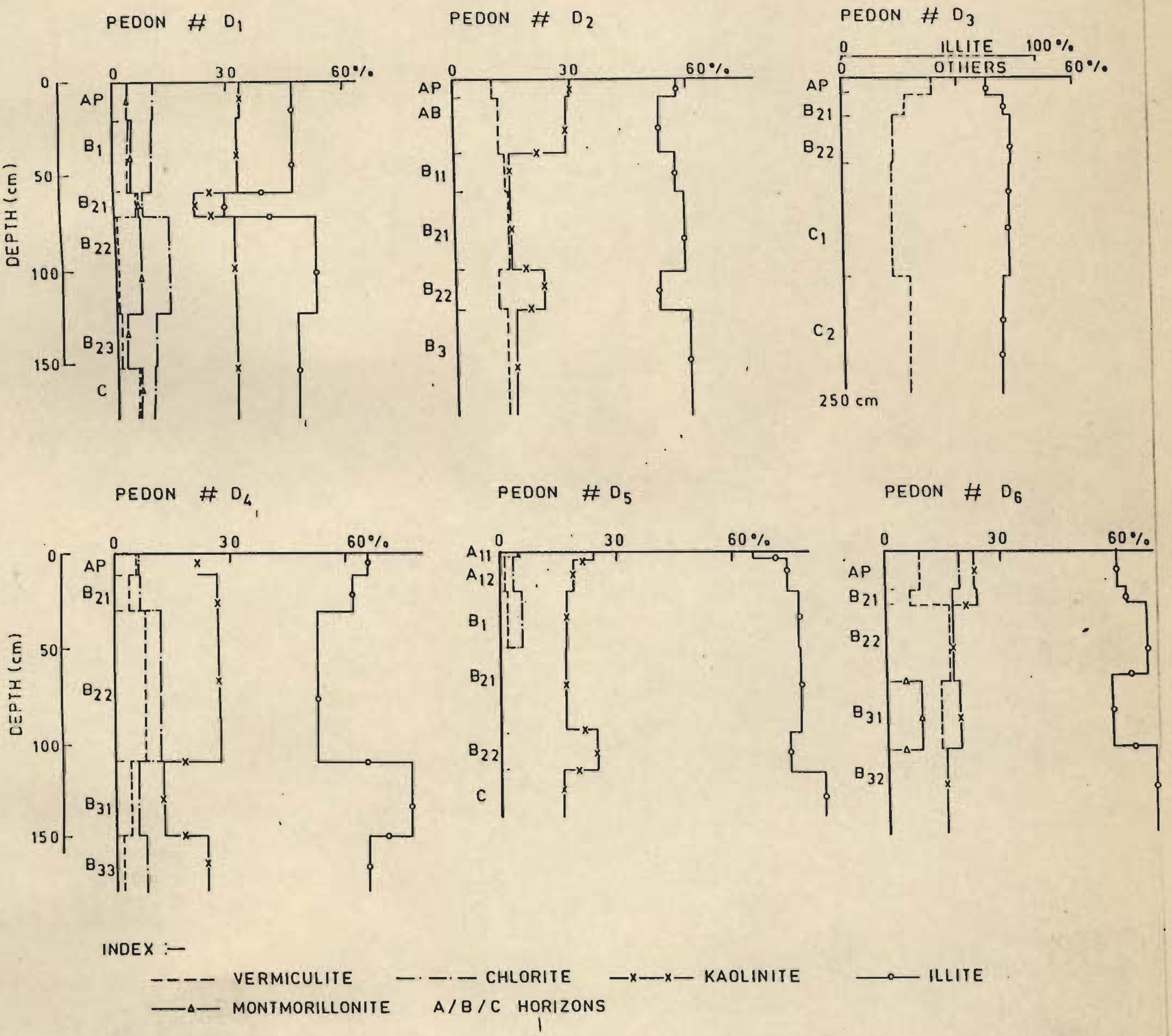


Fig. 3·26 – Variation of clay minerals within pedons of geomorphic units – Drishadvati Plain (D).

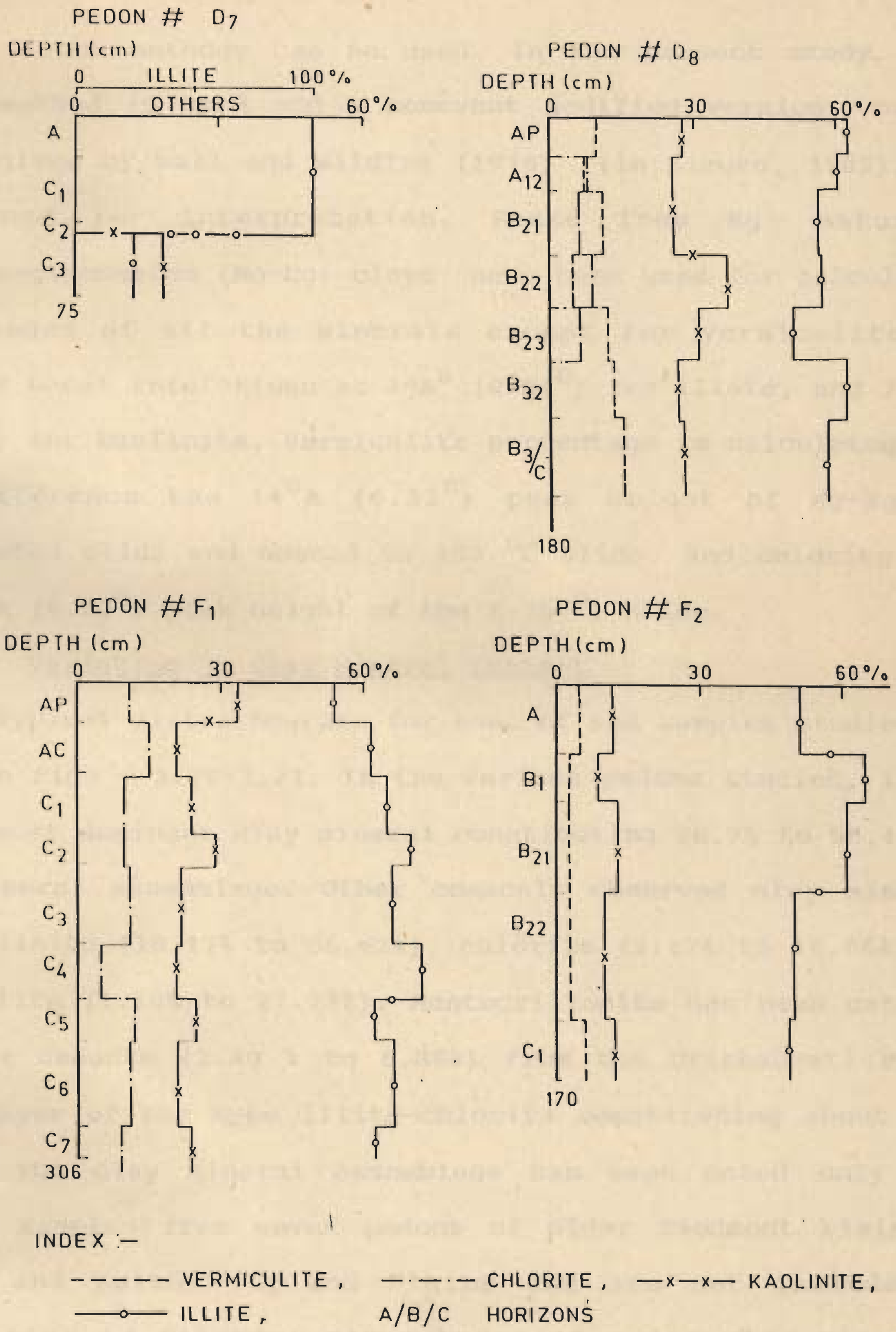


Fig. 3·27 – Variation of clay minerals within pedons of geomorphic units – Drishadvati Plain and Fluvio-Aeolian Plain.

either of the methods can be used. In the present study, peak height method is used and a somewhat modified version of the method given by Wall and Wilding (1976) (in Klages, 1982), has been used for interpretation. Peaks from Mg- saturated ethylene-glyconated (Mg-Eg) clays have been used for calculating percentages of all the minerals except for vermiculite and chlorite basal refelctions at 10A^0 (8.84^0) for illite, and 7.14A^0 (12.40^0) for kaolinite. Vermiculite percentage is calculated from the difference the 14^{0}A (6.22^0) peak height of Mg-Eg and K-saturated slide and heated to 350 ^{0}C slide. and chlorite from the 14^{0}A (6.22^0) peak height of the K-350^0) slide.

3.5.2.6 Variation in Clay Mineral Content

Typical diffractograms for some of the samples studied are given in Figs - 3.20-3.21. In the various pedons studied, illite is the most dominant clay mineral constituting 26.7% to 95.46% of clay mineral assemblage. Other commonly observed clay minerals are kaolinite (10.17% to 56.62%), chlorite (2.17% to 16.66%) and Vermiculite (1.10% to 27.73%). Montmorillonite has been detected in minor amounts (2.40 % to 6.88%) from the Drishadvati Plain. Mixed layer of the type illite-chlorite constituting about 5 to 10% of the clay mineral assemblage has been noted only from sixteen samples from seven pedons of Older Piedmont Plain and Karnal and Kaithal Upland Plains and are not included in calculation of relative percentages of major clay minerals, tabulated in Appendix v .

Variation of percentages various clay mineral species with depth for different pedons is depicted in Figs - 3.22 - 3.27).

Illite decreases with depth in the Yamuna Floodplain, whereas both increasing with depth and decreasing with depth trends are observed in various pedons of the Ghaggar and Drishadvati Plains. It does not show any good correlation with percentage of silt+clay. Both kaolinite and chlorite exhibit in general an antipathetic relationship with percetange of illite. Except for the presence of montmonrillonite in minor amounts in the pedons in the Drishadvati Plain, no good correlation of occurrence of various clays with geomorphic units can be recognised.

Clay mineral species recognised in the present study are similar to those reported from this region by earlier workers (Sehgal and de Conick, 1971, Sehgal, 1974, Satyanarayana et al., 1974). However, the presence of mixed layer clays in small amounts only in 15 samples out a total 183 samples studied suggests that their occurrence is not as extensive, as formerly thought by Kapoor et al. (1981a). Absence of any significant changes in clay minerals percentages within individual pedons and between various geomorphic units is also as expected, as the soils of the present study are very young (Late Quaternary) and large scale transformations of clays take much longer time.

3.6 RESUME

field observations necessarly required to get them prove with laboratory analysis. Grain-size analysis is found to be powerful tool of study to know grain-size distribution within the soil profile. Semi-quantitative analysis of clay minerals revealed that illite is the most dominant mineral. Illite has antipathic relationship with kaolinite and chlorite and have a positive relationship with clay content of soil samples. Clay minerals studied should not be used to know their variation between geomorphic units . Various molar rarios and accummulation indices for Al_2O_3 and Fe_2O_3 were calculated from major elements and found that silt+clay accummulation index and Fe_2O_3 accummulation index can be used in soil-development studies which leads to develop soil-chronosequence. Pearson product correlation matrix have proved that many of elements are related to each other and they pay important role in developing soil- profile.

CHAPTER - IV

4. MICROMORPHOLOGY

4.1 INTRODUCTION

Micromorphology deals with description and interpretation of distinctive arrangement of particles and voids, and pedo and biological features. Thus study of this aspect can help in identifiying the processes of soil formation, and reconstruction of sequence of events. Keeping the above in view, a fairly detailed micromorphological investigation of typical pedons has been undertaken.

4.2 METHODLOGY

Thirty four soil-profiles have been studied in the field and first described according to the methods of the Soil Survey Staff (1951). While studying the excavated soil profile, undisturbed oriented soil samples are collected with the metal boxes. Fourteen of pedons representing the major soil groups and geomorphic units of the study area have been selected for micromorphological investigations. The samples are impregnated done in vacuum as suggested by Jongerious and Heintzberger (1975). 2500ml Synolite 544 (resin), 5ml Acetone, Cyclonox LNC (catalyst) and Co-octoate with 1% Co (accelerator) are mixed thoroughly and used for impregnation of the undisturbed soil samples. Kubina size thin sections (9x6 cm) are prepared following a procedure described by Jongerious and Heinzberger (1975). Thin sections have bee studied under a streoscopic microscope in the Department of Earth Sciences, University of

Roorkee and National Bureau of Soil Survey and Landuse Planning, Nagpur. Slides have been studied in two stages- first in thick section (about 50 micron) and then slide finally ground to 20-30 microns. These have been also examined under different magnifications for understanding various features. These thin sections are described according to Brewer (1964) and Bullock et al. (1985).

4.3 MICROMORPHOLOGICAL DESCRIPTION OF DIFFERENT PEDONS

Micromorphology is described in terms of microstructures, biological activity, biorelicts, textural, amorphous and calcitic features. Organic material is present in very small amounts and could not be studied with the help of the available facilities. De scription of various pedons is given next.

4.3.1 Basin with Marl

Pedon # M1

Classification : Coarse loamy Typic Palaeorthids
Horizon : C2
Depth : 45 cm to 100cm.
No. of thin sections : One

Thin Section Description

1. Microstructure

Type and voids : Apedal soil material, mainly massive calcium carbonate (Fig - 4.1) kankars, with vesicular structre. Vescicles are filled with calcium carbonate. Mainly vughs of wide range, often interconnected, 30% to 40% of the area. Some elongated meso-voids, interconnected to not interconnected. The voids are not oriented and have a random basic and referred distribution pattern.

ii. Basic Mineral components:

C/f limit at 20 um : ratio of 10:90.

Coarse mineral componets (>20 um): Dominantly rounded subrounded, well sorted grains, pescentage of quartz is less, some biotite and plagioclse felspar (Fig- 4.2)

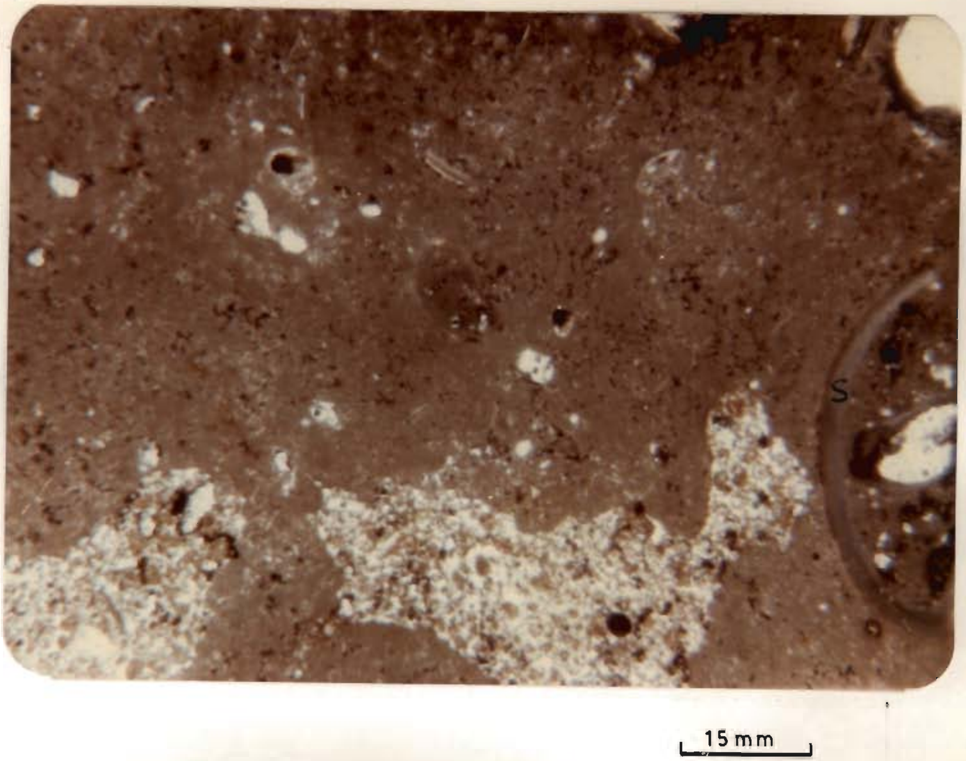


Fig. 4.1 Ostrocoda shell wall (S) and loose diseminated sand grains showing presence of extensive animal activity, Horizon C, (lacustrine marl), Pedon # MI (PPL).

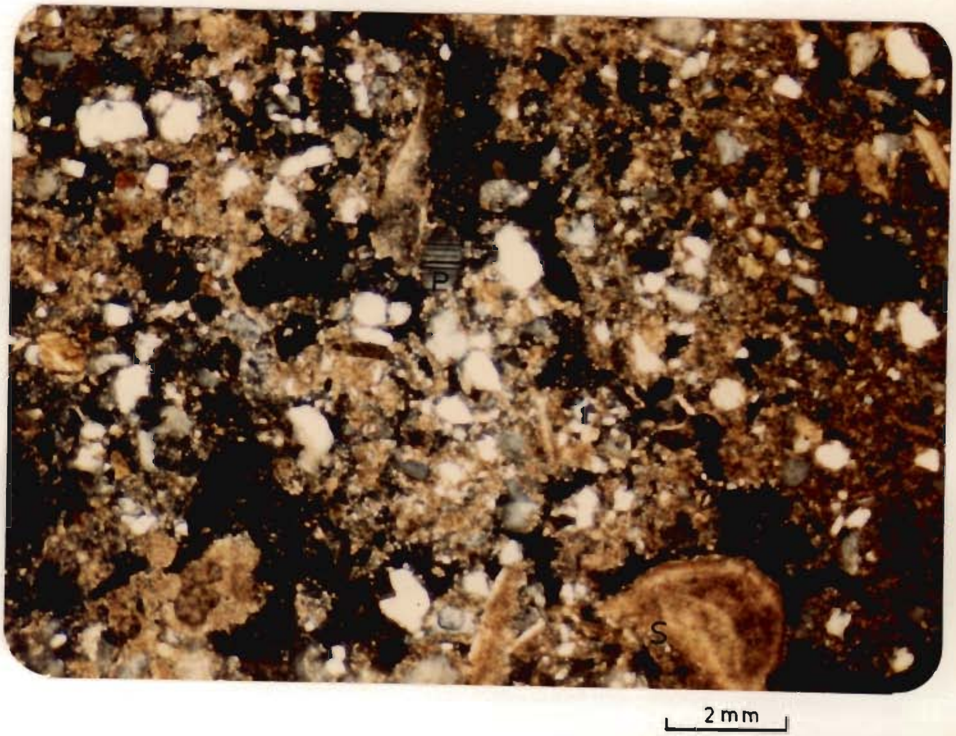


Fig. 4.2 Massive $CaCO_3$ material with vughy structure showing presence of quartz, biotite and plagioclase felspar (P), Guferic to chitonic related distribution and presence of Ostrocoda shell wall (S), Horizon C, (laustrine marl) Pedon # MI (XPL).

Fine mineral components (<20 um) : Mainly iron-rich clay and fine silt material of dark yellowish brown colour under transmitted light.

iii. Groundmass:

The C/f related sistribution is mainly gufuric to chitonic related distribution. The b-fabric of micromass is crystallitic b-fabric (crystic plasmic fabric, according to Brewer, 1964)

iv. Pedofeatures:

Textural pedofeatures (a) Complete dense infillings of calcium carbonate material in the vugh and voids. and (b) voids are coated with iron-rich clay and fine silt material.

Excremental pedofeatures (Fig- 4.3) and other features: Welded excrements (Fig- 4.4) composed of mineral material, interconnected. Lot of animal activity, fanual activity, weathering is much, micaceous minerals percentage is higher, some remnants of wood and occurence of shell walls (Fig- 4.1).

4.3.2. Older Piedmont Plain

Pedon # P1
Classification : Coarse lomy undic Ustochrept
Horizon : B1 to B3 and C, Depth : 58-202 cm

Thin Section Description

i. Microstructure

Types : Mainly spongy microstructure, weakly to moderately developed blocks. Continuity of solid material is broken by weak to moderate pedality, subangular blocky peds, 40 % of the area, medium size, mainly rough, smooth surface, partially accommodated.

Voids : Mainly interaggregate elongated voids (10-15%), with some compound voids, smooth unrelated and randomly arranged. Intra-aggregate voids are mainly packing voids between partially fused aggregates within peds and between grains in peds, irregular shape.

ii. Basic Mineral Components :

C/f limit at 20um; C/f ratio 10:90 to 30:70.

Coarse mineral components (>20 um) : Dominantly rounded to angular, medium to fine, moderately sorted, single mineral grains with variable sphericity: composition dominated by quartz and iron-oxide.

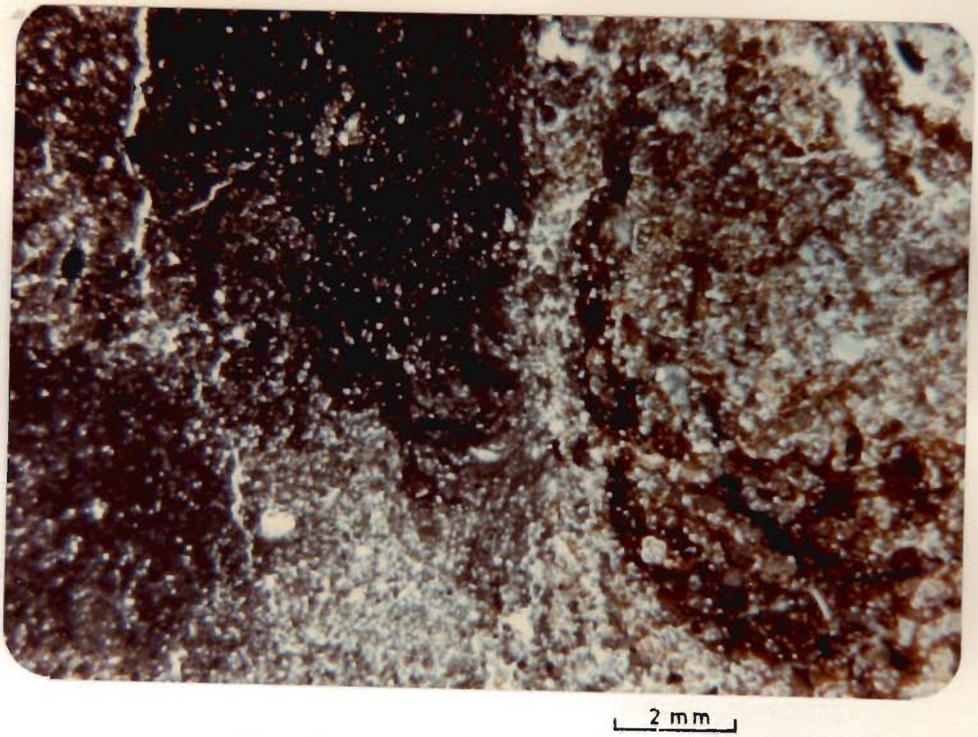


Fig. 4.3 Vughs are filled with $CaCO_3$ material and coating of void-walls with iron-rich material (F), Horizon C1, (latustrine marl), Pedon # M1 (PPL).

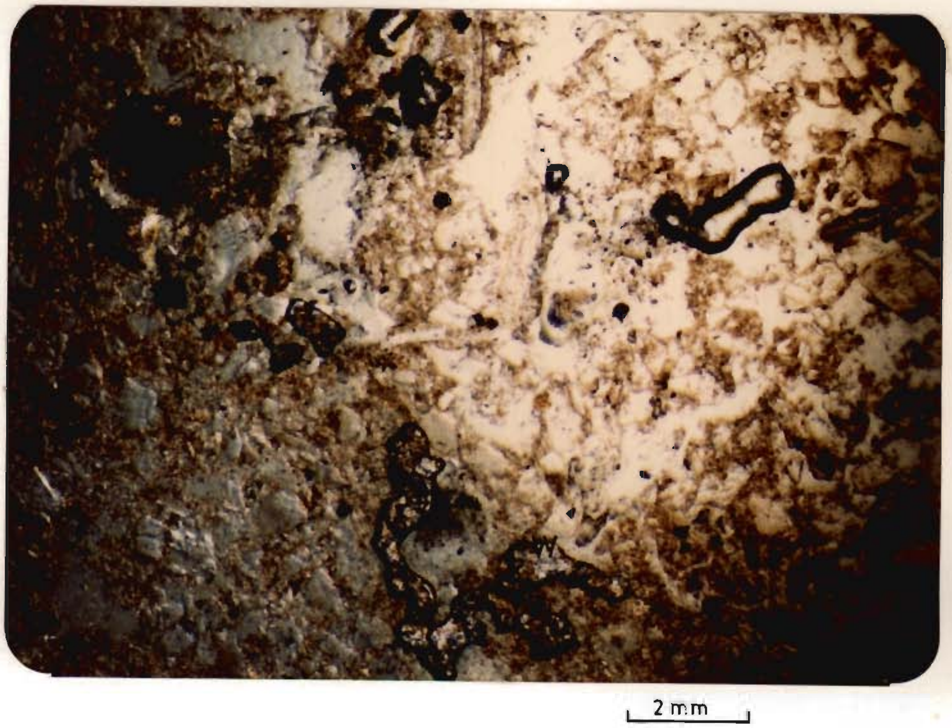


Fig. 4.4 Welded mineral excrements (W) showing extensive fanual activity, (Horizon C), (lacustrine marl), Pedon # M1 (PPL).

Fine mineral grains (<20 um) : Yellowish to reddish brown clay with some silt has speckled and dotted appearence.

iii. Groundmass

The c/f related distribution is mainly porphyric. The b-fabric of micromass is crystallitic b-fabric.

iv. Pedofeatures

Textural pedofeatures : (a) Crystallitic b-fabric with coating of iron rich material along voids. Enrichment of iron increase towards depth, and (b) Voids are filled with loose contineous infillings with pedal material (Fig- 4.5).

Amorphous and crypto-crystalline pedofeatures

Presence of discrete mottles, reddish brown to dark brown in colour, irregular, impregnated, fine-size mottles, which increases towards depth.

4.3.3 Pedon # P2

Classification : Fine loamy Typic Ustochrepts.
Horizon : B1 to B3
Depth : 10-180 cm
No. of thin sections : Four

Thin Section Description

i. Microstructure

Types : Pedal soil material (depth 105 - 280 cm) with granular microstructure with weakly to strongly developed pedality, 15-20 % of the area: .2 to 2 mm size, mainly rough and some smooth surface and partially accommodated.

Voids : (a) Macrocomplez packing voids, 50 % of total voids, straight and curved, weakly oriented, unrelated and meso-complex packing voids, remaining 50 % of the macrocomplex voids, weakly oriented and unrelated. and (b) macrocompound packing voids to meso-compound packing voids: 10-15 % of the area, much interconnected, occuring between peds, irregular, weakly oriented, random, some parallel and inclined.

ii. Basic Mineral Components :

C/f limit at 20 um: ratio is 70:30 to 60:40 towards depth.

Coarse mineral components (>20 um) : Dominantly rounded to angular, medium to fine, moderately sorted, single mineral grains with variablr sphericity. Composition dominated by quartz, weakly altered felspar (orthoclase and plagioclase), micaceous mineral

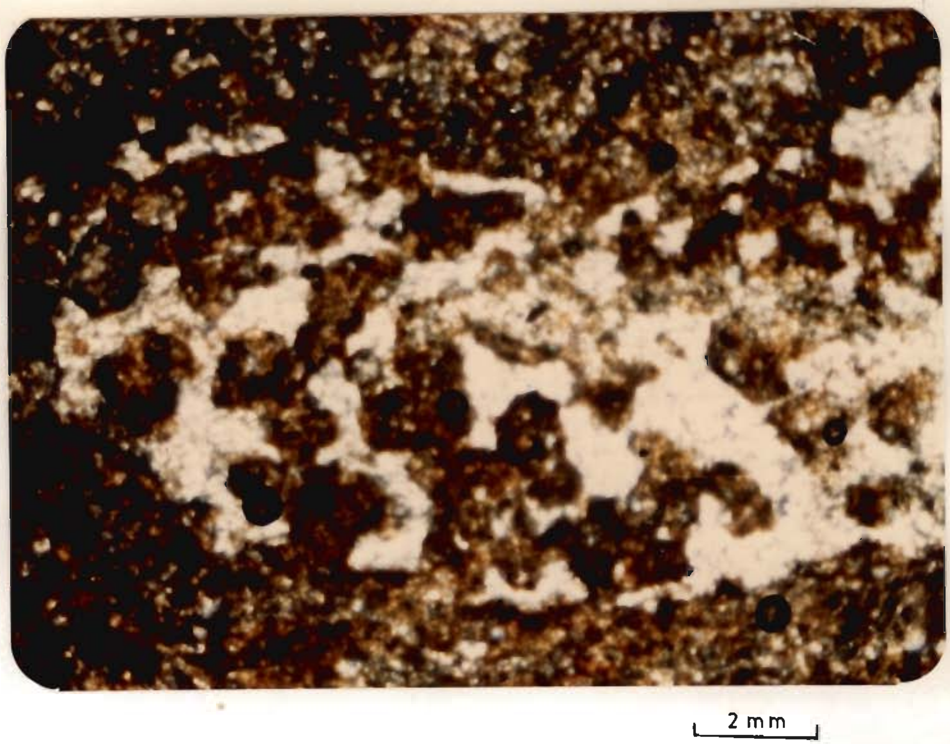


Fig. 4.5 Loose continuous filling of pedal material in voids, Horizon B12, Older Piedmont Plain, Pedon # P1 (PPL).

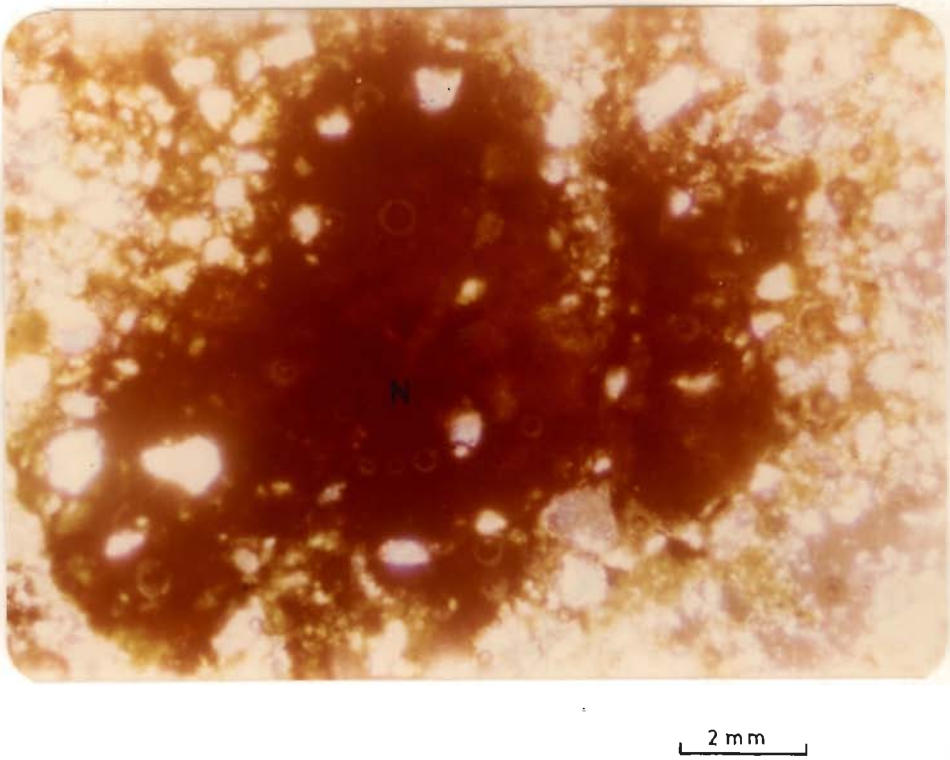


Fig. 4.6 Moderately impregnated typic subrounded iron-nodule (N), Horizon B3, Older Piedmont Plain, Pedon # P2 (XPL).

(biotite) and iron-oxide.

Fine mineral components (<20 um) : Yellowish to reddish brown material, containing mainly clay sized material with some silty material. It shows speckled and dotted appearence. Isotropic material around the grains and voids.

iii. Groundmass :

The C/f related distribution is mainly porphyric to close porphyric. The b-fabric of micromass is crystallitic b-fabric.

iv. Pedofeatures :

Amorphous and Cryptocrystalline pedofeatures :

Presence of discrete nodules and mottles (Depth 10-155 cm). Internal morphology Geodic type and externally amoiboidal, moderately impregnated nodules (Fig- 4.6), micro to meso, unsorted, yellowish brown to darkbrown, translucence under ordinary light and opaque under crossed nicols, 5-10 % of the area, low to medium variability and randomly distributed. Amorphous form of iron-coatings (Fig- 4.7) along the walls of the voids is increasing downwards as the fine grains soil increasing downward. Compact granular structure, 60 % of the sand grains, medium to very fine, smooth, partially accommodated peds, movement of iron rich clays between grains forming bridges and showing pseudo gleying effect (Fig 4.8).

4.3.4 Pedon # P3

Classification : Fine loamy Typic Ustochrepts.
Depth : 18 cm to 108 cm.
No. of thin sections: Three.

Thin Section Description

i. Micristructure

Type : Pedal soil material with prllicular grain structure. (Fig- 4.9) Spheroidal peds are granular with moderately (30% granular, 20% clay, 20% voids and 10% infillings). The peds are unaccommodated, walls are smooth with random and unrelated distribution.

Voids : (i) Inter-aggregate voids are compound packing voids between granules, equant to elongate, about 10% of the area, randomly distributed, weakly oriented and unrelated.

Basic Mineral Components :

C/f limit at 20 um : ration is 40:60.

Coarse mineral components (>20 um) : Single mineral grain mainly quartz, medium to poorly sorted, subrounded, no specific

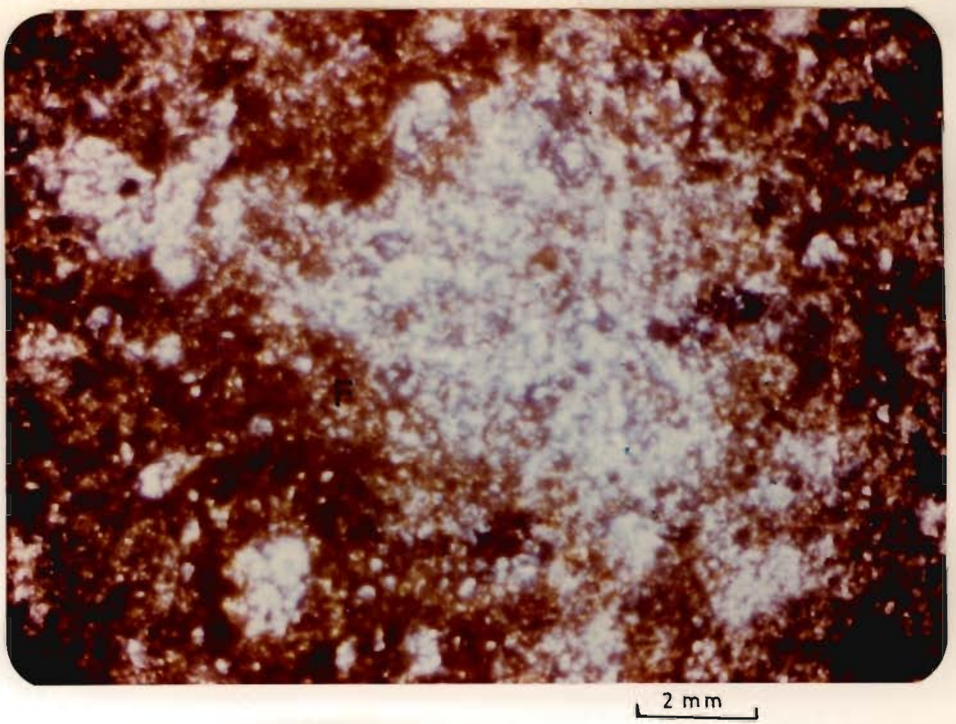


Fig. 4.7 Coating of iron (F), Horizon B31, Older Piedmont Plain, Pedon # P2 (PPL).

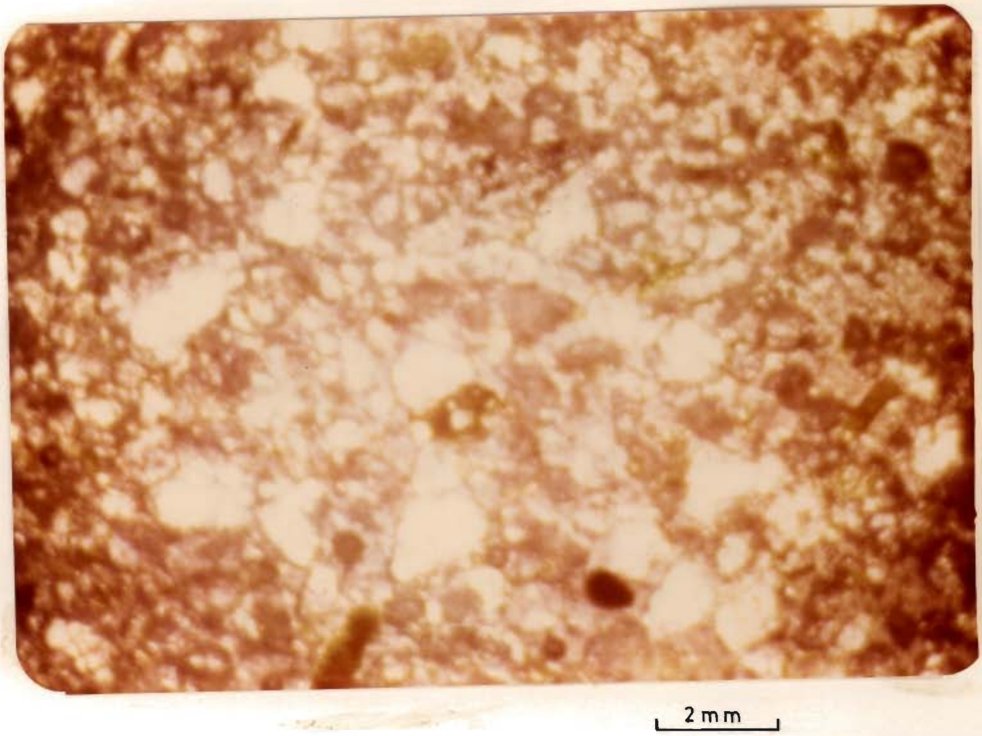


Fig. 4.8 Quartz grains surrounded by amorophous iron rich clay material and sesquioxide/magniferous nodules, showing (Psedo) gleying effect, Horizon B32, Pedon # P3 Older Piedmont Plain, (PPL).

Fig. 4.9 Quartz grains are surrounded by fine material which bridges the voids i.e. Pellicular grain microstructure, Horizon B2, Pedon#P3, Older Piedmont Plain (XPL).

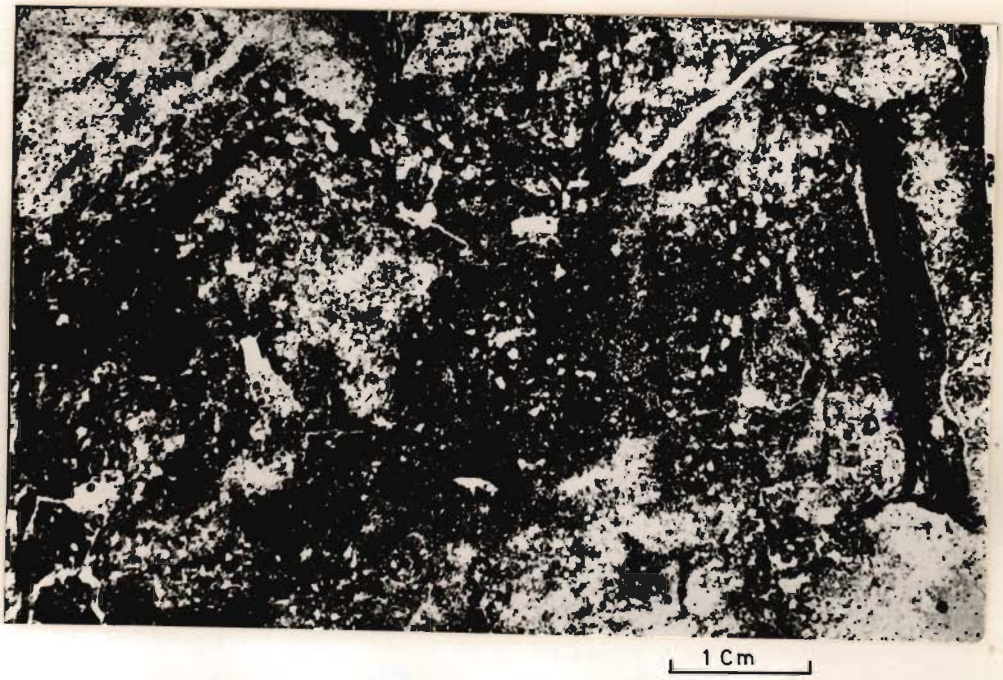


Fig. 4.10 Different voids filled with dense complete infillings of clay and fine silt material (D) and features related to animal activity, Horizon B3, Pedon # P3, Older Piedmont Plain (PPL).

character.

Fine mineral components (<20 um) : Most of the fine silt and clay material, yellowish brown colour under ordinary light and dark brown under crossed nicols

iii. Groundmass :

The coarse/fine related distribution is mainly porphyric and b-fabric of micromass is crystallitic b-fabric.

iv. Pedofeatures :

Fabric - pedofeature: Bowilike pedofeature distinct contrast, only one feature is present.

Amorphous-pedofeatures :

Presence of typic sub-rounded nodules and mottles. Nodules are black and opaque at low magnification and brown at higher magnification, moderately impregnated, <5% of the total area, predominant contrast, low variability, random basic distribution pattern and unrelated, referred and related distribution patteren.

Infillings : (a) Dense complete infillings of laminated silty grains and dense incomplete infillings of silty and clayey material. (Fig- 4.10) and (b) walls of voids and grains are coated with higher percentage of iron-rich material.

4.3.5. Younger Piedmont

Pedon : YP1
Classification : Coarse loamy Udic Ustochrepts.
Depth : 25 cm to 170 cm.
No. of thin sections : Three.

Thin section description

i. Microstructure :

Type : (a) Mainly granular with some part of spongy microstructure, weakly to moderately developed sub-angular blocks (Fig- 4.11). (b) Peds are mainly granules, moderately developed pedality, 40%-50% of the total area of thin section, mainly rough, some smooth and randomly distributed.

Voids : There are mainly interaggregate compound packing voids between crumbs and granules. Some elongated and some rounded in shape, 10 % - 15% of the area, walls are smooth, regular and moderately oriented with random basic and referred distribution pattern.

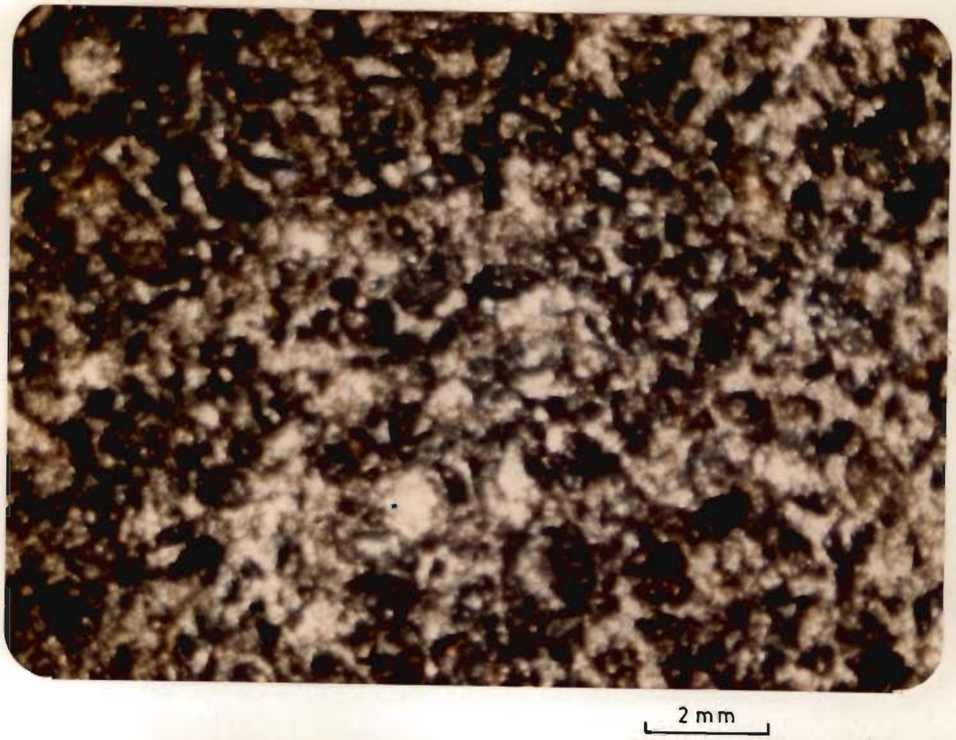


Fig. 11 Moderatively developed pedality with packing voids and Fe/Mn concretions, Horizon B3, Younger Piedmant (XPL).

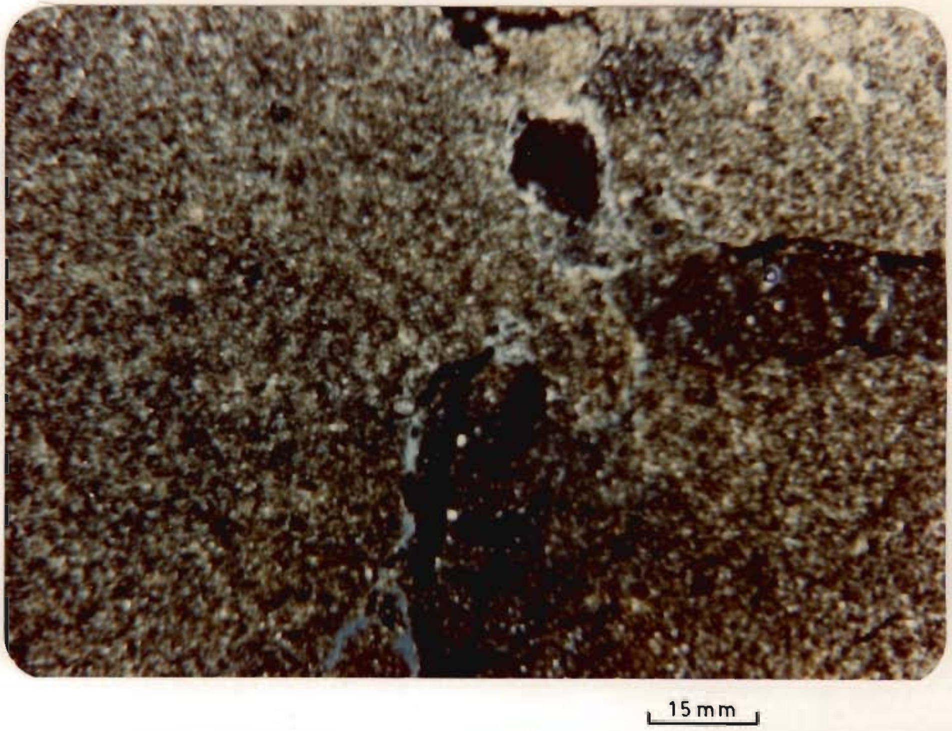


Fig. 4.12 Presence of two burrows (b) making different angles and filled with loose silt + clay material, Horizon C1, Pedon # YP1 (PPL).

ii. Basic Mineral Components :

C/f limit at 20 um: ratio of 20:80.

Coarse mineral components (> 20 um) : Dominantly rounded to subrounded fine to medium size, moderately sorted quartz grains with some flakes of biotite and some calcite.

Fine mineral components (< 20 um) : Fine material occures as partial to complete coats on grains and is mainly clay with fine silt material. It show s yellowish brown colour under transmitted light.

iii. Groundmass :

The C/f related distribution is mainly porphyric and b-fabric of micromass if manily cyrstallitic-b-fabric.

iv. Pedofeatures :

Textural-pedofeatures : Few silt and clay infillings and coatings around medium sized sand grains.

Amorphous-pedofeatures :

Brown, speckled, randomly distributed iron/manganese nodules, shape are rounded ot irregular.

v. Biological activity

Many burrows are present in thin sections and shows presence of biological activity within the pedon. Biological activity has also been seen with the help of naked eye in the field (Fig- 4.12).

4.3.6 Ghgger Floodplain

Pedon	: G2
Classification	: Coarse loamy Typic Ustochrepts.
Horizons	: B21 to C
Depth	: 26 cm to 127 cm
No. of thin sections	: two

Thin Section Description

i. Microstructure :

Type and voids :

Apedal soil material without clods or fragments, with a predominantly spongy microstructure. Mainly meso voids. Interconnected and have smooth walls and are irregular. elongated or subrounded shape. Estimated total void space is about 25% - 30%. The voids are not oriented and have a random orientaion pattern and unrelated distribution pattern.

ii. Basic Mineral Components :

C/f limit at 20 um : ratio is 30:70.

Coarse mineral components (>20 um): Single mineral grains dominated by quartz with some biotite. Muscovite, presence of flacky minerals seems to be high in comparision to other pedons.

Fine mineral components (<20 um) : Yellowish brown. mainly clay and silt size material with white to yellowish grey interference colous. The raddish brown iron-rich material is coating the walls of voids.

iii. Basic Organic Compounds :

Very few embedded fragments of altered root tissues.

iv. Groundmass :

The C/f related distribution is mainly porphyric. The B-fabric of micromass is reticulate striated b-fabric.(Fig-4.13)

v. Pedofeatures

Textural-pedofeatures : (a) Loose infillings of voids with soil fragments and silt-size particles. and (b) dominant voids are coated with iron-rich clay material, often discontineous and randomly distributed.

Crystalline and Amorphious pedofeatures : Yellow white nodules of calcium carbonate. often with smmooth, subrounded bounderies, random distribution, abundance: medium to many and showing calcitic hypo-coating in B21 horizon (Fig- 4.14).

4.3.7 Kaithal Upland ________ plain

Pedon # K1

Classification : Natric Ustochrepts
Horizon : B21 to B3 and C
Depth : 29 cm to 170 cm
No of thin sections : Five

Thin Section Description

1. Microstructure

Type and Voids: Apedal soil material, without clods or fragments with a predominaotly spongy microstructure (Fig- 4.15). Many channels and wide range vughs to are interconnected between 102 cm to 170 cm depth and are not interconnected in the rest of

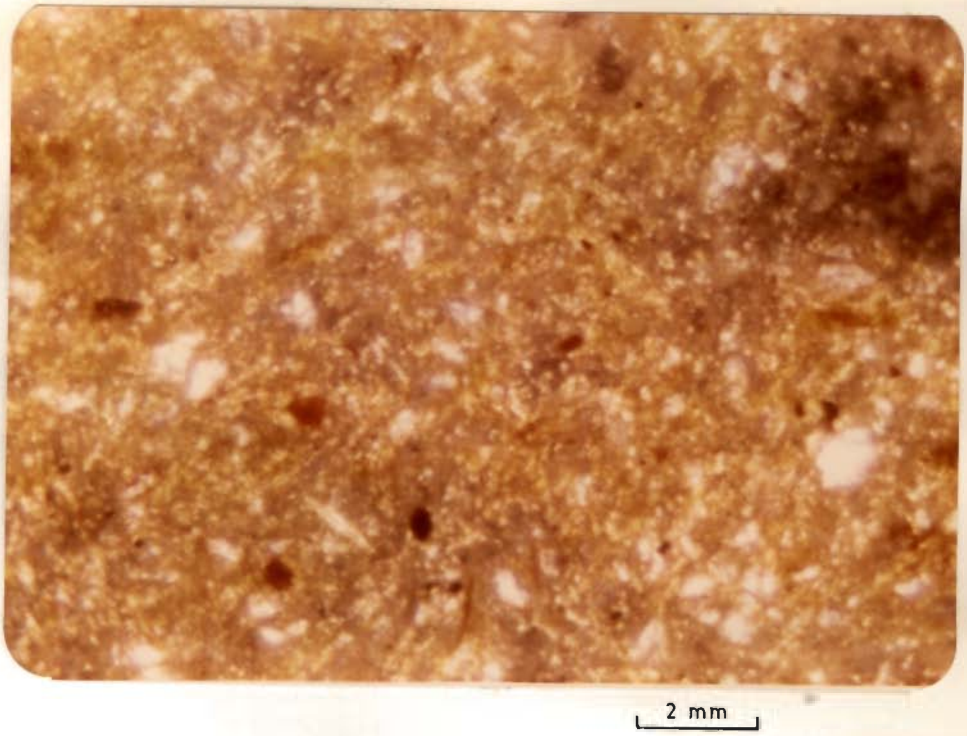


Fig. 4.13 Reticulate striated b-fabric, Horizon B21, Pedon # G2 (XPL).

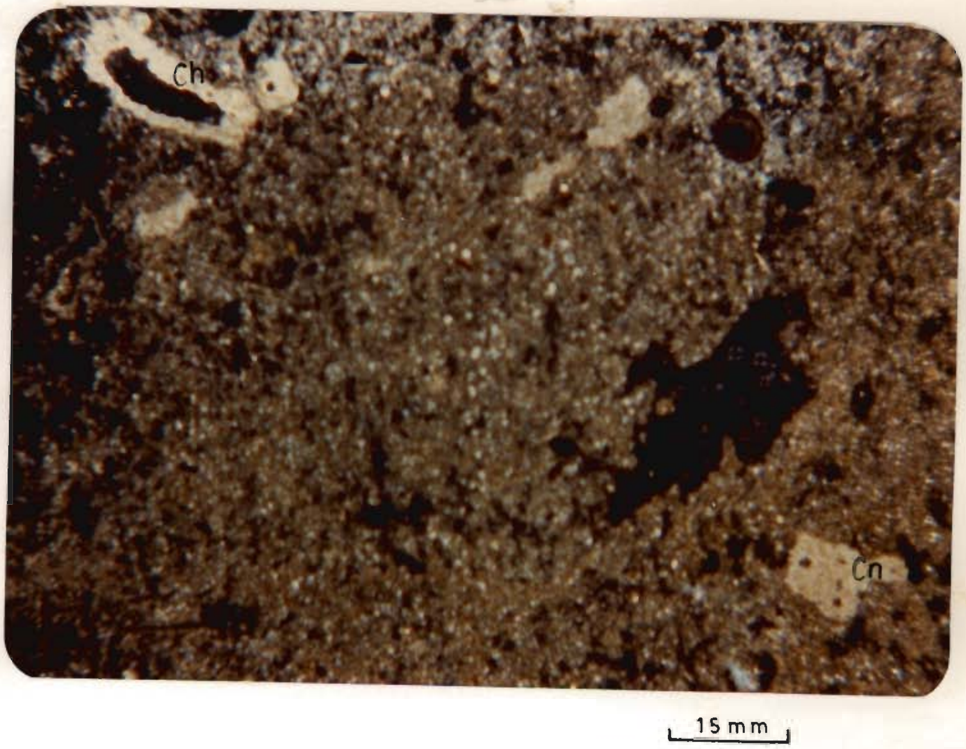


Fig. 4.14 Calcitic hypo-coating (ch) in B21 Horizon, Pedon # G2 with $CaCO_3$ nodules (Cn) (XPL).

the portion of the profile. These voids are elongated, walls, are smooth and irregular. Total void space increasing towards depth i.e. 15% to 25%. The voids are not oriented and have a random distribution patern.

ii. Basic Mineral Components

C/f limit at 20 um : ratio is 15:85 to 5:95.

Coarse mineral components (>20 um): Dominantly round to angular, poorly sorted single mineral grains with varible shperity, composition is dominated by quartz. Weakly altered felspar (orthclase and plagioclase) and micaceous mineral (biotite) at the top of the soil-profile, strongly altered at the depth of 102cm to 153cm depth. Presence of lublinite (Fig- 4.15) and calcite infillings along the voids.

Fine mineral components (<20 um): This consists of strongly speckled and dotted clay with fine micaceous material, silt and amorphous iro-oxide. Seggeration of iron along the void is increasing towards depth.

iii. Groundmass

The c/f related distribution is mainly chitonic between 29cm to 43cm depth and calcium carbonate nodules at the lower depth of the pedon. These nodules are covering main part of the area. The b-fabric of micromass is crystallitic to stipple-speckled.

iv. Pedofeatures

Textural pedofeatures: (a) Stipple-speckled b-fabric, with coating of along the voids. Porosity increases towards depth i.e. 10% to 15% , (b) Infillings of caly and silt size material. Seggeration of iron increasing towards depth. Packing voids and interconnected voids are filled with calcium carbonate material. (c) Hihger percentage of calcium carbonate nodules between 102 cm to 170 cm depth and decrease after it towards depth. Calcium carbonate nodules are forming the main part of the profile constituents (Fig- 4.16-4.17). (d) Few voids are having coating of clay to silty size material, discontineous to contineous and with random distribution, and (d) Loose discontineous infillings of soil-aggregate material within the voids between 102cm to 170cm depth and forming aggrotubles (Brewer, 1964.)

v. Excrement pedofeature:

Fanual activity has been seen between 102cm to 153cm depth (Fig- 4.18), presence of excrements, common to many, mainly composed of mineral material, loosely infilled, interconnected, coalsced. Composition is impure or speckled caly with fine silt, random distribution.

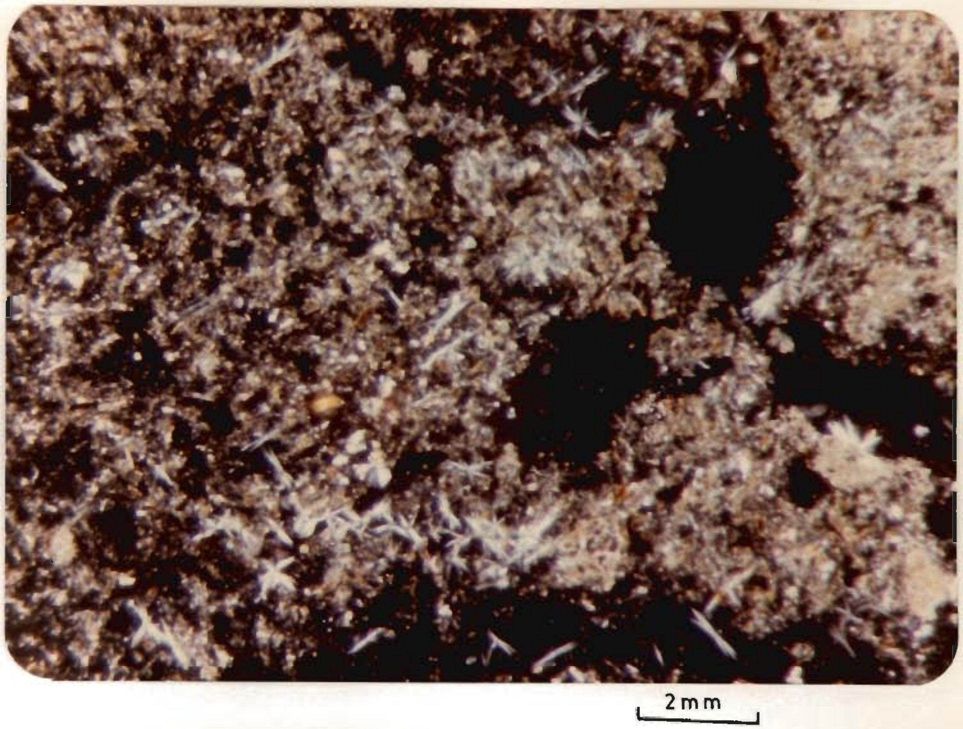


Fig. 4.15 Spongy microstructure with presence of needles of lublinite in pores, Horizon B32 Pedon#K1 (XPL).

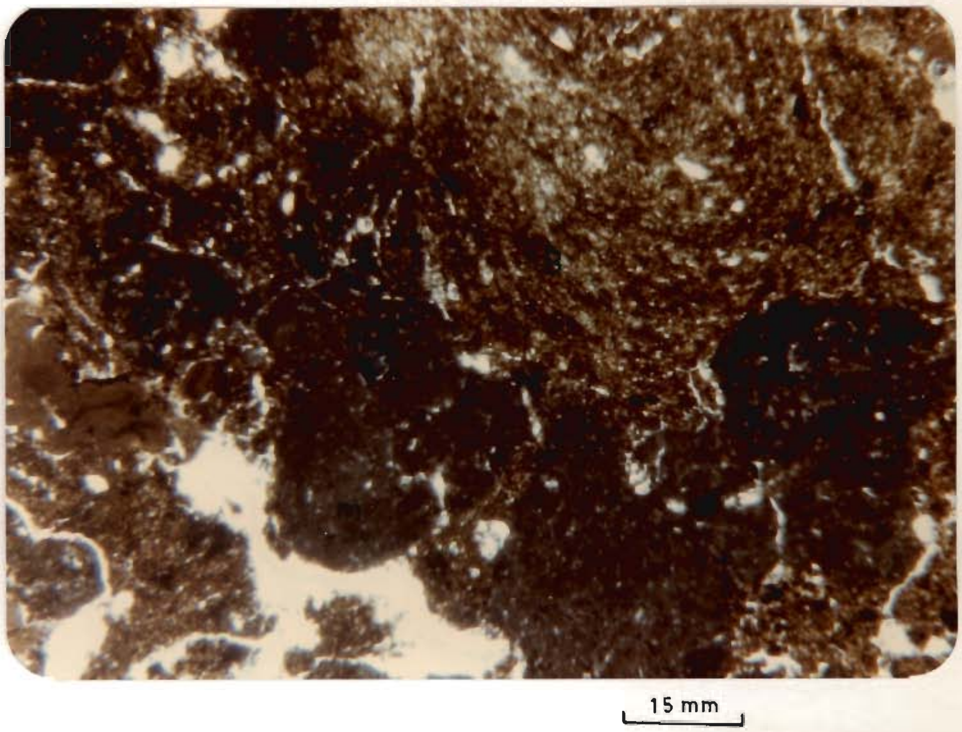


Fig. 4.16 $CaCO_3$ nodules (m) and bow like feature (b) with iron rich material, Horizon B32, Pedon # K1 (PPL).

Fig. 4.17 $CaCO_3$ nodules, neocalcan along the walls of voids, Horizon B32, Pedon # K1 (XPL).

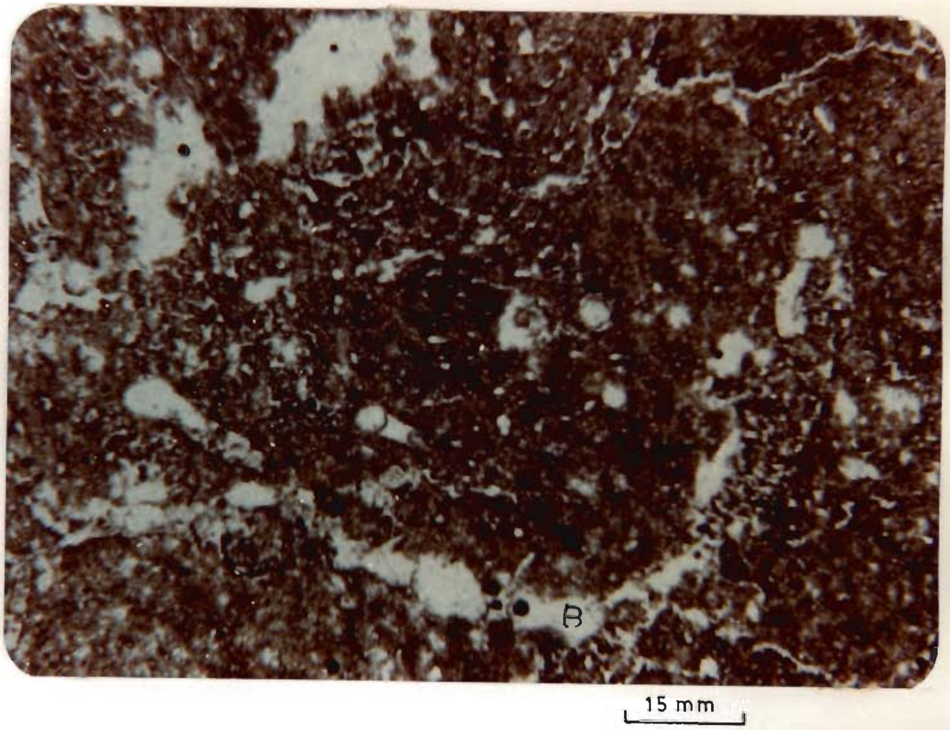


Fig. 4.18 Presence of many channels, vughs and semicircular burrow like feature (B) may be due to animal activity, Horizon B32, Pedon # K1 (PPL).

4.38 Kaithal Upland Plain

Pedon # K4
Classification: Coarse loamy Typic Ustochrepts.
Horizen : AC & C3-C4 (Archaeological site)
Depth : 11 cm to 45 cm and 147 cm to 285 cm
No of thin sections : Two

Thin Section Description

1. Microstructure

A. Type : Pedal soil material (11 cm to 45 cm) with compact grain structure and Apedal soil material (147cm-285cm) with spongy microstructure.

B. Peds : (1) Sub-angular blocks : Strongly developed pedalitly, 40 to 60% of the area, medium size, undulating to rugose and unaccommodated.

c. Voids : (i) Interaggregate Voids:

(a) Compound packing voids between granules, rootlets, and apedal soil material. 5% of the area, mainly rough walls, random arrangement. Voids are interconnected in apedal soil material at (14) cm-285 cm) depth.

(b) Intra-aggregate voids

Packing woids between partialy fused aggregates within peds and between grains in peds irregular shape range of size upto 0.1 mm, 5 to 10% of the area.

2. Basic Mineral Components:

Course/fine limit at 10 mm, ratio of 80:20.

A. Coarse fraction: all are randomly distributed, quartz, approx 80%, wide range of sizes 10-800 um poorly sorted, mainly <200 mm, angular and subangular. Biotite, ironoxide and some caluite are also present.

b. Fine fraction:

Most of the fine silt and clay in speckled yellowish brown in ordinary light and shows yellowish white interference colour.

3.4 Groundmass: The c/f related distribution in mainly chitonic to porphyritic. THe b-fabric of micromass is crystallitic b-fabric.

4. Pedofeatures :

(a) Loose infilling of voids with smaller soil aggregates. Dominant voids are filled with $CaCO_3$ material. (147cm-285 cm) and walls are coated with iron rich clay and silt material.

(b) many, subangular, deformed pedofeatures pedofeatures are rich in iron-oxide (Fig - 4.19)

(c) Intra-aggregate voids are filled with clay rich material and shows yellowish which interference colour under crossed nicols. (Fig- 4.19). It also shows development of pedality.

4.3.9 Karnal Unland Plain

Pedon # R2
Classification : Fine loamy Natric Ustochrepts
Horizon : B21 to B3 and C
Depth : 24 cm to 147 cm
No of thin sections : Three

Thin Section Description

1. Microstructure

Type: Apedal soil material, without clods or fragments, with a predominantly spongy microstructure.

Voids: Mainly meso to micro voids. THese voids have generally smooth and are irregular. The voids are not oriented and a random basic distribution pattern. Some interconnected mamellated vughs (Fig- 4.20). which are not related to each other and have unrelated basic and referred distribution pattern.

ii. Basic Mineral Components

C/f limit at 20 um : ratio of 20:80.

Coarse mineral components: Single mineral grains. Dominantly silt-size, Moderately sorted, sub-rounded quartz grains with biotite and calcite. The grains show some alteration effect.

Fine mineral components: Yellowish brown, limpid mainly clay sizes material, some amorphous iron-oxide ans show yellowish brown interference colours.

iii Groundmass

The c/f related distribution is mainly porphyric. The b-fabric of micromass is stippled-speckled to crystallitic. (Silasepic plasmic fabric of Brewer, 1984).

iv Pedofeatures

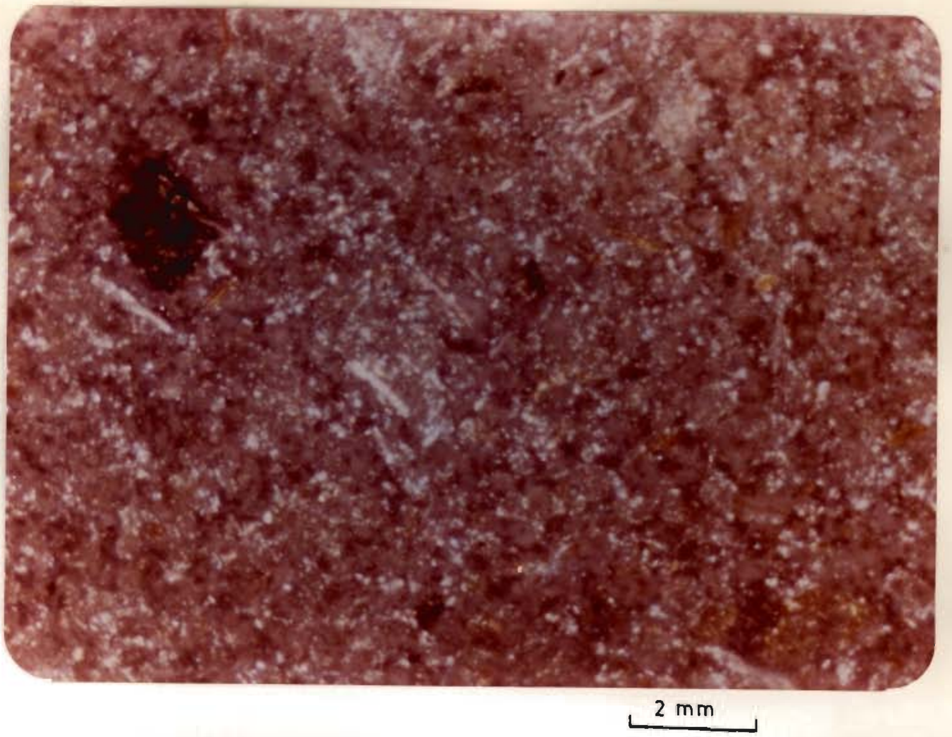


Fig. 4.19 Compact grain microstructure, Subangular fragmented deformed pedofeature (P) and development of pedality is shown by yellowish white interferance colours of fine material around the peds, Horizon AC, Archaeological site, Kaithal Upland Plain, Pedon # K4 (XPL).

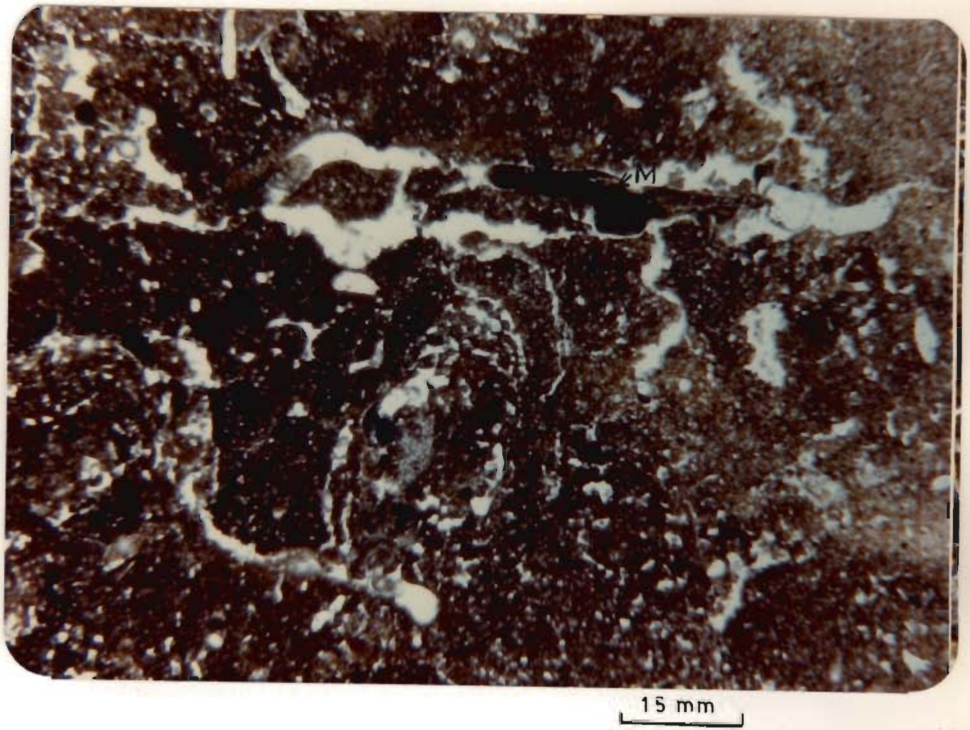


Fig. 4.20 Meso to micro voids with elongated vugh/channel with dense infilling of silt + clay material (M), Horizon B22, Pedon # R2 (PPL).

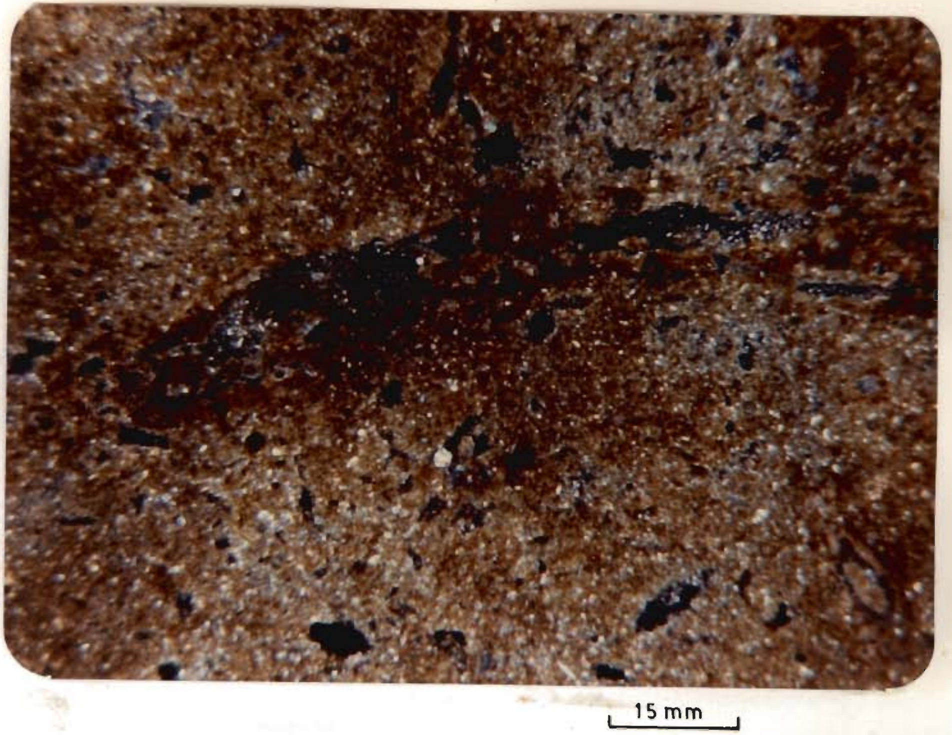


Fig. 4.21 Walls of channel and voids are coated with iron-rich clay materials forming ferri-argillans (A), Horizon B22, Pedon # R2 (XPL).

Fig. 4.22 White to reddish yellow interference colours of clay material/calcite around peds, (neo-calcans of Brewer, 1964) Horizon B22, Pedon # R2 (XPL).

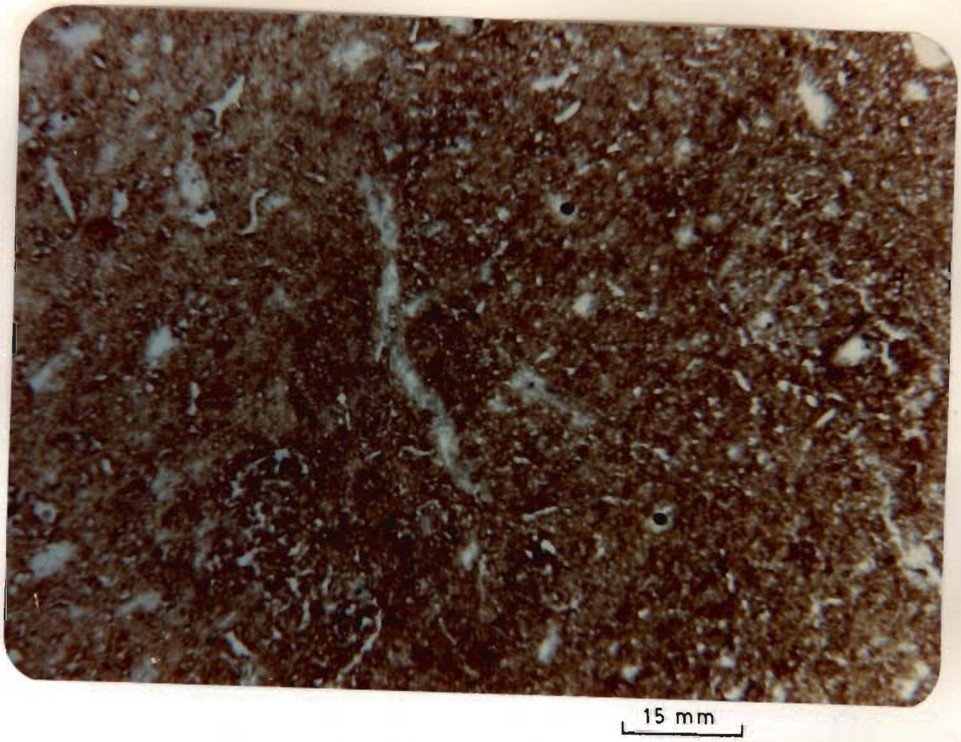


Fig. 4.23 Weakly developed pedality and presence of burrows showing animal activity within Horizon B3Ca Pedon # R2 (PPL).

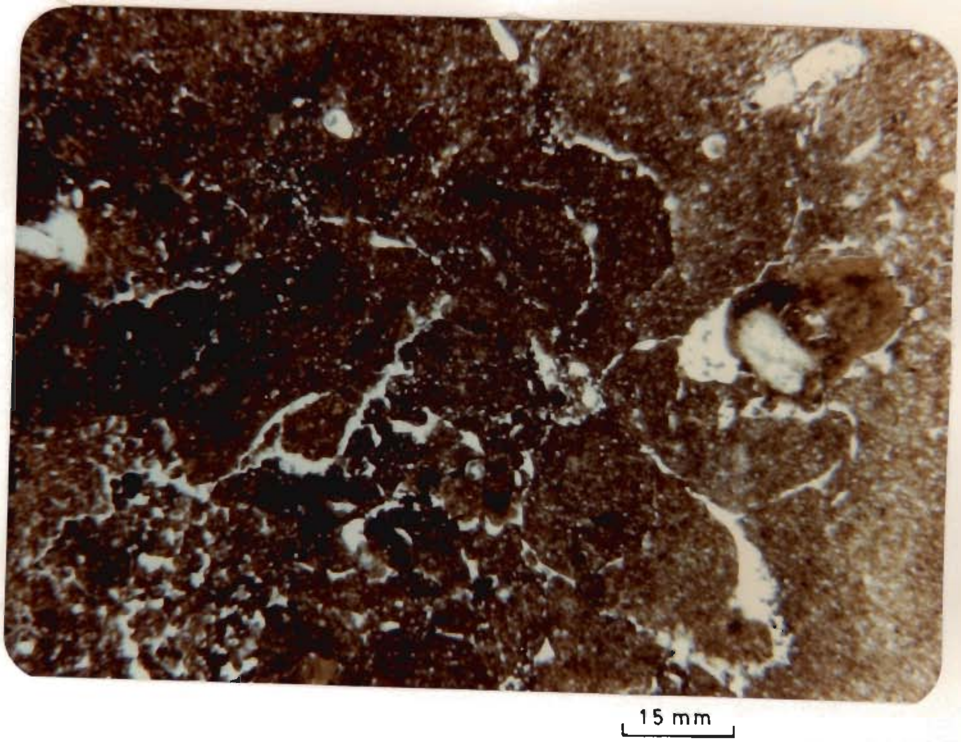


Fig. 4.24 Development of pedality and dense clay material in void, Horizon B21, Pedon # R2 (PPL).

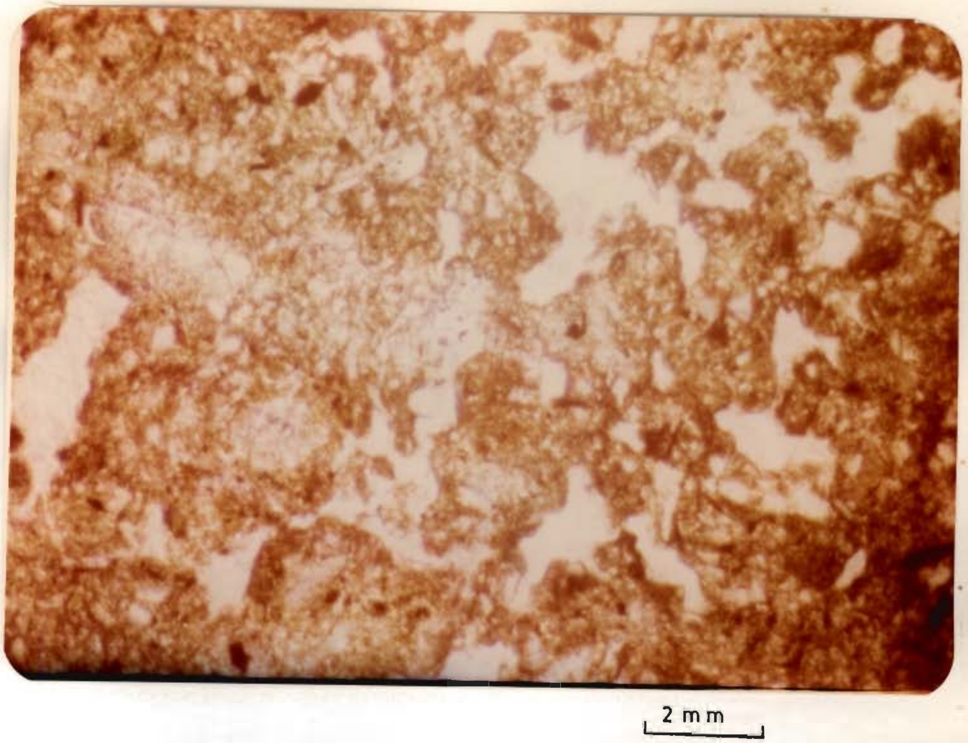


Fig. 4.25 Arrangement of voids shows weakly developed pedality, Horizon B3Ca and iron enrichment within soil-matrix, Pedon # R2 (PPL).

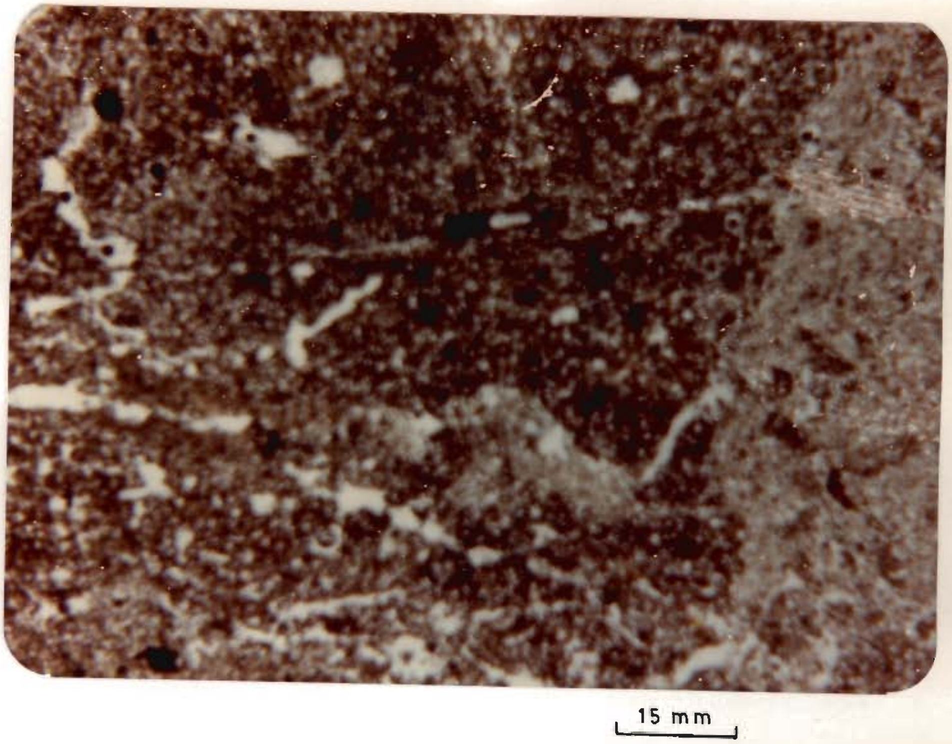


Fig. 4.26 Apedal soil material, Meso and micro voids and loose sand grains showing presence of animal activity, Horizon AB, Karnal Upland Plain (Rb), Pedon # R9 (PPL).

Textural pedofeatures: (a) Voids are filled with calcium carbonate nodules. Calcium carbonate nodules are coated with iron which material. Loose infillings of voids with clay and the walls of the voids. (b) Presence of vermiformed kaolinite, lot of fanual activity, weathering is prominent and Iron enrichment increases towards depth. Presence of very good ferri-argillians (Cutans, Brewer (1964) (Fig- 4.21 and neo-calcans Fig- 4.22) at the depth of 81cm to 104cm. Less vughs. Voids percentages reduces and calcium carbonate modules increases towards depth. Presence of animal activity in B horizon (Fig- 4.23), and development of pedality in B22 horizon&in C3Ca horizon (Fig- 4.24-4.25)

4.3.10 Pedon # R9

Classification : Coarse loamy Typic Ustochrepts.
Horizon : AB to C1
Depth : 10 cm to 140 cm.
No. of thin sections : Four

Thin Section Description

i. Microstructure

Type and Voids : Apedal soil material (Fig- 4.26) without clods or fragments with a predominantly spongy microsturcture. Mainly meso-voids and some micro-voids, 5% to 7% of the area to 15% to 20% of the area at depth, smooth walls, weakly oriented, orientation pattern and unrelated basic and referred distribution pattern. Some vughs, interconnected, elongated 10% to 15% of tha area, weakly oriented and unrelated. Meso voids are increasing towards depth (Fig- 4.26).

ii. Basic Mineral Components

C/f limit at 20 um: ration of 60:40 to 50:50 (at depth).

Coarse mineral components (>20 um) : Dominantly rounded to angular poorly sorted singly mineral grains. Composition dominated by quartz with biotite.

Fine mineral components (<20 um) : The fine fraction is mainly speckled clay with fine silt and shows Yellowish brown colour under transmitted light and white to dark yellowish brown colour under crossed nicols.

iii. Groundmass

The C/f related distribution is mainly close porphyric (Fig- 4.27). The b-fabric of micromass is crystallitic b-fabric.

iv. Pedofeatures

Textural- pedofeatures : (a) Loose incomplete infillings of silt and clay material along the voids forming aggrotubles (Brewer, 1964). Voids are coated with iron rich clay material and filled with calcium carbonate material. No organic matter, no root reminants. and (b) presence of coarse reddish moderately impregnated mottles.

4.3.11 Drishadvati Plain

Pedon # : D6
Classification : Coarse loamy Udic Ustochrepts
Horizon : B2 to B32
Depth : 27 cm to 150 cm.
No. of thin sections : Three

Thin Section Description

i. Microstructure

Type and Voids : Apedal soil material without clods of fragments with a predominantly spongy microstructure. Mainly meso-voids, rounded to subrounded, 5% to 10% of the area, smooth walls, random orientation pattern and unrelated basic and referred distribution pattern. Some interconnected vughs (27-105 cm depth) and shows development of pedality (Fig- 4.27) and are not connected between (105-150 cm depth). Voids are increasing towards depth upto 20%-25% of the area.

ii. Basic Mineral Components

C/f limit at 20 um ratio is 20:80.

Coarse mineral components (>20 um) : Dominantly rounded to angular, poorly sorted single mineral grains. Composition is dominated by sand and silt-size material, 15% to 20% of the area is covered by quartz grains, slightly altered and some felspar and biotite flakes are present.

Fine mineral components (<20 um) : Yellowish brown, mainly clay sized material, containing optically amorphous iron-oxide. The yellow brown material has speckled or dotted appareance in transmitted light and shows white to dark yellowish brown interference colours under cross nicols.

iii. Groundmass

The C/f related distribution is chitonic (Fig- 4.28) The b-fabric of micromass is crystallitic to stippled-speckled.

iv. Pedofeatures

Textural pedofeatures : (a) Loose infillings of voids with silt and clay matrial, forming pedotubles (Brewer, Calcium 1964)., (b) Voids are filled with $CaCo_3$ materials. carbonate

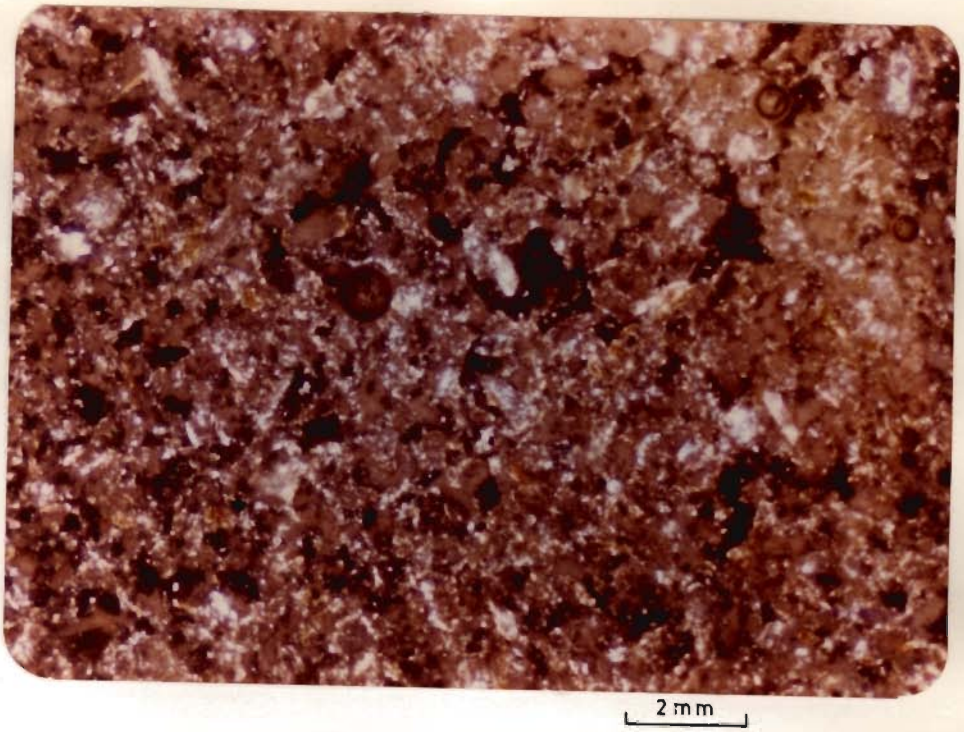


Fig. 4.27 Development of pedality is shown by whittish yellow interference colour material around peds (i.e. microcrystalline calcite along microvoids), Horizon B22, Pedon D6, Drishadvati Plain (XPL).

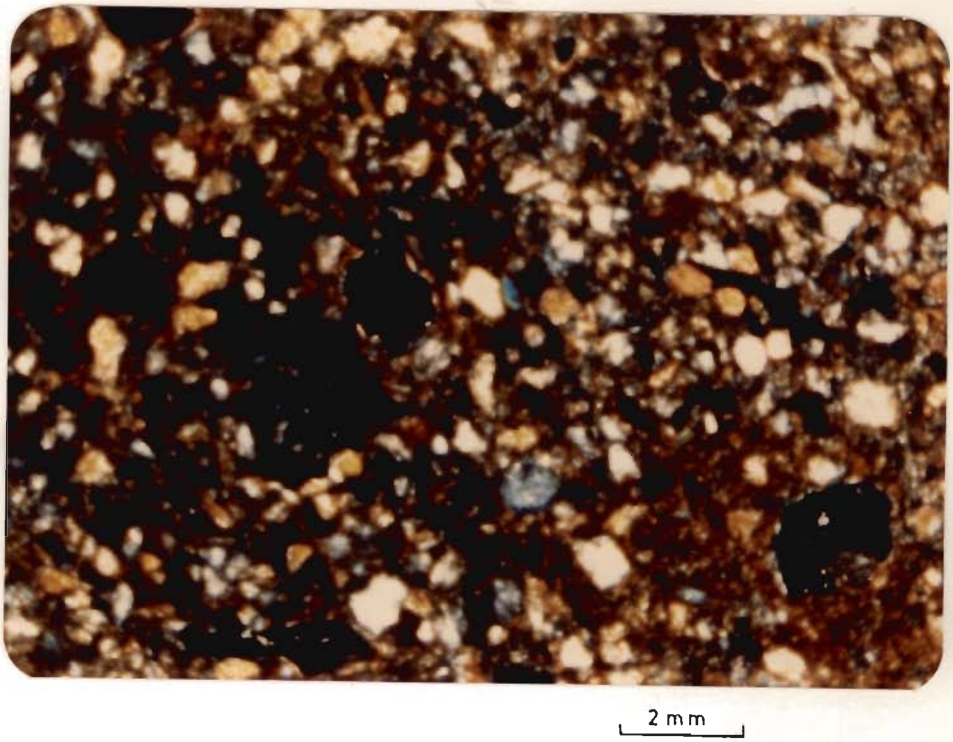


Fig. 4.28 Chitonic related distribution of coarse/fine material, Horizon B22, Pedon # D6, Drishadvati Plain (XPL).

nodules are coated with iron rich material. and (c) Yellowish brown material, under crossed nicols along the packing voids (105 cm to 150 cm) and arrangement of voids shows moderately developed pedality in this part of the pedon.

4.3.12 Pedon : D8
Classification : Coarse loamy Typic Ustochrepts.
Horizon : AB to C1
Depth : 29 cm to 160 cm.
No. of thin sections : Five

Thin Section Description

i. Miccostructure

Types and Voids : Apedal soil material without clods and fragments, with a predominantly spongy micro-structure (Fig - 4.29). Mainly meso-voids, elongated shape, interconnected. These voids have smooth walls. Estimated total area if 20% to 30%. The voids are not oriented and have a random basic and referred distribution pattern.

ii. Basic Mineral Components :

C/f limit at 20 um: ration of 40:60.

Coarse mineral components (>20 um) : Domnantly rounded to rubrounded quartz mineral with flakes of biotite and some iron-oxide.

Fine mineral components (<20 um) : This consists of strongly speckled and dotted clay with fine silt and iron-oxide and sowing light yellowish brown colour interference colour under transmitted light and white to dark brown interference colours under crossed nicols.

iii. Groundmass

The groundmass shows C/f related distribution is mainly porphyric and b-fabric of micromass is stipple speckled.

iv. Pedofeatures

Textural pedofeatures : (a) Few voids having coatings of mainly clay sized material with fine silt sized material, often discontineous, random distribution. and (b) arrangment of voids indicate weakly to poorly developed pedality.

4.3.13 Fluvio-aeolian Plain (Archaelogical Site Mithatal (Bhiwani)

Pedon # F1
Classification : Typic Ustrchrcpts

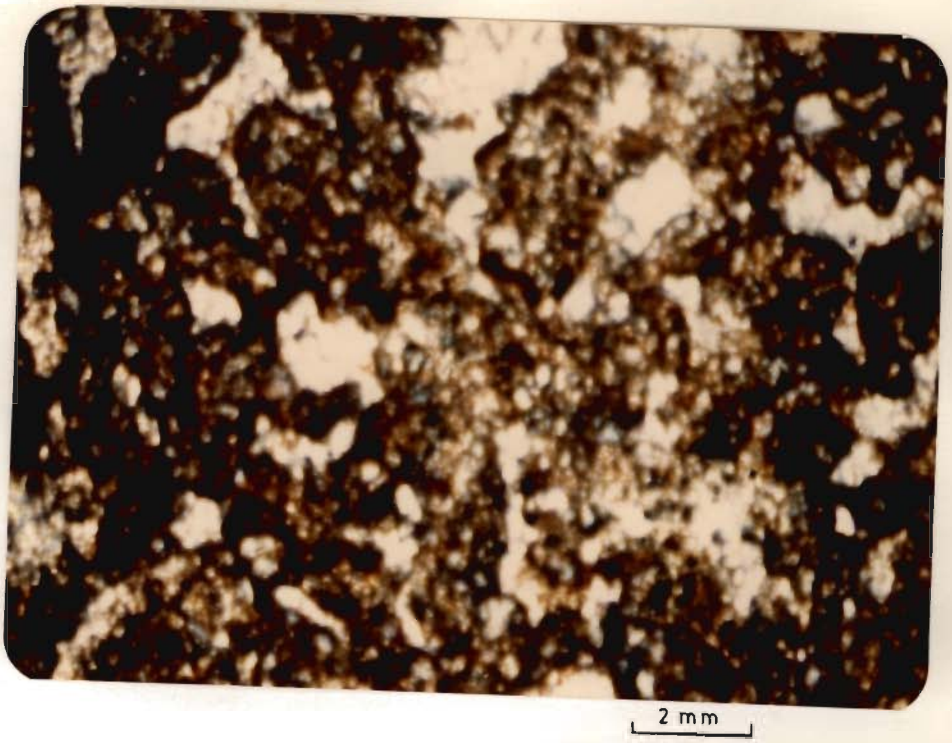


Fig. 4.29 Apedal soil material with spongy microstructure, and arrangement of voids showing weakly developed pedality, Horizon B22, Pedon # D8, Drishadvati Plain (PPL).

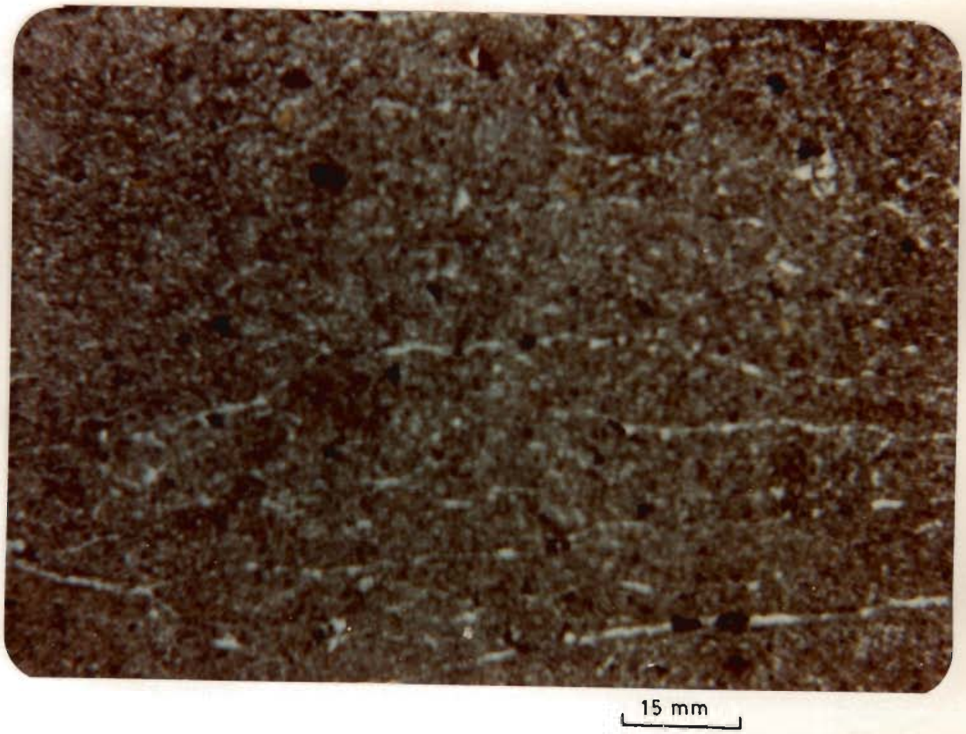


Fig. 4.30 Platy microstructure of Soil-aggregate in part of the slide, Horizon C3, Archaeological site, Pedon # F1 (PPL).

Horozion : C32 to C5
Depth : 115 cM to 231 cm.
No. of thin-Sections : 3

Thin Section Description

1. Microstructure :

Complex apedal microstructure; premonantly spongy microstructure (60%) and channel cum platy microstructure. Spongy microstructure is characterised by the presence of fine to meso voids, 15% of the area; smooth to irregular walls, weakly oriented to unrelated orientation pattern and radom, basic and referred distribution pattern. Platy structure is characterised by the presence of straight to curved, elongated channels; 10% of the area; smooth walls, straight to curved plains, moderately oriented, horizonal to inclined basic and referred distribution pattern. Development of pedality is shown in C5 horizon (Fig-4.31).

2. Basic mineral componenets :

Coarse/fine limit at 20 um : ratio of 20:80.

(a) Coarse mineral components (>20 um): Single mineral grains, dominantly quartz, silt-size, unstored, rounded, 80% of the area with Biotite and iron oxide. Slight altered grains.

(b) Micromass : (<20 m) : Light grey to yellowish brown speckled mixture of clay and fine-silt size material with white to yellowish grey interference colours.

3. Groundmass : The c/f related distribution is mainly open porhyric. The b-fabric of groundmass is crystallitic fabric.

4. Pedofeatures :

(ii) Fabric Pedofeature : Bow-like pedofeatures; 30% of the area.

(iii) Textural : (a) Dense complete infilling of clay (Fig- 4.32) (b) Few voids are coated with iron rich clay material and shows presence of ferri-argillans; 4 to 5% of the area; (Fig- 4.32) and dense incomplete infillings of pedal material (Fig- 4.33), mottled, limpid and impure clay pedofeatures.

(iii) Amorphous pedofeatures : Ferrigenous-hypo and quasi coating superimposed on a clay coating-aggregate modules, iron-modules, <5% of the area, black and opaque.

At the 203 cm. to 231 cm., the structure in spongy

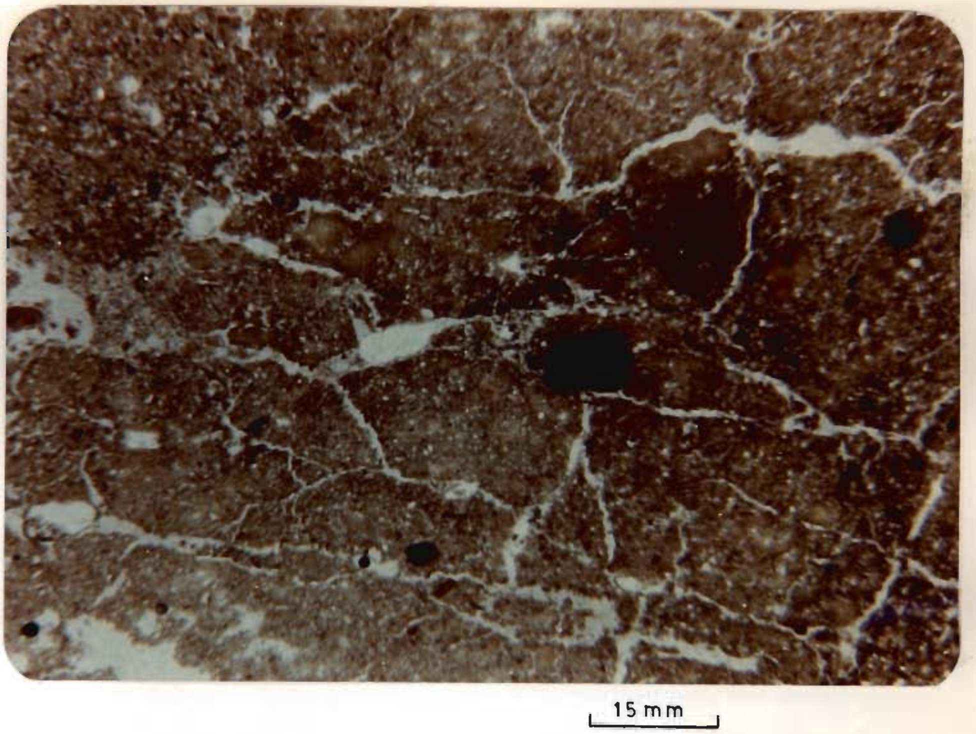


Fig. 4.31 Development of pedality and arrangement of voids and oxidation mottles. Horizon C5, Archaeological site, Pedon # F1 (PPL).

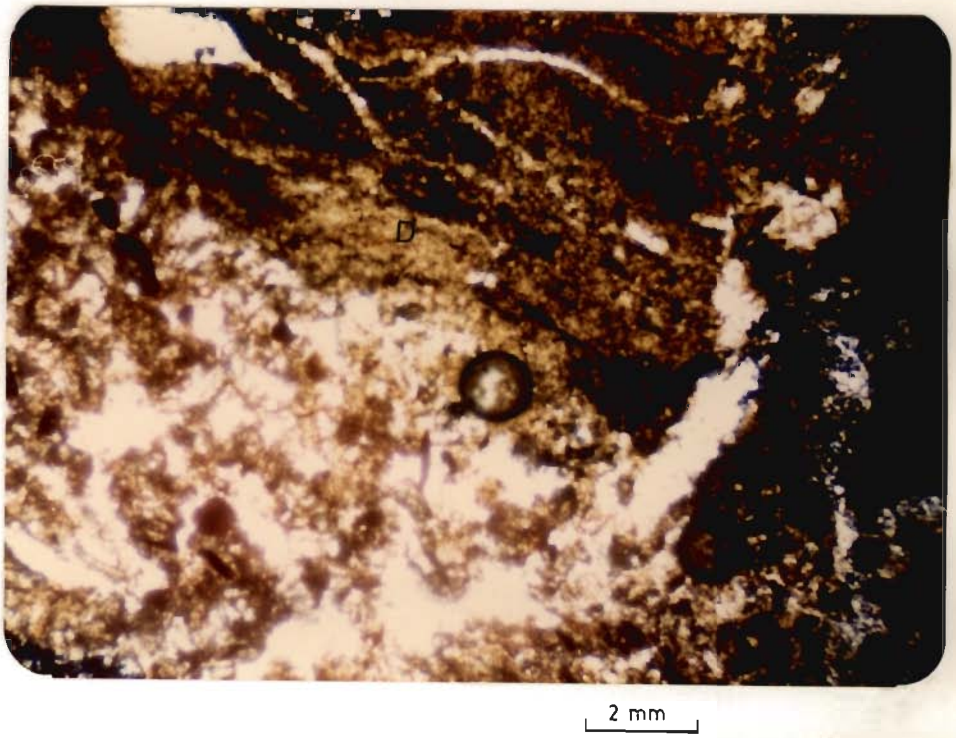


Fig. 4.32 Dense complete infilling (D) of iron-rich clay material and ferri-argillans (D), Pedon # F1 (XPL).

microstructure, with slight weathering weakly developed pedality.

4.3.13. Fluvio-Aeolian Plain

Pedon	# F2
Classification	:Typic Ustochrepts.
Horizon	:B1 to B22

Thin Section Description

i. Microstructurs

Type and voids : Apedal soil material without clods or fragments with a predominantly spongy microstructure. Mainly meso-voids and some micro-voids with smooth walls, random orientation pattern and unrelated basic and referred distribution pattern. Boids are not interconnected and shows moderately developed podality (30-50 cm) but some voids are not interconnected bvetween (50cm to 145cm depth).

ii. Basic Mineral Components

C/f limit at 20 um: ratio of 50:50.

Coarse mineral components : Dominantly rounded to subrounded, poorly sorted, single mineral grains. Composition is dominated by quartz.

Fine mineral components : Yellowish brown mainly clay sized material, with dotted or speckled appareance in transmitted light and shows white to dark yellowish brown interference colouts under crossed nicols.

iii. Groundmass

The C/f related distribution is mainly porphyric and b-fabric of micromass is crystallitic-b-fabric.

iv. Pedofeatures

Textural pedofeatures : (a) Loose incomplete infillings of voids with fine silt and clay sized materialsd. No organic material, no rotlets and no other pedofeature, and (b) voids are filled with calicium carbonate materials and coated with amorphous iron oxides (Fig- 4.34).

4.4 MICROMORPHOLOGICAL ASPECTS OF SOILS IN RELATION TO GEOMORPHIC UNITS

From the detailed micromorphological description of

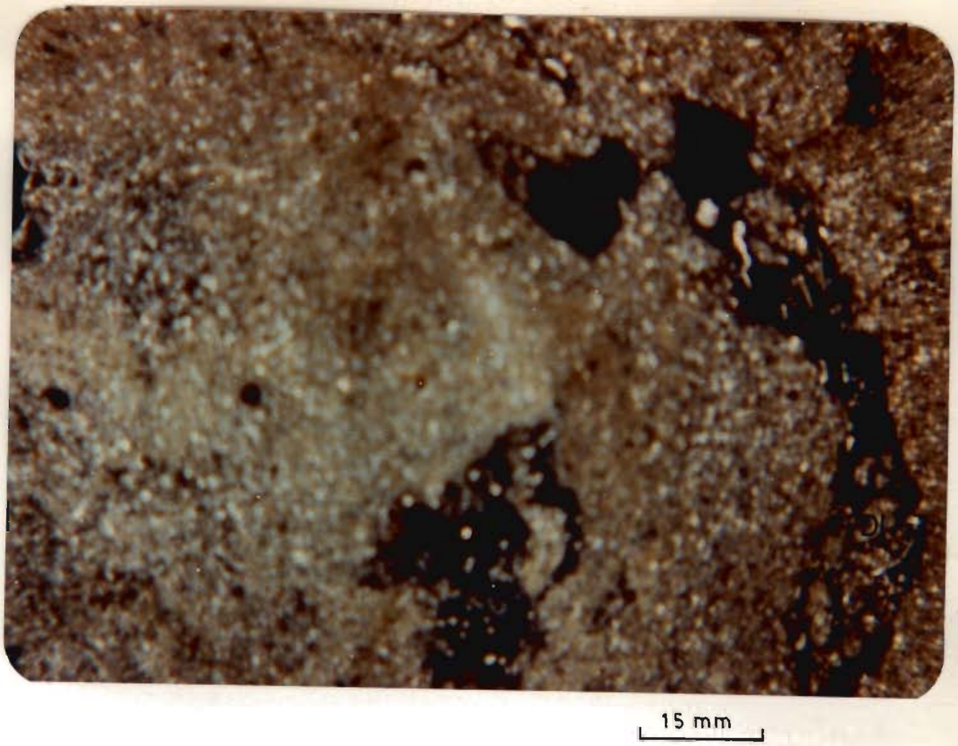


Fig. 4.33 Dense incomplete infilling of pedal material (DI) within voids and, Horizon C3, Archaeological site, Pedon # F1 (PPL).

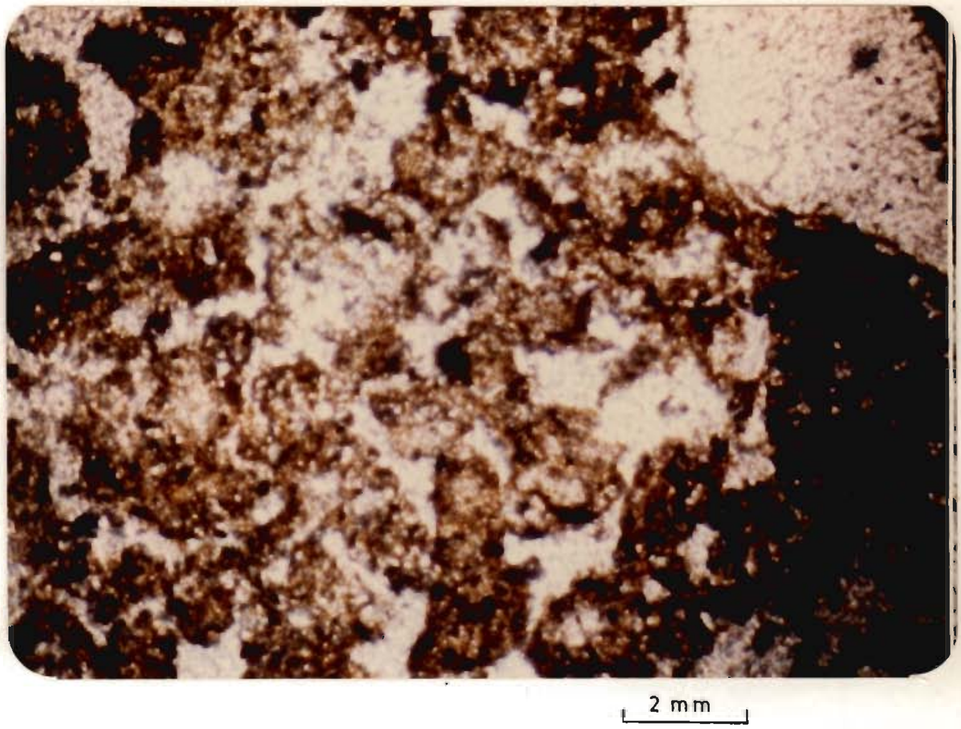


Fig. 4.34 Moderatively developed pedality and coating of voids by iron-rich clay material, Horizon B22, Fluvio-Aeolian Plain, Pedon # F2 (PPL).

different pedons, some generaliztion about soils of various geomorphological units can derived and given below.

4.4.1. Basin with Marl

This unit covers a part of the low lying area (basin) in the district of Bhiwani. Field observations show the presence of calcium carbonate layer with ostrocoda shells (Fig- 4.1) and a lot of animal activity. The soils are classified as Torripsamments, Palaeorthids and Camborthids. Micromorphologically the soil materials are apedal, mainly massive calcium carbonate with vesicular microstructure (Fig- 4.1). Mainly wide vughs with meso size interconnected voids are observed. Voids are filled with calcium carbonate materials. The coarse/fine ratio is 10:90. The coarse fraction is dominated by quartz, some biotite and plagioclase felspar with iron rich clay and silt size material (Fig- 4.2) . Related distibution of coarse fraction is guferic to chitonic and micromass of b-fabric is crystallitic type (crystic plasmic fabric of Brewer, 1964). Complete dense infillings of vughs with calcium carbonate material and coating of walls of voids with iron-rich clay and silt size material (Fig- 4.3) are the main textural pedofeature. Excrements, welded mineral excrements (Fig- 4.4) and reworking of soil mass (mainly mineral material) indicate extensive faunal activity. Some remnants of wood and fossil shell fragments are also observed.

4.4.2. Older Piedmont Plain

The area belongs to mainly Udic to Ustic climatic regime and the soils are classified as Ustochrepts. Micromorphologically the soils are dominated by quartz, mica, felspar and yellowish to reddish brown fine mineral material containing mainly clay size fraction with some silt size material. The observed microstructure is mainly pellicular grain type (Fig- 4.9) to spongy type. The voids are macrocomplex packing type (50%), macrocompound packing type (10-15%) to intraaggregate packing type. These are commonly weakly oriented and randomly distributed.

The presence of discrete nodules (Fig- 4.6) and mottles (5-10%), fine texture soil increasing towards depth and movement of iron rich clay material forming brideges between grains shows pseudo-gleying effects (Fig- 4.8). Dense complete infillings (Fig- 4.10) to dense incomplete infillings of silty grains and silty clay materials (Fig- 4.10) are also seen in pedons of this unit and loose discontineous infilling of pedal material (Fig- 4.5). The coarse/fine related distribution is mainly porphyric type and b-fabric of micromass is of crystallitic type.

4.4.3. Younger Piedmont Plain

This plain forms a broad ring around the Older Piedmont Plain and belongs mainly to Ustic moisture regime. Pedogenesis is quite at initial stage and soil shows the presence of iron-manganese concretions and mottlling in the profile. The main soil types are Ustipsamments, Ustorthents and Ustochrepts. Micromorphologically the soils are dominated by quartz, felspar, flakes of biotite and reddish brown fine mineral material. Microstructure is mainly granular type and some parts of thin sections showing spongy type, and weakly to moderately developed peds are observed (Fig - 4.11). Voids are mainly intraaggregate compound packing voids between crumbs and granules and moderately oriented with random distribution pattern. The coarse/fine ratio decreases with depth from 60:40 to 20:80, and related distribution for the coarse fraction is mainly porphyric type. Micromass shows crystallitic b-fabric. A lot of faunal activity is seen by naked eye in the field and confirmed by microscopic studies (Fig- 4.12). No calcium carbonate calcrete is observed. The illuviation cutans (Brewer,1964) are absent.

4.4.4. Yamuna Floodplain

The soils of the Yamuna Floodplain are mostly Ustochrepts and Haplaquents. Micromorphologically the soils are dominated by quartz, mica, felspar and light yellowish brown to dark brown, fine mineral material. Soil material is mainly pedal with compact grain microstructure. These are mainly rounded to subrounded packing voids (10-15%) moderately related and randomly distributed. The coarse/fine ratio at 20 microns varies from 80:20 to 60:40, with chitonic to porphyric related distribution. The micromass of b-fabric is stipple-speckled. In situ biotite flakes are weathered along with the occassional mottles, which are moderately impregnated. No calcium carbonate nodules are observed. Some voids are coated with clay size and fine silt material. No organic matter and no specific pedofeatures are seen.

4.4.5 Ghagger Floodplain

This unit covers north-east south-west portion of

Haryana. The climatic regime is monsoonic in the sourse area to subtropical in Ambala district and semi-arid in Sirsa district. The soils are classified as Ustochrepts, Camborthids, Calciorthids and Natrustalfs. Micromorphologically this unit shows wide range of characteristics. The soils are dominated by quartz, with lot of flaky biotite and yellow to brown fine mineral material. The microstructure is spongy with mainly meso-voids. The voids, in general, are better represented than groundmass. The calcite nodules (yellowish white, irregular, rather compact with soil fabric) are observed in the middle reaches (Fig- 4.14). The coarse/fine related distribution pattern is mainly porphyric. The b-fabric of micro-mass is reticulate striated type (Fig- 4.13) to crystallitic type. The voids are showing loose infillings of soil fragments and walls are coated with iron-rich clay material.

4.4.6. Kaithal Upland Plain

This plain comprises the higher ground between the rivers Ghagger and Chataung. The moisture regime ranges from Ustic to Aridic in this part of survey area. Soils are classified as Ustochrepts, Haplaquepts, Camborthids, Calciorthids and Torripsamments. Micromorphologically the soils vary in mineral composition. At some parts soil is dominated by quartz, felspar, calcite and in other parts with calcium carbonate nodules in the B3CCa horizons (Fif- 4.16-4.17). The microstructure varies from compact grain structure to spongy type. The voids are compound packing type, mostly interconnected vughs with many channels (Fig- 4.18) in other pedon in B and CCa horizons. The coarse/fine ratio varies from 80:20 to 15:85 and related distribution pattern is mainly chitonic to porphyric. The micromass of b-fabric is crystallic type. There are small (about 50 micron long) colourless needles growing in pores of the Pedon # K1 (Fig- 4.15). They correspond to lublinite by many others, especially from eastern Europe (Sehgal, 1972). Compact, discrete, relatively large (250-500 microns)(Fig- 4.17) irregular dense, microcrystalline nodules are most common in the calcic horizon. These are mainly textural pedofeatures with loose discontineous infillings of voids, and mostly with calcium carbonate materials (Fig- 4.17). The voids are coated with iron-rich clay material. The enrichment of iron increases with depth. Some deformed pedofeatures are related to aggregates and iron enrichment. Extensive faunal activity between 102 to 153 cm depth in Pedon # K1 (Fig- 4.16 and 4.18) has been observed.

4.4.7. Karnal Upland Plain

This unit occupies a high ground between the Yamuna Floodplain and Drishadvati Plain. Salinity and alkalinity hazard is highest in this unit. The soils are mainly Ustochrepts, Calciorthids, Torriorthids and Ustipsamments. Micromorphologically the soils dominated by silt-size moderately sorted, subrounded quartz grains with biotite and calcite. Calcium carbonate nodules are present in CCa horizons. The microstructure is mainly spongy and voids are meso to micro interconnected with some mamellated vughs (Fig- 4.20). The coarse/fine related distribution is mainly porphyric and b-fabric of micromass is stipple-speckled to crystallitic type. The pedofeatures are mainly related to voids. Which are coated with iron rich clayey material (Fig- 4.21). Calcium carbonate nodules form CCa horizons. The calcic horizons are dominated by crystic fabric and microcrystalline calcite, calcium carbonate nodules including grains of quartz, muscovite and biotite and shows good example for neocalcans or calcans (Gawande et al., 1979) (Fig- 4.22). The grains are cemented by non-birefrengent substances, mainly iron-manganese rich, reddish brown material and forming neo-ferrans (Fig- 4.21). The soils showed shining ped faces and thin patchy clay skins in the field and were tentatively delineated to Bt horizon, but thin section studies of these pedons did not confirm these conclusins or no real illuviation cutans (Brewer, 1964) could be noticed under polarised microscope but only ferri-argillans could be observed. Similar observations were earlier made by Sehgal (1974) from northwestern India. Presence of animal activity in B-horizons of different pedons of the unit (Fig- 4.23), B22 horizon shows development of pedality (Fig- 4.24) and weakly developed pedality in B3Ca horizon (Fig- 4.25).

4.4.8. Drishadvati Plain

This unit consists of old relict floodplain of the river Drishadvati and situated between Kaithal and Rohtak Upland Plains. The soils are mainly Ustipsamments, Natrustalfs and Ustochrepts. Wide variation in field morphological characters is reflected in a large range of micromorphological characteristics of the unit (Fig- 4.27-4.29). The field observation regarding the presence of oxidation mottles in upper part of soil-profiles and calcium carbonate concretions below it, have been confirmed by microscopic studies. Micromorphologically the soils are dominated by quartz, biotite, felspar, yellowish brown mainly clay sized fine material and optically amorphous iron-oxide. The microstructure is mainly spongy with apedal soil material (Fig- 4.29). The voids are meso to micro (5-20%) commonly interconnected, and some interconnected vughs are also present at lower depth. The coarse/fine ratio varies from 60:40 to 20:80 with porphyric to close porphyric related distribution pattern. The b-fabric of micromass is stipple-speckled to crystallitic type. Pedofeatures are mainly related to voids and textural pedofeatures. Loose incomplete infillings with coating of voids by iron-rich clay and silt size material is a common feature. The calcium carbonate nodules below 1m depth and moderately impregnated, randomly distributed mottles above 1m depth are common. Development of pedality is shown by pedon # D6 of this unit between 27-105 cmm depth (Fig- 4.27) and chitonic related distribution (Fig- 4.28).

4.4.9 Fluvio-Aeolian Plain

Soils of this unit have intermediate characters between soils of Drishadvati Plain and Aeolian Plain. The soils are classified as Ustochrepts and Ustipsamments. Micromorphologically the soils are dominated by well sorted single mineral grains quartz, with yellowish brown, mainly clay size fine mineral material. The soil material is mainly apedal with spongy microstructure with some part of platy microstructure (Fig- 4.30). The voids are mainly meso to micro type, randomly oriented and interconnected. The coarse/fine ratio is 50:50 with porphyric related distribution of coarse fraction and crystallitic b-fabric of micromass. Pedofeatures are mainly related to voids (Fig- 4.30-4.34). Loose incomplete infillings of voids with fine silt and clay material is seen. No organic matter, no rootlets and no other specific pedofeature are recognised. Voids are filled with calcium carbonate material and coated with iron-rich material in the Pedon # F1 (Archaeological site), development of pedality (Fig- 4.31), dense complete infillings (Fig- 4.32) and dense incomplete infillings of pedal material (Fig- 4.33). Other features related to this pedon are presence of ferri-argillians, mottles and ferrigenous- hypo and quasi quatings.

4.5 DISCUSSION OF MICROMORPHOLOGICAL FEATURES

Comparison of degree of weathering in different geomorphic units based on micromorphological characteristics must take into account two factors i.e. climatic gradient in the area and vwide variation in degree of development of soils within individual geomorphic units. The Older Piedmont, Younger Piedmont lie in ustic moisture regions and major parts of the Ghaggar Floodplain, and Yamuna Floodplain. The Dishadvati Plain, Karnal and Kaithal Uplands all have a climatic gradient from ustic to airdic from northeast to southwest. Basin with kankar, Fluvioaeolian plain and units like Aeolian Plain, Aravalli Hills also lie in the ardic zone. Many units have been subjected to human activity and erosive action of ephemeral streams since the start of soil formation. Thus only the pedons with best develpoed soils should be used for comaparison of different geomorphic units.

Among the geomorphic units with mainly ustic moisture regime, The Older Piedmont Plain is characterised by pellicular grain microstructure and should be the unit with most developed soils in the study area as suggested by Courty and Fedroff (1985). Younger Piedmont Plain shows the presence of pedality with granular to spongy microstructures. The voids are mostly packing voids with some channels . Clear effect of faunal activity are observed in sandy soils, wherever large channels infilled with clean sand are easily seen with naked eye. Thus the Younger Piedmont is ranked next in degree of weathering. The Yamuna and Ghaggar Floodplains with A/C horizons are marked as least developed soils.

Yaalon (1971) suggested that features resulting from irreversible or self terminating process are resistant and therfore the best indicators of palaeopedogenic conditions, example from accumulation environments are calcretes, silcretes, calcic, gypsic and petrocalcic horizons. The Kaithal Upland Plain, Rohtak Upland Plain and Drishadvati Plain show accumulation of pedogenic calcretes between 50cm to 160cm depth. The Kaithal and Karnal Upland Plains approach to dynamic equilibrium at slow rate producing good diagnostic features which are relatively persistant in palaeosols (e.g. argillic, cambic horizons). Basin with Marl shows complete preservation of fossils indicating a lacustrine environment. Some exposure and reworking by funa is indcated by the presence of welded mineral excrements in the upper parts of Calcic horizon. This unit is also considered equivalent to abvoe three, as conditions for the formation of pedogenic and lacustrine calcium carbonate deposits may have been favorable at the same time in the past. These units seem to be equivalent to the Older Piedmont or have slightly less developed soils.

Based on the above discussion, different geomorphic untis can be arranged according to the degree of development of soils as follows:

Ustic soil moisture regime	Ustic to Ardic soil moisture regime
Yamuna Fooldplain	
Younger Piedmont	Fluvio-Aeolian Plain
	Basin with Marl (top aeolian soil only)
	Karnal Upland Plain
	Kaithal Upland Plain
Older Piedmont	Drihadvati Plain

CHAPTER - 5

SUMMERY, SYNTEHSIS AND CONCLUSION

5.1. INTRODUCTION

Haryana State (India) over its major part, is underlain by the Indogangetic Plains and is bordered by the outer Himalayan ranges i.e. Siwalik Ranges in the northeast and by the northern tip of the Aravalli Ranges in the southwestern (Fig.1.1). The area is characterised by different soil moisture regimes i.e. ustic in the northeastern parts, ustic in central portion and aridic in the southwest. In the southwestern part, plains gradually merge into the Thar Desert. This region including the adjoining area of Panjab is known to have witnessed drastic changes in course/dicharges of the rivers like the Saraswati, Yamuna and Sutlej since Protohistoric times. The area has also been a scene of tectonic activity since Mid-Miocene (Parkash and Kumar, *in press*), probably climatic changes during the middle and late Holocene similar to those observed in the adjoining Thar Desert region (Singh, 1971, Singh et al., 1974) and exploitation by man since Protohistoric period. All the above factors could have resulted in instability of environment and are likely to be reflected in physiography and soils of the area. The present investigation attempts to study soil-landscape relationships in the area and work out the role of the above mentioned factors in their development.

In the present study, an attempt has been made to provide a regional distribution of soils and landforms. Tectonic features and geomorphic units with distinctive soils have been identified and mapped, typical pedons from geomorphic units have been studied in the field and detailed laboratory studies of 184 typical soil samples from 34 pedons (Locations shown in Fig. 1) for their grain size distribution, clay mineralogy, major and minor elements and micromorphological features have been undertaken. The field and laboratory data have been used to develop a soil- chronosequence for the area. The data have been interpreted in terms of evolution of soils, landforms and drainge pattern and role of tectonism and time in their evolution brought out.

5.2. FIELD AND LABORATORY PROCEDURES

Various geomorphic units with distinctive soils have been identified and delineated on a map (Fig.2.10) using Survey of India topographic sheets, detailed contour map, various type of Landsat imageries, digital image processing of Landsat MSS (multispectral scanner) CCTs (computer compatible tapes), published landform-soil maps, description of 150 pedons from published and unpublished sources and 34 pedons studied by the author. Extensive field work has been done by field traverses and spot checks to confirm geomorphic units and their boundaries established from remote sensing studies. Augering has been undertaken at a number of sites for selection of 34 soil-profiles for excavation. Master and sub- horizons are recognised and morphological properties like colour, texture, soil structure, consistence, mottling, lime content etc. as suggested by U.S.D.A. (1966, p. 138) have been noted in the field.

One hundred and eighty-four samples collected from typical subhorizons from 34 soil-profiles have been analysed for sand, silt and clay percentages by sieving and pipette method described by Carver (1971). Organic carbon and total sulphur have been determined in the Mat-600 electric furnace by dry combustion method as suggested by Jackson (1967). Soil pH and EC of 1:2 soil:water suspension and extract respectively have been determined. Total elemental and trace elemental analysis have been carried out by two solutions method as suggested by Shapiro (1975) using an atomic absorption spectrometer. Semi-quantative analysis of clay minerals for all the soil sample collected have been undertaken using a procedure adopted by Klages and Hopper (1982). Micromorphological studies have been performed by collecting insitu, undisturbed soil samples in metal boxes, impregnating soils with resin and preparing Kubina size thin sections by a procedure described by Jongerious and Heintzberger (1975). Thin sections have been studied under a petrological microscope and described following terminologies of Brewer (1964) and Bullok et al. (1985).

Results obtained from the laboratory analyses have been used to determine overall soil texture, accumulation indices for silt+clay, Al_2O_3 and Fe_2O_3 similar to clay accumulation index of Levine and Ciolkosz (1983) and molar ratios (Birkeland, 1984, p. 81). Also colour index for all the pedons has been calculated following Rockwell et al. (1985).

5.3. GEOMORPHIC UNITS AND SOILS

The following thirteen geomorphic units with characteristic features have been recognised (Fig. 2.10):

i. Siwalik Hills

- ii. Aravalli Hills
- iii. Old Sutlej Plain
- iv. Aeolian Plain
- v. Basin with Marl
- vi. Older Piedmont
- vii. Younger Piedmont
- viii. Yamuna Floodplain
- ix. Ghagger Floodplain
- x. Kaithal Upland Plain
- xi. Karnal Upland Plain
- xii. Drishadvati Plain
- xiii. Fluvio-Aeolian Plain

Except for the geomorphic units of the Siwalik and Aravalli Hills, all other units form a part of the Indogangetic plains. A brief description of field aspects, soil types and micromorphology of soils for the various geomorphic units is given below. Since the first four units listed above have not been studied in detail for their soils, microscopic description of their soils is not given here. Micromorphologically, soils of the geomorphic units studied reveal a certain amount of uniformity in coarse and fine fraction mineralogy. The soils are dominated by quartz, felspars and mica (biotie, muscovite) in the coarser fraction and yellowish to reddish brown fine material in the finer fraction.

5.3.1 The Siwalik Hills

The Siwalik Hills lie at heights from 350m to 700m and they end to the south in an undulating sub-montane tract of the Older Piedmont. These are underlain by a great thickness of clays, sands and conglomerates. They are badly dissected and are being eroded on a large scale. Streams like the Saraswati, Markanda and Chautang originate in these hills. The soils are shallow and are loamy sand to fine sandy loam and at places contain boulders. These are well drained, non-saline, non-alkaline and without calcium carbonate concretions.

5.3.2 Aravalli Hills

This unit lies in the southwestern region of the study area and consists of low altitude (<775 m) ridges and isolated rounded hills. This hilly terrain acts as a divide between the plain with extensive aeolian activity to the west and the area with little sand dune activity to the east. The Aravalli Hills are underlain by rocks of Aravalli and Delhi Supergroups. The Older Aravalli Supergroup is composed of mainly ferruginous quartzite, slate, schist and crysalline limestone. The overlying Delhi Supergroup consists typically of quartzites and schists. This area is subjected to severe wind erosion. The Aravalli Hills are usually naked or with little soil on them. Dominant soils are Typic Ustipsamments, Typic Ustochrepts, Typic Ustorthents and Lithic Ustorthents. The Aravalli Hills are surrounded on all sides by a narrow belt of pediments. These pediments may be covered by a thin sheet of sand cover, or be covered by a thin soil. Major soils on these landforms are Typic Camborthids with redder hues due to ferrugenous parent material, Torripsamments, Typic Camborthids and Typic Torriorthents.

Within the Aravalli Hills, a few small basins with impeded drainage are observed. At places, soils in these basins contain a large amount of salts. Major soils in these areas are Typic Ustochrepts, Aquic Ustochrepts and Haplaquepts.

5.3.3. Old Sutlej Plain

This unit occurs north of the Ghaggar Floodplain. It is a part of a large plain lying between the present courses of the Ghaggar and Sutlej rivers and covering major part of the state of Panjab (India). It is basically an alluvial plain formed due to shifting of the river Sutlej northward and consists of coarser sandy material along paleochannels and finer silts and clays in the intervening areas between the paleochannels. The alluvium is marked by abundance of disseminated impure calcareous matter in the form of irregular concretions. Wind has reworked sand and has heaped it in the form of dunal ridges along the paleochannels. Between the dunal ridges, almost flat plains are observed. In these areas salt afflorescence is also common. Soils have weak to moderately developed profiles and major soils are Ustochrepts, Ustipsamments, Haplaquepts and Natrustalfs. (Sehgal, 1974; Sidhu et al., 1976; Anand et al., 1977; Sharma et al., 1978).

5.3.4 Aeolian Plain

The Aelian Plain in southwestern region of the State is a part of the aeolian accumulation of the great Thar Desert of India. It is essentially a flat plain dotted with stabilized longitudinal dunes and active barchan dunes. In some areas, outcrops of the Aravalli Supergroup are also present, which diversify the landscape and soil characteristics. Climate is semi-arid to arid and subsoil water is brackish in nature. Sediments brought in by ephemeral monsoonal streams are reworked by aeolian activity during dry months. Calcium carbonate nodules are found at a depth between one to two meters depending upon the thickness of the sand cover. The soils are sandy to fine loamy and are classified as Typic Camborthids and Typic Torripsamments.

5.3.5 Basin with Marl

This unit covers a part of the topographic low (basin) northeast of the Aravalli Hills with a few cms to 2m of marl layer and covered by 1-2 m thick aeolian sands and has been interpreted by Bhatia and Singh (in press)to be of mesohaline lacustrine origin. The Marl contains numerous animal shells (Ostrocoda) (Fig. 4.1). Soils are sandy loam to loam and classified as Torripsamments, Palaeorthids and Camborthids. Micromorphologically the soil material is apedal, with massive calcium carbonate material and vesicular structure. Mainly vughs of coarse micro size to medium meso size, interconnected voids and filled with calcium carbonate material. The coarse/fine related distribution is mainly guferic to chitonic and micromass shows crystallitic b-fabric. Voids are coated with iron- rich clay and silty material. Extensive animal activity, shell fragments, welded mineral excrements (Figs. 4.4.) some remnants of wood have also been observed.

5.3.6 Older Piedmont

South of the regional uplift of the Siwaliks lies, with an average slope of $6x10^{-3}$, semi-circular shaped Older Piedmont Plain. Major streams draining the area, like the Sarasvati, Markanda and Chautang, are ephemeral in nature and are subparallel to each other. These streams have dissected deep into the plain. Smaller low order tributaries to the major streams form dendritic patterns and have removed soil cover from their catchment areas. Non-dissected portions of the plain exhibit thick soil cover.

Soils of the undissected parts of the Older Piedmont Plain are mostly sandy loam to loam. They are classified as coarse loamy to fine loamy Udic Ustochrepts. Soil colour index is 4.75. Oxidation mottles and Fe-Mn concretions are present fairly abundantly in the subsurface horizons, indicating gleying effects. Soil structure is mainly subangular blocky. The soils are free from calcium carbonate concretions and are non-saline in nature. Microstructure is mainly pellicular grain (Fig- 4.9) to spongy. Voids are macrocomplex packing voids, macrocompound packing voids and intraaggregate packing voids and are weakly oriented and randomly distributed . Fe/Mn mottles observed in the field are confirmed by microscopic examination (Fig- 4.6). Dense incomplete infillings of pedal material in the voids are observed. Dense complete infillings of silt grains and silt+clay materials (Fig- 4.10) at some places shows movement of these material within the profile. The coarse/fine related distribution is mainly porphyric and b- fabric of micromass is crystallitic b-fabric.

5.3.7. Younger Piedmont

This plain forms a 25-50km broad ring around the Piedmont Plain and is gentle sloped (av. slope= $4.4x10^{-3}$). Deposition in this plain is still taking place from ephemeral streams originating in the Older Piedmont and Siwalik HIlls. Terminal fans have been described from this unit by Mukerji (1975) and Parkash et al. (1983).

The soils in the Younger Piedmont are mainly sandy to clayey. The soils are classified as Ustipsamments and Ustochrepts. Development of iron-manganese concretions and oxidation mottling has been observed in the field. No calcium carbonate concretions were seen in the soil profile and soils are non-saline in nature. Mixed colour index is 5.00, and the high value of this index is due to the presence of oxidation mottlling/Fe-Mn concretions. The soils show mainly subangular blocky structure. The soils are non-saline in nature. The microstructure is mainly granular and some part showing spongy structure. Voids are mainly intraggregate compound packing voids between crumbs and granules. The coarse/fine related distribution is mainly porphyric and micromass of b-fabric is crystallitic b- fabric. Lot of faunal activity is recognized in the field as well as on microscopic scale.

5.3.8. Yamuna Floodplain

Haryana state is bounded on the east by the River Yamuna. The whole flodplain is entreched and the degree of entrenchemnt increases further downstream of the present area. The landscape aspects are related to channel remnants of the former river courses and related features like levees, basins, channel bar and channels. Pedogenesis is at quite an initial stage. The soils are mainly sandy to coarse loamy and classified as Ustochrepts, Ustifluevents and Haplequents. Calcium carbonate concretions are observed in distal part of the area. Mixed soil colour index is 4.2. The soils are non to highly saline in nature. Soils are mainly pedal with compact grain structure and packing voids. The coarse/fine related distribution is chitonic to porphyric and micromass of b-fabric is stipple-speckled.

5.3.9. Ghagger Floodplain

The Ghaggar river forms the border between Haryana and Panjab states. The climatic regime varies from monsoonic to semi-aridic. Two distinct subdivisions of the Ghaggar Floodplain i.e. active, narrow floodplain and the older 8-13 km wide, abandoned floodplain can be recognised from the Landsat imageries (Fig.5.4. Floodplain boundaries in the lower reaches are not well defined. The Ghagger Floodplain can also be divided longitudinally into upper, middle and lower parts. Soils of upper parts are non-saline and classified as Ustochrepts. The soils of middle and lower parts are free to low in salt content and classified as Ustochrepts, and Natrustalfs. In general, the soils belong to coarse loamy to fine loamy family. The presence of both oxidation mottles over the most of the floodplain and development of calcium carbonate concretions mainly in the lower parts of the lower parts of the floodplain is observed. Mixed soil colour index is 4.63. The microstructure is spongy with meso-voids. Calcrete nodules are observed in the middle reaches. The coarse/fine related distribution is mainly porphyric and micromass of b-fabric is reticulate striated b-fabric. Loose infillings of soil fragments and coating of iron-rich clay material along the walls of voids are observed.

5.3.10 Kaithal Upland Plain

This plain comprises the higher ground between the river Ghagger and Chataung. The moisture regime changes from Ustic to aridic. Soils are non to slightly salt affected, coarse loamy to fine loamy and classified as Ustochrepts, Haplaequepts, Camborthids, Calciorthids and Torripsamments. Calcium carbonate concretions are present in soils, but these are free from oxidation-reduction mottles. Mixed soil colour index is 4.33. The microstructure varies from compact grain to spongy and voids from compound packing voids to vughs with some channels. The coarse/fine related distribution is mainly porphyric and micromass is crystallitic b-fabric. There are small (about 50 microns only) colourless needle of lublinite, growing in the pores of soil in the pedon #K1 (Fig. 1). Compact discrete, relatively large (250-500 microns) irregular, dense, nodules of calcium carbonate are present in the calcic horizons (Fig. 4.16). Voids are also filled with $CaCO_3$ rich material and walls are coated with neo-calcans. Loose discontinous infillings are observed in voids. The presence of faunal activity between 102 to 153 cm depth is observed in the pedon #K1 (Fig. 4.16).

5.3.11 Karnal Upland Plain

This unit occupies higher ground between the Yamuna Floodplain and Drishadvati Floodplain. Salinity and alkalinity hazard is highest in this unit. Mixed soil colour index is

4.65. This unit can be subdivided into three subunits i,e. Ra, Rb and Rc (Fig 2.10). The first subunit Ra occurs in the northern parts and shows strong salinity. The second subunit Rb adjoining to the Ra in the southern part, has medium to low salinity. It is irrigated by canal on a large scale and it probabely produced oxidation mottles observed in the upper 1 m of the soil profle. The third subunit Rc occur within the extreme south and lies between the Aravalli Hills and the Yamuna Floodplain. It is affected by wind activities though it is not in the geographic continuity with subunits Ra and Rb , soils in this subunit are considered to be equivalent to those of subunits Ra and Rb in respect of degree of soil development. These subunits soils mostly belongs to coarse loamy to fine loamy family and are classified as Ustochrepts and Natrustalfs. Calcium carbonate concretions are present in Cca horizons of soils, below 1 m in all this subunits. Microstructure is mainly spongy and voids vary from meso to micro type and some interconnected mamellated vughs are also present (Fig. 4.20). The micromass of b-fabric is stipple- speckled to crystallitic in nature. Neocalcans and ferriargillans (Fig. 4.21-4.22) are observed in some of the thin sections. Calcans have been earlier reported from this unit by Gawande et al. (1979). However, no illuviation cutans (Brewer, 1964) are not noticed under microscope. B_{22}horizon shows the development of pedality (Fig. 4.24).

The salinity affected areas in Ra subunit in the north lie in such a fashion that they form a dichotomic pattern (Fig-2.5)(Howard, 1967). This salinity pattern is thought to result from remobilisation of salts by overflow in recent times. Interestingly the finer slope pattern of the area brought out by salinity distribution pattern suggest that the older drainage during the deposition of sediments of Ra subunit was from the Yamuna river side.

5.3.12 Drishadvati Plain

This unit consists of relict floodplain of the river Drishadvati. At present, the Chataung river, flows through central part of this unit. Mixed soil colour index is 4.61. The soils are mainly sandy to fine loamy and classified as Ustipsamments, Natrustalfs and Ustochrepts. The presence of moderately impregnated and randomly distributed oxidation-reduction mottles in the upper one meter and calcium carbonate concretions in soil-profile below it, is characteristic feature of these soils. Microstructure is spongy and voids varies from meso to micro size and some interconnected vughs are present. The coarse/fine related distribution is mainly porphyric and micromass of b-fabric is stipple-speckled to crystallitic. Loose incomplete infillings within the voids and and walls of voids are coated with iron-rich silty clay material.

5.3.13 Fluvio-Aeolian Plain

The plain is flat in nature and large portions of the surface are covered with aeolian sands and shifting dunes. Mixed soil colour index for soils is 3.8. Soils are light in texture and belongs to coarse loamy family in areas of wind activity and are of heavy texture (fine loamy) in low lands. The soils are classified as Ustochrepts, Ustipsamments and Ustifluvents.

Micromorphologically, apedal soil material with spongy microstructure and meso to micro, randomly oriented voids are present in the soils. The coarse/fine related distribution is porphyric and micromass is crystallitic b-fabric type. Loose incomplete infillings in voids and coating of fine silt and clay material along voids. An archaeological site pedon #F1 shows good development of soil with dense complete infillings, ferri-argillans, mottles and ferrugenous hypo and quasi-coatings.

Some prominent faults have been delineated in the area of study. The Main Boundary Fault separating the Siwalik Supergoup sediments from the unfossiliferous sediments of the Lesser Himalaya in the north identified all along the Outer Himalaya from Kashmir to Assam has been marked in the area. The contact of the Siwaliks with the alluvium of the Indogangetic Plains to the south is considered to be a fault and called the Foothill Fault. The western boundary of the Yamuna Floodplain is a set of normal faults trending NE-SW to NNW-SSE, with eastern side being the downthrow block. The Ghggar Floodplain is considerd to lie along a fault, as some paloechannels of the Sutlej river terminate against it obliquely. Another fault called Souhtern Boundary Fault separating rocks of the Aravalli and Delhi Supergroups from the Indogangetic Plain sediments is supposed to lie along a topographic depression just northeast of the Aravalli Ranges in the study area.

5.4. CLAY MINERALOGY, AND MAJOR AND TRACE ELEMENTS OF SOILS

Semiquantative analysis of clay minerals of the soils by X-ray diffraction technique indicates that illite is the most dominant mineral (26.7-95.46%). The other significant minerals are kaolinite (10.17-56.62%), chlorite (2.17-16.66%) and vermiculite (1.10-27.73%). Montmorillonite (2.40-6.88%) and illite-chlorite mixed layer minerals (5-10%) are observed in small quantities. Clay minerals donot show significient variation with depth in soil-profiles. In general, illite has antipathic relationship with kaolinite and chlorite and it has a positive correlation with clay content of soil samples. No correlation between geomorphic-units and contents of various clay minerals in their soils has been observed.

Major elements percentages of soils has been used to calculate molar ratios and accummulation indices (**APPENDIX IV**) and these are discussed in the following section. Total trace element contents for Cu and Mn vary widely i.e. Cu values are from 2.5 ppm to 378.8 ppm and Mn content varies from 350 ppm to 780 ppm. Zn content varies within a vary small range (50-100 ppm). Mn content has been found to increase with depth with higher development of soils.

Statistical analysis of data comprising 28 variables, including field soil properties, percentages of various size fractions, amounts of major and minor elements, and various molar ratios, for 183 soil samples has been carried out by calculating Pearson product correlation matrix. This analysis brings out that the variation observed in the data can be explained by four major groups of variables. The first group includes variables like, percentages of Fe_2O_3, Al_2O_3, silt+clay, various molar ratios etc. and is interpreted to indicate the degree of soil-profile development. The second and third groups are considered to represent $CaCO_3$ accumulation content and soil salinity. The fourth group is comprised of percentages of various clay minerals and is related mainly to clay content in different samples (Fig. 3.19a)

5.5 SOIL-CHRONOSEQUENCE

Earlier Rockwell et al. (1985) have attempted to date some geomorphic surfaces using the degree of soil-profile development and identified different members of a Late Pleistocene-Holocene soil-chronosequence in the Ventura Basin of U.S.A. Somewhat similar approach is being utilized here. It is well realized that soils in the area of present study are comparatively young and consequently effects of parent material could be strong on the development of soil profiles. Also, a climatic gradient exists from northeast to southwest in the study area. In view of these limitations, an integrated approach of using field properties, e.g. soil colour index, presence/absence of $CaCO_3$ concretions and Fe/Mn oxidation mottles/concretions and laboratory data on accumulation indices for silt+clay, Fe_2O_3, and Al_2O_3 and silica:sesquioxides molar ratio and micromorphological features have been utilized to prepare a soil-chronosequence given in Table 5.1. Ranges of molar ratioes silica:sesquioxide for soils of different geomorphic units show wide difference from the data of other indices mentioned above and thus given less emphasis. As all the soils on different geomorphic surfaces (units) are exposed and they have been developing since the formation of these surfaces, the above sequence can be classified as post-incisive chronosequence of Vreeken (1975).

In all three members Q_1, Q_2 and Q_3 of the soil-chronosequence with increasing age have been recognised. These members include soils of different geomorphic units as follows: Q_1- Yamuna Floodplain, Q_2- Younger Piedmont, Fluvio-aeolian Plain, Ghagger Floodplain and top portion of Basin with Marl, and Q_3- Drishadvati Plain, Rohtak Upland Plain, Kaithal Upland Plain and Basin with Marl (Paleolacustrine Marl only) and Older Piedmont. In ranking members of this soil-chronosequence, the maximum values of different accumulation indices and minimum values of silica:sesquioxide molar ratioes for different geomorphic units have been taken into account (Fig. 5.1) due to the fact that individual geomorphic units have been subjected to modification by stream action and man's operations to level the land for agricultural purposes since Protohistoric times, leading to removal of top soil cover at places at different times.

In general, soil matrix colour index and indices for accummulation of Silt+clay, Al_2O_3 and Fe_2O_3 and micromorphology of soil give almost similar ranking to soils of differnt geomorphic units in the proposed soil- chronosequence (Table 5.1) except for the Younger Piedmont. High values of colour index for this unit are due to development of oxidation mottling/Fe/Mn concretions in soils as result of poor drainage conditions., This phenomenon is also probably responsible for high accumulation indices for this unit.

In preparing the above soil-chronosequence, micromorphology has been very useful. In the ustic soil moisture

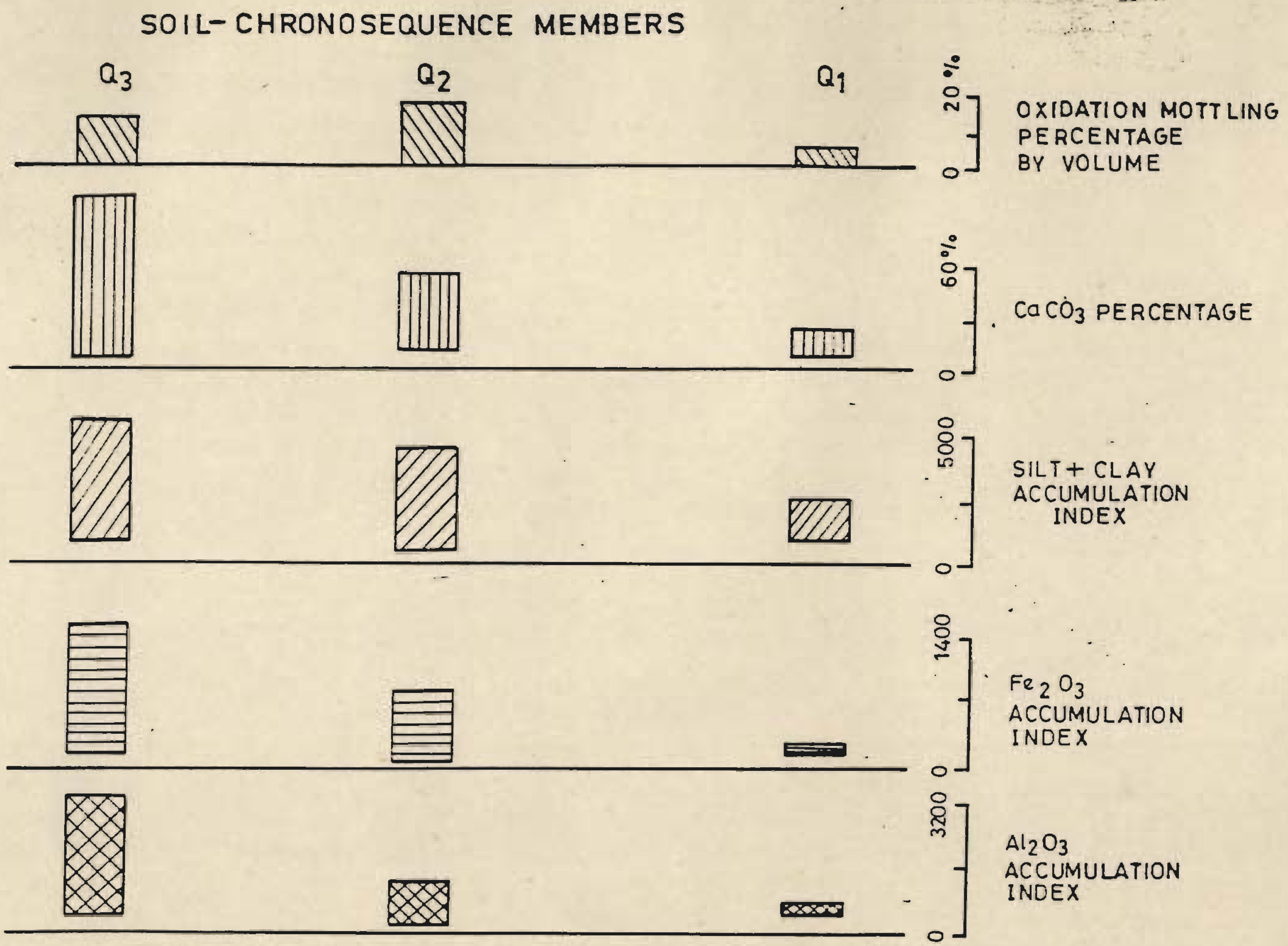


Fig. 5.1 – Ranges of oxidation mottles mottling and $CaCO_3$ percentages various accumulation indices

TABLE 5.1 : SOIL - CHRONOSEQUENCE

Soil group	Geomorphic Unit	Age of chronosequence members (Yrs.)	Field Properties Oxidation Mottles	Fe-Mn Concretions	$CaCO_3$ Concretions	Total Silt+clay accummulation index values	Al_2O_3 accummulation index values	Fe_2O_3 accummulation index values	Soil Matrix-colour index	$SiO_2/(Al_2O_3+Fe_2O_3)$	Micromorphological characteristics
Q1	IYamuna Floodplain I	1000	Few			Nil	409.6-135.8	168.0-43.40	4.2	3.09-2.71	Granular with packing voids
Q2	IYounger Piedmont I I	3500	15-20%	5-10%		2248.7	592.90	326.1	5.0	5.43-4.41	Pedality, packing voids & oxidation mottles, small amounts of pedogenic calcrete only in distal part of the Ghagger Floodplain.
	IFluvio-Aeolian IPlain (Basin with IMarl, top soil Ionly)		5-10%			181.9-457.1	287.9	264.30	3.8	2.89-2.09	
	I IGhagger Floodplain I		10%		5-35%	1144.8-402.5	528.4-500.2	197.7-40.34	4.6	4.00-2.93	
Q3	IDrishadvati Plain I I	5000	5-10%		10-20%	2292.9-285.0	1148.8-170.1	651.3-173.75	4.6	5.15-1.74	pedogenic calcrete , Ferriargillans, Pedality. (Oxidation mottles in the Drishadvati Floodplain and part of Karnal Upland plain)
	IKarnal Upland plain I I I				20-60%	1540.0-88.4	1387.4-517.45	648.9-87.7	4.6	4.56-1.74	
	IKaithal Upland Iplain I				20-40%	4048.2-253.4	680.98 506.57	616.0-608.31	4.33	6.04-1.11	
	IBasin with Marl I(Palaeolacustrine IMarl) I I				20-80%	Nil	-	-	-	-	Lacustrine $CaCO_3$ deposit, welded mineral excrements
	I IOlder Piedmont Iplain I		5-10%			4780.9-552.90	3121.5-380.0	1358.6-298.0	4.75	7.53-2.16	pellicular grain microstructure.

regime, the Older Piedmont is characterised by pellicular grain microstructure and classified as the oldest member. The Ghagger Floodplain (in udic soil-moisture regime), Younger Piedmont and Fluvio-aeolian Plain soils are younger, as they exhibit pedality and mostly packing voids. The Yamuna Floodplain is commonly characterised by A/C soil horizons and is the youngest.

Due to the presence of pedogenic calcretes between 50 cm to 160cm depth in the Drishadvati Plain and Karnal and Kaithal Upland Plains and these are grouped together. Basin with Marl is grouped with them, as it is assumed that conditions for $CaCO_3$ deposition in lakes and its formation in soil profile started at a particular time in the past. This group of soils developed in aridic soil moisture regime and is equivalent to the soils of the Older Piedmont under the ustic soil moisture regime.

In the proposed soil-chronosequence, the Yamuna Floodplain has been assigned to the youngest member of soil-chronosequence, though it shifted approximately to the present position probably 5000 B.P, as dicussed below. This aspect needs to be discussed a little further. If the river has a confined floodplain like that of the Yamuna river, tectonic stability of the area determines the age of soils exposed in the floodplain. If the area is tectonically stable, the river will migrate across its floodplain and rework its sediments frequently, as is the case presently with the Yamuna river. Under the circumstances, all soils on the surface of the floodplain are likely to be very young and marked by A/C or A/B/C profiles, with weakly developed B horizons.

A cross-section along a NE-SW line across Haryana,

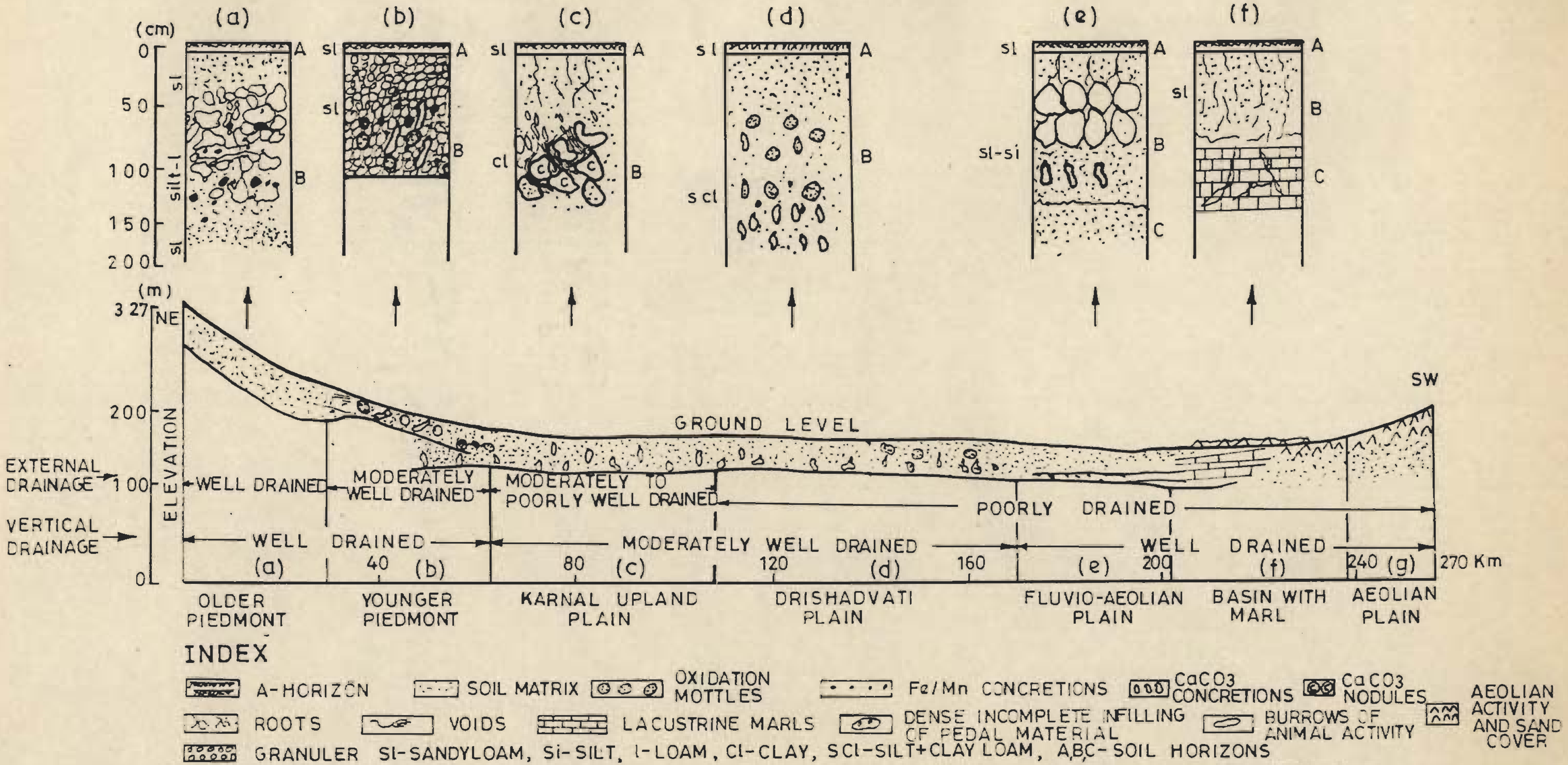


Fig. 5·2—Diagrammatic representation of typical pedons and cross-section along NE-SW showing the relationship between soils of different geomorphic units of Haryana showing relationship among soils of different geomorphic units is given in Fig. 5.2. The ephemeral streams are eroding the Older Piedmont and Siwaliks and depositing sediments on the Younger Piedmont. Sediments of this unit are prograding over the Drishadvati Plain and Karnal and Kaithal Upland Plains. To the southwest, wind is a dominant agent. It has completely reworked earlier fluvial sediments in the Aeolian Plain and Basin with Marl and partially in the Fluvio- aeolian Plain. Some transportation of sediments over small distance by wind may also have taken place.

Two carbon dates from marls of the Basin with Marl obtained by Bhatia and Singh (in press) are 5363+110 B.P, and 3640 B.P. Keeping these as reference dates, tentative ages are assigned to different members of the soil- chronosequence (Table 5.1).

5.6 SOIL, LANDFORM AND DRAINAGE EVOLUTION - A DISCUSSION

Haryana and the adjoining area of Panjab have witnessed changes in courses/discharges since Protohistoric period. This had profound effect on the growth and decay of various civilizations in the region. Thus, changes in drainage pattern in the region has been of deep interest to geographers, geologists and archaeologists and considerable literature is available on the subject. A brief summary of the main ideas concerning this aspect is presented below.

Rivers like the Satadaru, Saraswati and Drishadvati have been mentioned in the Rigveda, the oldest surviving record in any Indo-European language. The Satadaru has been identified with the modern Sutlej. Oldham (1874, 1893) opines that the modern Ghagger is the same as the old Saraswati and this idea has been accepted by later workers (Stein, 1942; Singh, 1952; Krishnan, 1952; Indras, 1967; Wadia, 1966). Cunnigham (1877) identified the Drishadvati with modern Pokshi river. However, later workers (Rapson, 1914; Keith, 1922; Dey, 1927; Vashishta, 1962; Sarma, 1974; Kar and Ghose, 1984) have defined the course of the mighty Drishadvati as being along the present Chataung river, which has minor discharge only during the monsoon period.

Pal et al. (1980) have mapped paleochannels in Haryana and Panjab using Landsat imageries and conclude that the Sutlej and Yamuna were tributaries of the Ghaggar till about Late Harappan time. Then Sutlej shifted slowly northward to the present position and Yamuna shifted through the course of the Drishadvati to the present position due to tectonic processes. The River Saraswati lost its dicharge, as there is a reference to its drying up in the epic Mahabharat. Mahabharat period is now considered to be equivalent to the Painted Grey Ware (PGW) culture which lasted from 1000 B.C. to 600 B.C. Also archaeological evidence seems to support this conclusion. The Harappan sites are abundant along the old course of the Saraswati in Rajasthan and further downstream and only a few PGW sites clustered close to a narrow course of the Saraswati are known, indicating dwindling discharge of the river.

Shifting of the Yamuna river has been more controversial than that of the Sutlej. Wilhelmy (1969), Bhan (1971, 1972), Sharma (1980) and Pal et al. (1980) think that the Yamuna flowed northward to join the Saraswati river during the Pre-Mahabharat period and later shifted to the present course. Raikes (1968) hypothesizes that the Yamuna alternately shifted three times to the Indus and Ganga systems between 2500 B.C. and 500 A.D. Gupta et al. (1977) and Kar and Ghose (1984) donot favour the idea that the Yamuna was a tributary of the Ghaggar during the period under consideration.

No agreement exists regarding climatic changes during the Holocene. Archaeologists like Stein (1931), Marshal (1931), Piggott (1950) and Wheeler (1953) think that during the early and mature Harappan culture period (2500 B.C.- 1700 B.C.), climate was more wetter than at present and later due to drier climate during late Harappan period (1700BC - 1000BC), the culture withered. Indirect evidence for these changes seems to have been provided through palyonogical studies of sediment cores from lakes in Rajasthan (Singh, 1971; Singh et al., 1974). According to these studies, the period >8000 B.C. was marked by a severe dry climate. The period of 8000-3000 B.C witnessed slightly wetter condition than before. The period of of 3000-1800 B.C. was a wet phase coinciding with the prolification of the Harappan culture. Later drier conditions set in and these have continued with minor modifications till present. Postulation of a wetter climate for the Harappan period has been opposed on palyonological grounds by Vishnu-Mittre (1972, 1978), on archaeological evidence (Thapar,1977; Pande 1977) and other bases (Flam, 1976; Seth, 1978). Misra (1984) has argued that climatic changes suggested by Singh et al. (1974) can be as well explained by changes in courses/discharges of rivers of the area due to tectonic processes.

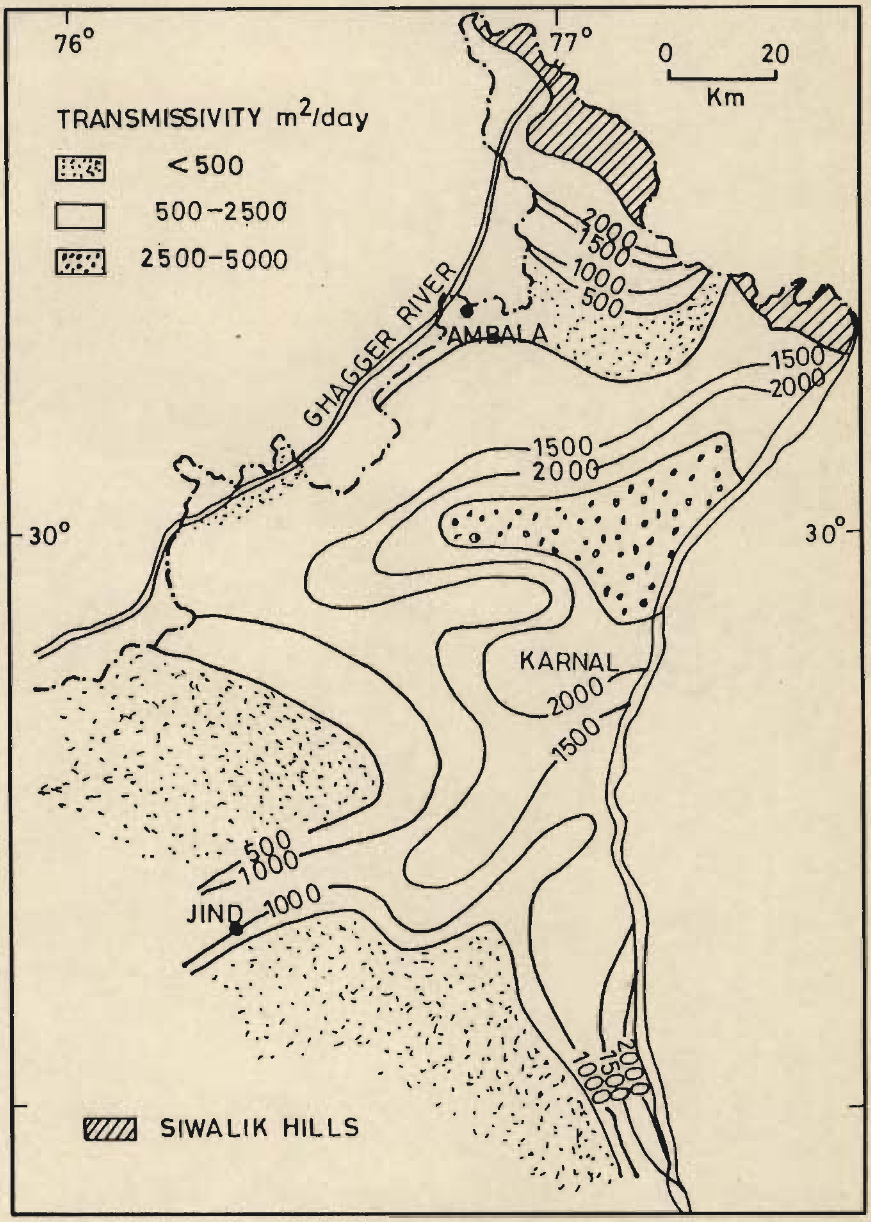


Fig. 5·3 – Transmissivity of the alluvial aquifer in 0 to 150 m depth, Haryana after tanwar, 1983.

Before discussing the present data, it must be emphasized that soil and morphological data cannot provide a fine chronological resolution of events as required by archaeologists and dates mentioned herein may be taken to indicate a period rather than too literally. Also normally large rivers like the Kosi, Gandak and even Sutlej from different parts of the Indogangetic Plain form fairly large valleys/ floodplains and such features should be taken as evidence of the presence of former courses of large rivers rather than small paloechannels.

Taking into account soils and landforms of the area under investigation, the following sequence of events is proposed:

1. A map showing distribution of hydraulic transmissivity (Fig. 5.3) in 150m thick sediments below the surface shows that aquifer (mainly sandy) thickens to the northeast to the point where the Yamuna debouches into the plains. Also slope pattern in the northern parts of Karnak Upland Plain (Fig - 2.5) suggest an ancient drainage from the Yamuna river side.Thus the River Yamuna flowed to Haryana to form a part of the Indus system in the past, though it is difficult to assign age to this phase in the absence of any detailed chronological data. During the latest part of the above phase, probably the Yamuna flowed through the wide Drishadvati Plain between the Kaithal and Karnal Upland Plains. The river Yamuna changed to its present course due to activity along the Yamuna faults leading to downwarping of the eastern block about 5000 B.P. as discussed below.

2. Next phase is the development of mesohaline lakes along the depression northeast of the Aravalli Ranges and development of

soils with calcretes along the Karnal and Kaithal Upland Plains and Drishadvati Plain in ustic to aridic soil moisture regime and calcrete-free soils on the Older Piedmont under ustic moisture regime. All these units belong to the Q_3 member of the soil-chronosequence. The whole area was marked by a stable environemnt with little erosion or deposition and conductvie to development of soils. This phase lasted from 5000 B.P. to about 3500 B.P. and it approximately coincides with the wet phase of Singh (1971) and Singh et al. (1974) and early and mature Harappan culture period,

No large river like Yamuna crossed the area, otherwise a very wide valley/ floodplain should been superimposed on the landscape of the area and should have been noticeable in the Landsat imageries. Also lacustrine lakes, in which marls were deposited, could not have existed for 1500 years close to the large river withopt g'tting drained out.

Longspell of dry climate in the present area coinciding with the Last Glaciation in higher latitudes (Wasson et al., 1983) probably resulted in accumulation of $CaCO_3$ and other alkali salts in the surficial sediments of this general area and these were redistributed during this phase. However, climate was no different from the present. Even now due to occasional high monsoon rainfall ephemeral streams flood large plain areas northeast of the Aravalli Ranges and form temporary lakes. Also, formation of soil calcrete is taking place in southwestern part of Haryana, even presently (Courty and Fedoroff, 1985). Thus formation of calcareous soils and deposition of lacustrine marls

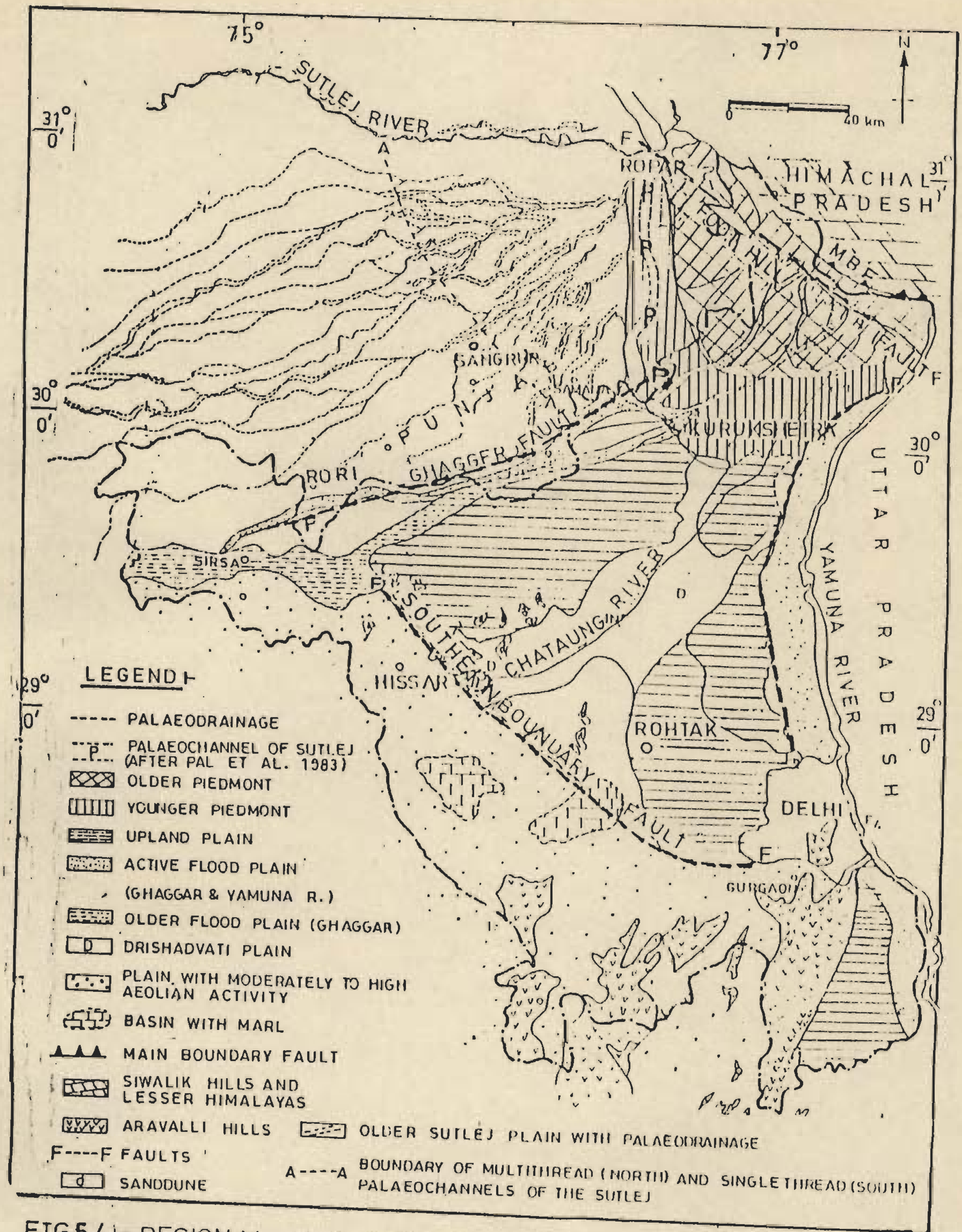


FIG.5.4 — REGIONAL MAP SHOWING DIFFERENT UNITS RELATED WITH VARIOUS GEOMORPHIC PROCESSES

was related to the shifting of the Yamuna river rather than to a climatic change and the present climatic regime probably began earlier than 5000 B.P.

Here it is pertinent to discuss the paleochannels reported by Pal et al. (1980). Major paleochannels of the Sutlej and Yamuna reported by them lie along the Younger Piedmont. This was the first impression of the author too during examination of a number of Landsat FCC's (false colour composites) of the area. However, detailed examination of imageries and digital analysis of the Landsat CCT's of the area indicates that it is a much wider geomorphic unit, characterised by higher moisture content and distinctive soils (Younger Piedmont) and does not represent any paleochannels across the major NE-SW slope.

One of the paleochannels of Sutlej mapped by Pal et al. (1984) (marked P in Fig.5.4) cuts across the trend of other paleochannels which indicate a gradual northward migration of the Sutlej. That relationship can be interpreted only as a movement of the Sutlej slowly northward and sudden movements to the south to occupy the palaeochannel P in Fig.5.4 and then to the north to take up the present position in fairly recent times. For such drastic changes, no historical evidence is available.

The above discussion also implies that the Yamuna fault became active about 5000 B.P. and the Yamuna river shifted from a position of a tributary of the Indus System to the present course and joined the Ganga river.

3. Last phase starts at about the time of 3500 B.P. It is marked by the end of lacustrine sedimentation, covering of the area of units Basin with Marl and Fluvioaeolian Plain with a

thin sheet of sediment probably by a stream flowing along the present Chatuang rivulet and later reworking these areas and the Aeolian Plain by the wind. As mentioned below, the Sutlej which formed a tributary of the Ghagger, shifted away to form an independent tributary of the Indus during this process, consequently the Ghagger had a drastic decrease in discharge, abandoned large parts of the floodplain and occupied a much smaller part of it. In the north, the Older Piedmont got slightly tilted as and uplifted as suggested by the nearly parallel incised drainage. This tilt was probably due to movement along the Foothill Fault in the northeast and slight warping at the southwestern margin of the Older Piedmont. It resulted in erosion in parts of the Older Piedmont and start of deposition along the Younger Piedmont. The Younger Piedmont sediments have prograded over the Drishadvati Plain and Karnal and Kaithal Upland Plains. Thus at this time, soils of Q_2 members of soil-chronosequence started developing.

The Panjab (India) region reacted differently during the above mentioned tectonic movement affecting the Older Piedmont. It broke loose from the Haryana block along the Ghaggar Fault and tilted northwestward shifting the river Sutlej in the process. This tilting continued till about 1300 A.D., when it came to occupy the present course (Pal et al., 1980, p.325). Thus the Ghaggar Fault was active from 1500 B.C. to 1300 A.D. Since then a slight uplift of the Panjab region has led to entrenchment of the floodplain of the Sutlej. Study of the Landsat imageries indicates that during the northward shift, change of channel pattern from multithread braided stream to single thread straight or meandring stream for the Sutlej took place almost at the same distance from Ropar, where it debouches into the plains (Fig. 5.4). This can be intrerpreted to suggest that there was no change in the hydrologic regime of the river and also no significant change in climate during this period.

Filling up of the Basin with Marl and later reworking of the alluvial deposits by wind in the southwestern regions of Haryana coincides with a tectonic event leading to shifting away of the course of large Sutlej river from this general area. Probably this tectonic event is also the cause of the above geomorphic changes and rather than a change in climate.

In summary, the development of soils and landforms of Haryana, can be best explained by taking into account regional aspect into consideration and tectonics resulting in changes in river courses.

5.7. CONCLUSIONS

Following are the salient conclusions:

i. Thirteen geomorphic units have been identified and delineated on the map using various remote sensing techniques, field work and published literature. The geomorphic units are: (a) Siwalik Hills, (b) Aravalli Hills, (c) Old Sutlej Plain, (d) Aeolian Plain , (e) Basin with Marl (f) Older Piedmont, (g) Younger Piedmont, (h) Yamuna Floodplain, (i) Ghagger Floodplain, (j) Kaithal Upland Plain, (k) Karnal Upland Plain, (l) Drishadvati Plain and (m) Fluvio-Aeolian Plain.

ii. Pearson product correlation matrix calculated for 27 variables comprising field properties, total major and trace element contents, molar ratios and clay mineral contents for 183 soil samples suggests that soil properties are highly interrelated and variables can be arranged into four groups of interrelated variables. These groups are interpreted to indicate (a) degree of development of soil-profile, (b) $CaCO_3$ accummulation, (c) soil salinity and (d) clay mineral contents.

iii. Major clay minerals identified are illite, kaolonite and vermiculite and minor amounts of montmorillonite and illite-chlorite mixed layer clays occur in the soils of the area. Semi-quantitative analysis of these minerals reveals that their contents donot show any relationship with depth or geomorphic units. Illite shows antipathic relationship with kaolinite and chlorite, and positive correlation with clay content.

iv. Silt+clay content, Fe_2O_3 and Al_2O_3 accummulation indices (calculated in a similar way as clay index of Lavine and Ciolkosz, 1983), presence and absence of $CaCo_3$ concretions and oxidation mottling/Fe-Mn concretions, and micromorphological aspects such as degree of development of pedality, grain structure and ferri-argillans are all used in an integrated way to know the development of profiles of soils of different geomorphic surfaces and to construct a soil-chronosequence for the area of study.

v. Soils of different geomorphic units can be classified into three members Q_1 (1000 B.P.), Q_2 (3500 B.P.) and Q_3 (5000 B.P.) of the post incisive soil- chronosequence. Soils of different geomorphic units included in the various members are: Q_1-Yamuna Floodplain, Q_2-Younger Piedmont, Fluvio-aeolian Plain and Ghagger Floodplain and top portion of the Basin with Marl, and Q_3Karnal and Kaithal Upland Plains, Basin with Marls (Paleolacustrine Marls only) and Older Piedmont.

vi. Five major faults recognised in the area of investigation are the Main Boundary Fault, Foothill Fault (forming contact of the Siwaliks with Indogangetic Plains), Southern Boundary Fault (southern contact of the Indogangetic Plains with the Aravallis), Ghagger Fault and Yamuna Fault. Evolution of the soils and landforms suggests that the Yamuna Fault was active about 5000 B.P. causing change of course of the Yamuna from southwest to south. The Ghagger Fault and Foothill Fault become active about the time of 3500 B.P. The Ghagger Fault continued its activity till about 1300 A.D. and was responsible for the shifting away of the Sutlej river from a tributary of the Ghaggar to its present course.

vii. Tectonism has played a significant role in shifting of river courses and development of landforms and soils of the study area and climate seems to have remained almost similar to the present since about 5000 B.P.

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APPENDIX I

PEDON	LOCATION	LONGITUDE	LATITUDE
BASIN WITH MARL			
M1	Riwasa (Bhiwani)	76° 0' 00''	28° 43' 0''
M2	Birohar (Bhiwani)	76° 0 22' 30''	28° 35' 48''
OLDER PIEDMONT PLAIN			
P1	Gopal Mohan (Near village Morani, Tahsil-Jagadhari, (Ambala)	77° 18' 30''	30° 19' 00''
P2	2km from Sahzadpur on Sahzadpur-Rampur road	77° 01' 30''	30° 28' 00''
P3	Near village Bilaspur (Ambala)	77° 17' 00''	30° 16' 30''
YOUNGER PIEDMONT PLAIN			
YP1	Village Chandakheri (Ambala)	77° 17' 45''	30° 17' 30''
YAMUNA FLOODPLAIN			
Y1	Village Kishanpura near Khizababad (AMBALA)	77° 29' 10''	30° 17' 30''
Y2	1/2 km from village Navel (Karnal)	77° 08' 00''	29° 46' 46''
Y3	Village Murthal (4km from Sonipat)	77° 10' 4.8''	29° 02' 25''
GHAGGER FLOODPLAIN			
G1	1/2 km from Jamekeswar temple, Narayangarh (Ambala)	77° 08' 12''	30° 29' 40''
G2	Near Urlana (Kaithal)	76° 11' 30''	29° 57' 00''
KAITHAL UPLAND PLAIN			
K1	3 km from Kaithal on Kaithal-Thaneswar road	76° 25' 30''	29° 51' 00''
K2	1/2 km from Badi-Ghaso (Jind)	76° 10' 30''	29° 32' 25''
K3	10 km N of Jind, village Kat-kalan	76° 16' 30''	29° 31' 30''
K4	Siswal (Hissar), an archaeological site	75° 30' 45''	29° 13' 00''
KARNAL UPLAND PLAIN			
R2	Behind CSSRI agriculture farm, Gudah (Karnal)	76° 56' 00''	29° 30' 00''

R3	Village Gudah (Karnal)	76° 57′ 30″	29° 29′ 30″
R4	Village Kalyana(Panipat)	76° 53′ 24″	29° 18′ 06″
R5	1/2 km from pedon R3	76 03′ 24″	29° 16′ 30″
R6	Village Dhigal(Jhajjar-Rohtak road)	76° 38′ 10″	28° 45′ 54″
R7	1/2 km from pedon R5	76° 38′ 40″	28° 45′ 40″
R8	1/2 km from village Badli (Jhajjar)	76° 43′ 45″	28° 34′ 02″
R9	Village Badli (Jhajjar)	76° 43′ 45″	28° 34′ 00″

DRISHADVATI PLAIN

D1	Village Bastali on Karnal -Kaithal road	76° 43′ 30″	29° 44′ 10″
D2	1/2 km from Nisang bus stand on Nisang-Kaithal road.	76° 45′ 30″	29° 41′ 20″
D3	Village Jalalpur, 1/2 km from Jind.	76° 17′ 40″	29° 18′ 30″
D4	1.5 km from Narnaund (Hansi)	76° 06′ 40″	29° 12′ 20″
D5	2.5 km west from Narnaund	76° 05′ 42″	29° 12′ 00″
D6	2 km from chanut on Hansi -Barwala road.	75° 47′ 40″	29° 12′ 30″
D7	3oo m from village Bhiwani-Rohila (Hissar)	75° 37′ 02″	29° 03′ 36″
D8	Village Karori (8 km from Hissar on Hissar-Bala-samund road)	75° 36′ 35″	29° 06′ 56″

FLUVIO-AEOLIAN PLAIN

F1	Mithathal (Bhiwani)	76° 11′ 00″	28° 52′ 50″
F2	8.3 km from Bhiwani on Bhiwani-Tosam road	76° 04′ 00″	28° 49′ 00″

APPENDIX II

FIELD DESCRIPTION OF PEDONS

AP1.1 BASIN WITH MARL

Pedon : # M1
Classification : Coarse loamy Typic Palaeorthids
Location : Riwasa (Bhiwani)
Date of examination: 2/4/86
Landform : Basin
Landuse : Nil
Climate : Semi-arid to arid
Present material : Alluvium
Hydrology (a) Drainage - Well drained
(b) Depth of groundwater= at higher depth.
Moisture condition in profile : Dry throughout
Evidence of erosion : Nil
Presence of salt/alkali: Nil
Human influence : Nil

Horizon	Depth	Morphological description
A	0-25	Light yellowish brown (10YR 5/4, d) and brown (10YR, 5/3, m); sandy loam; friable; structureless ;friable (dry and moist);slightly-sticky, slightly-plastic; common medium roots; strong effervescence; gradual wavy boundary.
C1	25-50	Dark yellowish brown (10YR 4/3, d) and darkish brown (10YR 4/3, m); sandy loam; subangular blocky ; slightly-sticky, slightly-plastic (wet); friable (moist); few fine roots.
C2	50-75	Light yellowish brown (10YR 5/3, m) and light yellowish brown 10YR 6/3, d); sandy loam; hard (dry); angular blocky; slightly-sticky, slightly-plastic (wet); friable (moist); common fine interstital pores; few fine roots; strongly calcareous ; gradual wavy boundary.
C3	75-150	Grayish white (10YR 8/2, d); loam; massive thick deposition of lacustrine marl (mainly calcium carbonate i.e more than 65%); hard (dry), plastic (wet), medium to coarse voids, many vughs and channels; vughs are filled with calcium carbonate rich material; features related to extensive animal activity; channels are filled with loose soil-matrix material;presence of ostrocoda fossils; violent effervescence.

AP1.2 BASIN WITH MARL

Pedon : #M_2
Classification : Coarse loamy Typic Ustochrepts

Location : 2 km north of Birohar (Bhiwani)
Date of examination: 3/4/86
Landform : Basin
Landuse : Sugarcane, wheat and gram in nearby areas.
Climate : Semi-arid to arid
Present material : Alluvium
Hydrology (a) Drainage - Well drained
(b) Depth of groundwater= 8 m.
Moisture condition in profile : slightly moist above kankars.
Evidence of erosion : Nil
Presence of salt/alkali: Nil
Human influence : Nil

Horizon	Depth	Morphological description
A	0-10	Light yellowish brown (10YR 5/4, d) and brown (10YR 5/3, m); loam; friable; subangular blocky ;friable (moist); non-sticky, slightly-plastic (wet); common very fine roots; strong effervescence; gradual wavy boundary.
C1	10-45	Yellowish brown (10YR 4/3, d) and darkish brown (10YR 4/3, m); loam; subangular blocky ; non-sticky, slightly-plastic (wet); slightly-friable (moist); very fine roots; strongly calcareous ; violent effervescence; gradual wavy boundary.
C2	45-100	Dark whitish gray (10YR 7/2, m); sandy loam; massive structure; hard (dry); slightly-plastic (wet); common coarse tubular and fine interstital pores; few fine roots; thick deposition of lacustrine marl; channels are filled with loose soil matrix material; lacustrine marl is softer than pedon # M1; violent effervescence.

AP1.3 OLDER PIEDMONT PLAIN

Pedon #P1
Classification : Coarse loamy Udic Ustochrepts.
LOcation : 2 km away from Sahzadpur on Sahzadpur-Rampur road.
Date of examination: 5/1/87
Landform : Dissected Piedmont plain
Landuse : Sugarcane, mustard, wheat.
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Good;
(b) Depth of groundwater= 20m.
Moisture condition in profile : Slightly moist
Evidence of erosion : Dissected topography
Presence of salt/alkali: Nil
Human influence : Nil

Hor-	Depth	Morphological description

izon	cm)	
A	0-18	:Light yellowish brown (10YR 6/4, d), loam, hard (dry) subangular blocky, slightly sticky, slightly plastic, few, coarse vertical and common, medium interstatial pores, many medium, few fine roots; gradual wavy boundary.
B	18-58	Brown to darkbrown (10YR 4/3, m), silt-loam, friable (moist), slightly sticky, slightly plastic, common medium vertical and common medium to fine interstatial pores, gradual wavy boundary.
B12	58-102	Brown to darkbrown (10YR 4/3, m), silt loam, friable (moist), common to medium interstatial pores, many fine roots; few ferro-manganese concretions, gradual wavy boundary.
B21	102-155	Yellowish brown (10YR 5/4, m), silty clay loam, friable (moist), subangular blocky, slightly sticky and slightly plastic, common medium to fine interstatial pores with random vertical pores, few fine roots, few ferro-manganese concretions, common medium dark yellowish brown (10YR 4/6) mottles are distinct, gradual wavy boundary.
B22	155-175	Two colours, dark yellowish brown (10YR 4/3, m) and yellowish brown (10YR 5/4, m), silty clay, friable (moist), slightly sticky, slightly plastic, common fine vertical and interstatial pores, very few fine roots, few fine to medium, dark yellowish brown (10YR 4/6) mottles and faint clear smooth boundary.
B3	175-187	Two colours, yellowish brown (10YR 5/4,m) and dark yellowish brown (10YR 4/4), friable (moist), loam, subangular blocky, slightly sticky, slightly plastic to non-plastic, common fine interstatial pores, very few fine roots, clear smooth boundary.
C	187-202	Yellowish brown (10YR 5/6, m), sandyloam, friable(moist), structureless, non-sticky, non-plastic, common fine interstatial pores.

AP1.4 OLDER PIEDMONT PLAIN

Pedon #P2
Classification : Fine loamy Typic Ustochrepts.
LOcation : Village Gopal Mohan, near village Mohari, Tahsil.Jagadhari(Ambala)
Date of examination: 26/12/86
Landform : Dissected Piedmont plain
Landuse : Sugarcane, wheat, bajra.
Climate : Semi-arid
Present material : Alluvium

Hydrology (a) Drainage - Well-drained
(b) Depth of groundwater=upland-50m, lowland-30m.
Moisture condition in profile : moist after 10cm.
Evidence of erosion : Regional E3, particular E.
Presence of salt/alkali: Nil
Human influence : Brick-klin.

Horizon	Depth (cm)	Morphological description
A	0-10	Brown (10YR 5/3, d), (10YR 3/3, m), sandy loam, subangular blocky, slightly sticky, non-plastic, fine and very fine interstatial pores, no effervesence, clear, smooth boundary, medium roots are abundent.
B21	10-33	Dark brown (10YR 2.5/3), loam, subangular blocky, slightly sticky, plastic, fine and very fine interstatial pores, no effervesence, common fine roots; gradual wavy boundary.
B22	33-120	Dark brown (10YR 3/3, m), sandyloam, subangular blocky, slightly sticky, plastic, fine and very fine interstatial pores; no effervescence; few, fine roots; dark brown (7.5YR 3/3), many coarse, faint, mottling; few, Fe/Mn concretions, gradual wavy boundary.
B31	120-155	Dark brown (10YR 3/3, m); sandy loam; subangular blocky; slightly sticky, slightly plastic; fine and very fine interstatial pores; no effervescence; dark brown(7.5YR 3/3), common, fine, Fe/Mn concretions; clear smooth boundary.
B32	155-180	Dark brown(10YR 3/3, m); sandy loam; subangular blocky, non-sticky, non-plastic; fine interstatial pores; no effervescence; dark brown (7.5YR 3/3), many, fine, Fe/Mn concretions; clear smooth boundary.
C	180-210	Dark brown (10YR 4/4, m); sandy loam, subangular blocky; non-sticky, non-plastic; fine interstatial pores; no effervescence.

AP1.5 OLDER PIEDMONT PLAIN

Pedon #P3
Classification : Fine loamy Typic Ustochrepts.
LOcation : Near Bilaspur village, district Ambala.
Date of examination: 26/12/86
Landform : Non-Dissected Piedmont plain
Landuse : Sugarcane, Bajra, wheat.
Climate : Ustic
Present material : Alluvium

Hydrology (a) Drainage - Well drained.
(b) Depth of groundwater= 25 m.
Moisture condition in profile : Slightlt moist
Evidence of erosion : Nil
Presence of salt/alkali: Nil
Human influence : Nil

Hor-izon	Depth cm)	Morphological description
A	0-18	Dark brown (10 YR 4/4), Sandy loam, subangular blocky; slightly sticky, slightly plastic; fine and veryfine interstatial pores; common, fine; common, medium roots; no effervescence; clear smooth boundary.
B1	18-46	Yellowish brown (10 YR 5/4); loam; subangular bloccky; slightly sticky, slightly plastic; fine and very fine interstatial pores; few, fine Fe/Mn concretions; no effervescence; gradual smooth boundary.
B2	46-89	Dark brown (10 YR4/4); loam; subangular blocky ; slightly sticky, slightly plastic; fine and very fine interstatial pores; few fine roots; common fine Fe/Mn concretions; no effervescence; gradual smooth boundary; sand pockets.
B3	89-108	Dark brown (10 YR4/4); sandy loam; subangular blocky ; slightly sticky plastic;fine and very interstatial pores; common fine Fe/Mn concretions; sand pockets; no effervescence; gradual smooth boundary.
C	108-150	Dark brown (10 YR4/4); sandy loam; subangular blocky; slightly sticky, slightly plastic; fine and very fine interstatial pores; common fine Fe/Mn concretions; medium sand pockets; no effervescence.

AP1.6 Younger PIedmont

Pedon : #YP1
Classification : Coarse loamy Udic Ustochrepts.
LOcation : Village Chandakheri (Ambala)
Date of examination: 4/1/87
Landform : related with the Saraswati river system.
Landuse : Sugarcane, Mustard, wheat.
Climate : Udic to Ustic
Present material : Alluvium
Hydrology (a) Drainage - Moderately well drained.
(b) Depth of groundwater= 5 m.
Moisture condition in profile : Slightlt Moist below 10cm depth.
Evidence of erosion : Nil
Presence of salt/alkali: Nil

Human influence : Cultivated

Hor-izon	Depth cm)	Morphological description
AP	0-8	Vary pale brown (10 YR 7/4, d), Yellowish brown (10 YR 5/4, m); Sandy loam; friable (dry), loose soil; subangular blocky; non-sticky, non-plastic; medium to fine interstatial pores; medium to fine roots; no effervescence; clear smooth boundary.
AP2	8-25	Yellowish brown (10 YR 4.5/4, m); sandy loam; subangular bloccky; non-sticky, non-plastic; few coarse to medium and common fine interstatial pores; no effervescence; clear smooth boundary.
B21	25-539	Yellowish brown (10 YR4.5/4); sandy loam; friable (moist); subangular blocky ; slightly sticky, slightly plastic; few coarse to medium vertical channels and common medium to fine interstatial pores; very few coarse and few fine roots; no effervescence; clear smooth boundary;
B22	53-72	Yellowish brown (10 YR4.5/4, m); and pale brown (10 YR 6/3, two colours of soil matrix; sandy loam; subangular blocky ; slightly sticky plastic;few coarse vertical and common, medium to fine interstatial pores; very few fine roots; Fe/Mn concretions, about 10-15% by volume; common medium dark brown (10 YR 3/4) oxidation mottles; no effervescence; gradual wavy boundary..
B31	72-123	Yellowish brown (10 YR4.5/4, m); and pale brown (10 YR6/3, m), two colours of soil matrix;sandy loam; subangular blocky; slightly sticky, slightly plastic; few coarse vertical channels and common medium to fine interstatial pores; common medium Fe/Mn concretions,about 15% by volume, percentage is increasing downward; common medium, dark brown (10 YR 3/4) oxidation mottles, distinct; no effervescence; gradual wavy boundary.
B32	122-170	Two colours of soil-matrix i.e (Yellowish brown, 10 YR 4.5/4/, m and pale brown, 10 YR6/3, m), percentage of yellow patches by volume is higher than above mentioned horizons; loam; subangular blocky; slightly sticky, slightly plastic; coarse ferro-manganese concretion, about 20% by volume; few coarse and common medium size dark brown (10 YR 3/4)oxidation mottles are distinct

AP1.7 YAMUNA FLOODPLAIN

Pedon # Y1

Classification : Coarse loamy Udic Ustochrepts.

LOcation : Village Kishanpura near Khizababad (Ambala)

Date of examination: 4/1/87
Landform : Yamuna river system
Landuse : Sugarcane, mustard, wheat.
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Good;
(b) Depth of groundwater= 25m.
Moisture condition in profile : Slightly moist
Evidence of erosion : Nil
Presence of salt/alkali: Nil
Human influence : Cultivated land

Horizon	Depth cm)	Morphological description
Ap	0-8	Light yellowish brown (10YR 6/2, d), loam, slightly hard (dry) subangular blocky, slightly sticky, slightly plastic; common, medium to fine interstatial pores, common medium and many fine roots; gradual wavy boundary.
AB	8-33	Dark brown (10YR 4/3, m); loam; slightly hard (moist), subangular blocky; non- sticky, non-plastic; few medium to fine interstatial pores; common fine roots; presence of coarse fragments (about 5% by volume); gradual wavy boundary.
B3	33-73	Dark brown (10YR 4/3, m), sandy loam, friable (moist), non-sticky, non-plastic; subangular blocky to structure less; many vertical and medium interstatial pores, very few very fine roots; coarse fragments (10% by volume); gradual wavy boundary.
C1	73-140	Dark brown (7.5YR 3/3, m), sandy loam; friable (moist), subangular blocky, non-sticky and non-plastic, common medium to fine interstatial pores; very coarse sand as the pieces of rock fragments.
C2	140-150	Layer with maximum percentage of boulders by volume.

AP1.8 YAMUNA FLOODPLAIN

Pedon #Y2
Classification : Coarse loamy Fluvauentic ? Ustochrepts.
Location : 1/2 km (355^{o}) from village Navel bus stand (Karnal)
Date of examination: 9/4/86
Landform : Yamuna river system
Landuse : Peddy, Sugarcane, pulses.
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Good;
(b) Depth of groundwater= 7m.
Moisture condition in profile : Moist

Evidence of erosion : Nil
Presence of salt/alkali: Nil
Human influence : Cultivated land

Horizon	Depth cm)	Morphological description
Ap1	0-10	Light yellowish brown (10YR 6/2, d), sandy loam, slightly hard (dry); subangular blocky, slightly sticky, slightly plastic (wet); slightly friable (moist); common fine interstatial pores, weak effervescence; gradual wavy boundary.
AP	10-20	Light yellowish brown (10YR 6/3, m); sandy loam; subangular blocky; non- sticky, slightly plastic (wet); few fine interstatial pores; common fine roots; weak effervescence; gradual wavy boundary.
B	20-90	Dark yellowish brown (10YR 4/3, m), silt loam, non-sticky, slightly-plastic (wet); friable (moist); subangular blocky; common medium tubular pores along roots; few very fine roots; common medium oxidation mottling dark brown (10 YR3/2); weak effervescence; gradual wavy boundary.
C1	90-152	Dark yellowish brown (10YR 4/2, m), silt loam; friable (moist), subangular blocky, non-sticky and non- plastic (wet), common fine interstatial pores; coarse calcium carbonate concretions ; dark brown (10YR 3/2) oxidation mottling, distinct; weak effervescence; gradual wavy boundary.
C2	152-180	Dark yellowish brown (10YR 4/3); loamy sand; subangular blocky; slightly plastic (wet); slightly friable (moist); medium to fine interstatial pores; dark brown (10YR 3/2), common, fine mottling distinct; weak effervescence; gradual wavy boundary.

AP1.9 YAMUNA FLOODPLAIN

Pedon #Y3
Classification : Coarse loamy Typic Ustochrepts.
Location : Village Murthal (6 km from Sonipat on Panipat-Sonipat road)
Date of examination: 8/4/86
Landform : Yamuna river system
Landuse : Peddy,Sugarcane, pulses.
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Good;
(b) Depth of groundwater= 7 to 9 m.
Moisture condition in profile : slightly moist
Evidence of erosion : Nil
Presence of salt/alkali: Nil

Human influence : Cultivated land

Horizon	Depth cm)	Morphological description
Ap	0-15	Light yellowish brown (10YR 6/2, d), loamy sand; subangular blocky,non-sticky, slightly plastic (wet); slightly friable (moist); common medium interstatial pores,common medium and fine roots; weak effervescence; gradual wavy boundary.
AC	15-70	Brown to darkbrown (10YR 4/3, m); sandy loam; subangular blocky; non- sticky, slightly plastic (wet); friable (moist) few fine interstatial pores; no effervescence; gradual wavy boundary.
C1	70-108	Dark yellowish brown (10YR 4/4, m), loamy sand; non-sticky, slightly-plastic (wet); friable (moist); subangular blocky; common fine to very fine interstitial pores; no effervescence; gradual wavy boundary.
C2	108-180	Dark brown to brown (10YR 4/3, m), sandy loam; friable (moist), subangular blocky, non-sticky and slightly- plastic (wet), common fine interstatial pores; no effervescence; gradual wavy boundary.

AP1.10 GHAGGER FLOODPLAN

Pedon #G1
Classification : Coarse loamy Udic Ustochrepts.
Location : 1/2 km from Jamkeswar temple, Narayangarh (Ambala)
Date of examination: 5/1/87
Landform : Floodplain
Landuse : Sugarcane, wheat and mustard.
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Well drained
(b) Depth of groundwater= 13 m.
Moisture condition in profile : Moist below 10 cm
Evidence of erosion : Nil
Presence of salt/alkali: Nil
Human influence : Cultivated Land

Horizon	Depth	Morphological description
AP	0-10	Brownish yellow (10YR 6/6, d); sandy loam; hard (dry); subangular blocky; non-sticky,non-plastic; few coarse and many medium vertical and interstitial pores; common medium roots; no effervescence; gradual wavy boundary.

AB	10-40	Dark yellowish brown (10YR 4/4, m); loam; subangular blocky ; slightly-sticky, slightly plastic (wet); friable (moist); few coarse and common medium interstatial pores; common fine roots; no effervescence; gradual wavy boundary.
B21	40-63	Dark yellowish brown (10YR 4/4, m); loam; slightly-sticky, slightly-plastic (wet); slightly friable (moist); subangular blocky; common medium to fine interstital pores; no effervescence; common fine roots; clear smooth boundary.
B22	63-121	Dark yellowish brown (10YR 4/4, m), loam; subangular blocky; non-sticky and slightly- plastic (wet), slightly friable (moist); common medium to fine interstatial pores; common very fine roots; coarse to fine dark brown (10YR 3/3) oxidation mottles and Fe/Mn concretions; no effervescence; clear smooth boundary.
C	121-180	Light yellowish brown (10YR 6/4, m) and dark yellowish brown (10YR 4/4, m); loam; subangular blocky; non-sticky and slightly plastic (wet); slightly friable (moist), common medium to fine interstitial pores; common medium dark brown (10YR 3/3) oxidation mottles, 10% by volume and Fe/Mn concretions.no effervescence.

AP1.11 GHAGGER FLOODPLAN

Pedon #G2
Classification : Coarse loamy Ustic Ustochrepts.
Location : Near Urlana
Date of examination: 27/12/86
Landform : Floodplain
Landuse : Sugarcane, wheat and mustard.
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Well drained
(b) Depth of groundwater= 19-21m.
Moisture condition in profile : Moist
Evidence of erosion : Nil
Presence of salt/alkali: Non-saline
Human influence : Cultivated land

Horizon	Depth	Morphological description
AP	0-26	Yellowish brown (10YR 5/4, m); loam; subangular blocky; non-slightly-sticky,slightly-plastic; few medium and common fine interstitial pores; many medium roots; moderate effervescence; clear smooth boundary.

B21	26-66	Dark yellowish brown (10YR 4/4, m); loam; subangular blocky ; slightly-sticky, slightly plastic (wet); friable (moist); few medium and common fine interstatial pores; common fine roots; moderate effervescence, 5% by volume soft calcium carbonate concretions; gradual smooth boundary.
B22	66-102	Dark yellowish brown (10YR 4/4, m); silt loam; slightly-sticky, slightly-plastic (wet); slightly friable (moist); subangular blocky; few medium and common fine interstital pores; moderate effervescence; few fine roots; clear smooth boundary.
C	102-127	Yellowish brown (10YR 5/4, m); silt loam; subangular blocky; slightly-sticky and slightly-plastic (wet), slightly friable (moist); few medium and common fine interstatial pores; 30-35% coarse, hard calcium carbonate concretions; violent effervescence.

AP1.12 KAITHAL UPLAND PLAIN

Pedon : #K1
Classification : Fine loamy Natric Ustochrepts.
Location : 3 km from Kaithal, right side of Thaneswar- Kaithal road.
Date of examination: 27/12/86
Landform : Plain
Landuse : Peddy, sugarcane and wheat (surrounding areas).
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Good
(b) Depth of groundwater= 3-4 m.
Moisture condition in profile : Slightly moist.
Evidence of erosion : Nil
Presence of salt/alkali: Strongly salt-affected
Human influence : Nil

Horizon	Depth	Morphological description
A11	0-7	Pale brown (10YR 6/3, d) and brown (10YR 4/3, m); loam; platy structure; slighty-sticky, slightly-plastic (wet); few medium and common fine interstitial pores , common fine roots; strong effervescence; gradual wavy boundary.
A12	7-29	Brown (10YR 4/3, m); silt loam; platy structure; slightly-sticky, slightly plastic (wet); friable (moist); few coarse, few medium and

		fine interstatial pores; few fine and many medium roots; moderate effervescence; gradual wavy boundary.
B21	29-43	Dark brown (10YR 3/3, m);silt loam; slightly-sticky, slightly-plastic (wet); slightly friable (moist); subangular blocky; few fine roots; common fine interstital pores; moderate effervescence; clear smooth boundary.
B22	43-60	Brown (10YR 4/3, m), silt loam; angular blocky; slightly-sticky and plastic (wet),friable (moist); common fine interstatial pores; few coarse and fine roots; strong effervescence; gradual wavy boundary.
B31	60-102	Brown (10YR 5/3, m); silt loam; subangular blocky; slightly sticky and slightly plastic (wet); friable (moist), few medium and common fine to very fine interstitial pores; strong effervescence; gradual wavy boundary.
B32	102-153	Brown (10YR 5/3, m); silt loam, subangular blocky; slightly sticky and slighty plastic (wet); few coarse, few medium and common fine interstitial pores; strong effervescence; 25-30% medium hard calcium carbonate concretions; gradual wavy boundary and features related to biological activity.
C	153-170	Yellowish brown (10YR 5/4, m); silt loam; massive; few fine interstital pores; slightly-sticky and slightly plastic (wet); violent effervescence.

AP1.13 KAITHAL UPLAND PLAIN

Pedon : #K2
Classification : Fine loamy Natric Ustochrepts.
Location : 1/2 km from Badi-Ghaso,near Narwana (Jind).
Date of examination: 23/3/86
Landform : Plain
Landuse : Gram, bajra, mustard and wheat.
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Moderately well drained
(b) Depth of groundwater= 15-20 m.
Moisture condition in profile : Slightly moist.
Evidence of erosion : Nil
Presence of salt/alkali: Non-saline
Human influence : Cultivated land

Hor-	Depth	Morphological description

izon

AP	0-10	Brown (10YR 5/3, m) silt loam; platy structure; slighty-sticky, slightly- plastic (wet), friable (moist); few medium and common fine interstitial pores , common fine roots; moderate effervescence; gradual wavy boundary.
B1	10-38	Brown (10YR 4/3, m); silt loam; platy structure; slightly-sticky, slightly plastic (wet); friable (moist); common fine interstatial pores; common fine roots; moderate effervescence; gradual wavy boundary.
B21	38-78	Dark yellowish brown (10YR 3/4, m) loam; slightly-sticky, slightly-plastic (wet); slightly friable (moist); platy structure; few fine roots; common fine interstital pores; strong effervescence; gradual wavy boundary.
B22	78-115	Brown (10YR 3.5/3, m), clay loam; platy structure; non-sticky and slightly- plastic (wet),friable (moist); common fine interstatial pores; few coarse and fine roots; strong effervescence; 20% by volume calcium carbonate concretions; gradual wavy boundary.
B3	115-180	Yellowish brown (7.5YR 4/3, m); loam; subangular blocky; slightly sticky and slightly plastic (wet); few fine interstitial pores; violent effervescence.

AP1.14 KAITHAL UPLANDPLAN

Pedon : #K3
Classification : Coarse loamy Typic Ustochrepts.
Location : 10 km North of Jind (village Kat-Kalan)
Date of examination: 1/1/87
Landform : Plain
Landuse : Sugarcane, wheat and bajra.
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Moderately well drained
(b) Depth of groundwater= 20 m.
Moisture condition in profile : Slightly moist
Evidence of erosion : Nil
Presence of salt/alkali: Non-saline
Human influence : Cultivated land

Horizon	Depth	Morphological description
AP	0-10	Light yellowish brown (10YR 6/4, d); sandy loam; friable; subangular blocky; non-sticky,non-

plastic; many medium to fine interstitial pores; few fine roots; moderate effervescence; gradual wavy boundary.

AC	10-30	LIght yellowish brown (10YR 6/4, m); sandy loam; subangular blocky ; non-sticky, non-plastic (wet); friable (moist); few common fine interstatial pores; few fine roots; moderate effervescence; gradual wavy boundary.
C1Ca	30-65	Light yellowish brown (10YR 6/4, m); loamy sand; non-sticky, non-plastic (wet); friable (moist); subangular blocky; few fine interstital pores; strongly calcareous about 20% by volume calcium carbonate concretions; gradual wavy boundary.
C2Ca	65-100	Pale brown (10YR 6/3, m); sandy loam; subangular blocky; non-sticky, non-plastic; strongly calcareous, abot 20% by volume calcium carbonate concretions; few fine to very fine interstitial pores; gradual wavy boundary.
C3Ca	100-135	Light yellowish brown (10YR 6/4, m), sandy loam; subangular blocky; non-sticky and slightly- plastic (wet), slightly friable (moist); few fine to very fine interstatial pores; about 40% by volume calcium carbonate concretions; gradual wavy boundary.
C4Ca	135-160	Light yellowish brown (10YR 6/4, m); sandy loam; subangular blocky; non-sticky and slightly plastic (wet); slightly friable (moist), common fine to very fine interstitial pores; about 40% by volume calcium carbonate concretions (layer no. 2); gradual wavy boundary.
C5Ca	160-185	Very pale brown (10YR 7/4, m); sandy loam; subangular blocky; slightly sticky and slightly plastic; common fine interstitial pores, strong effervescence.

AP1.15 KAITHAL UPLANDPLAN

Pedon : #K4

Classification : Coarse loamy Typic Ustochrepts.

Location : Siswal village (Hissar), an archaeological site

Date of examination:29/12/86

Landform : Plain

Landuse : Nil

Climate : Semi-arid

Present material : Alluvium

Hydrology (a) Drainage - Moderately well drained

(b) Depth of groundwater= 13 m.

Moisture condition in profile : Slightly moist
Evidence of erosion : Nil
Presence of salt/alkali: Non-saline
Human influence : An archaeological site

Horizon	Depth	Morphological description
A	0-11	Light gray (10YR 7/2, d) and brown (10YR, 5/3, m); sandy loam; friable; typical thick platy structure;friable (dry and moist);slightly-sticky, slightly-plastic; common medium interstitial pores; strong effervescence; gradual wavy boundary.
AC	11-45	Very pale brown (10YR 7/3, d) and darkish brown (10YR 4/3, m); sandy loam; angular blocky ; slightly-sticky, slightly-plastic (wet); friable (moist); few common common fine interstatial pores; strong effervescence; gradual wavy boundary.
C1	45-100	Brown (10YR 5/3, m) and light yellowish brown 10YR 6/3, d); silt loam; hard (dry); angular blocky; slightly-sticky, slightly-plastic (wet); friable (moist); common fine interstital pores; strongly calcareous ; clear smooth boundary.
C2	100-147	Very pale brown 7/3, m); sandy loam; slightly hard (dry); angular blocky; slightly sticky, slightly plastic;moderately calcareous, termite activity ; few coarse and common fine interstitial pores; gradual wavy boundary.
C3	147-247	Very pale brown (10YR 7.5/4 ,m); sandy loam; structureless, indurated grains;; non-sticky and non- plastic (wet), common fine interstatial pores; clear smooth boundary.
C4	247-285	Yellowish brown (10YR 5/4, m); sandy loam; subangular blocky; non-sticky and non- plastic (wet); slightly friable (moist), common fine interstitial pores; clear smooth boundary.
C5	285-306	Dark gray (10YR 4/1, m); sandy loam; subangular blocky; slightly sticky and slightly plastic; common fine interstitial pores, strong effervescence.
C6	306-400	Auger sample.

AP1.16 KARNAL UPLAND PLAIN

Pedon # R1
Classification : Coarse loamy Typic Ustochrepts.
Location : 1/2 km from Kachhwa bus stand (Karnal)
Date of examination: 9/4/86
Landform : Upland plain
Landuse : Peddy,Sugarcane, wheat, berseem.
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Good;
(b)Depth of groundwater= 7-8m.
Moisture condition in profile : Dry to slightly moist
Evidence of erosion : Nil
Presence of salt/alkali: Previously alkaline, presently non-alkaline after gypsum treatment by CSSRI, Karnal.
Human influence : Cultivated land

Horizon	Depth cm)	Morphological description
AP1	0-10	Light yellowish brown (10YR 6/3, m), clay; slightly hard (dry); subangular blocky, slightly sticky, slightly plastic (wet); slightly friable (moist); common fine to very fine interstatial pores; few fine roots; weak effervescence; smooth wavy boundary.
AP2	10-60	Light yellowish brown (10YR 6/3, m); silt- loam; subangular blocky; slightly-sticky, slightly plastic (wet); few fine interstatial pores; few fine roots; weak effervescence; gradual wavy boundary.
B2	60-225	Light yellowish brown (10YR 6/3, m);loam; slightly-sticky, slightly-plastic (wet); friable (moist); subangular blocky; fine interstital pores; weak effervescence; gradual wavy boundary.
C	225-300	Yellowish brown (10YR 6/4, m), sandy loam; subangular blocky; slightly-sticky and slightly-plastic (wet), common fine interstatial pores; weak effervescence; gradual wavy boundary.

AP1.17 KARNAL UPLAND PLAIN

Pedon # R2
Classification : Fine loamy Typic Natrustalfs.
Location : Behind CSSRI agriculture farm, village Gudah (Karnal)
Date of examination: 28/12/86
Landform : Upland plain

Landuse : Nil
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Imperfectly drained
(b) Depth of groundwater= 5-6m.
Moisture condition in profile : Moist
Evidence of erosion : Nil
Presence of salt/alkali: Strongly salt-affected.
Human influence : Barren land

Horizon	Depth cm)	Morphological description
A11	0-5	Very pale yellowish brown (2.5YR 7/4, d) and brown to dark brown (10YR 4/3, m); silt-loam; slightly hard (dry); subangular blocky, slightly sticky, slightly plastic (wet); slightly friable (moist); strongly calcareous; many very fine vertical and oblique discontineous pores; few fine roots; strong effervescence; smooth wavy boundary.
A12	5-24	Brown to dark brown (10YR 4/3, m); silt- loam; moderate, medium subangular blocky; sticky and plastic (wet); firm (moist); strongly calcareous; many very fine interstatial pores; few fine roots;strong effervescence; smooth clear boundary.
B1t	24-41	Dark yellowish brown (10YR 3/4, m);silt loam; very-sticky and plastic (wet); firm (moist); strong medium to coarse subangular blocky; strongly calcareous; very few very fine roots; patchy thin cutans; many very fine vertical and oblique discontineous pores;clear and smooth boundary.
B21t	41-81	Dark brown (10YR 3/3.5, m), silt loam; strongly developed medium to coarse subangular blocky; sticky and plastic (wet), strongly calcareous; many very fine vertical and oblique discontineous pores; clear smooth boundary.
B22t	81-104	Dark brown (10YR 4/3, m); silt loam; strongly developed coarse angular blocky; very firm (moist); very sticky and plastic; 4-7% of 5-15 mm size hard calcium carbonate concretions; thick contineous cutans;many very fine vertical and oblique discontineous inped pores; clear and wavy boundary.
B3Ca	104-117	Pale brown (10YR 6/3.5, m); silt loam; strong coarse angular blocky; very firm (moist), very sticky and plastic (wet); strongly calcareous; about 30% by volume of 50 mm size calcium carbonate concretions; thick contineous cutans; clear and smooth boundary.
CCa	117-150	Pale brown (10YR 6/3.5, m); silty clay loam;

moderate medium to coarse angular blocky; very firm (moist); sticky and plastic (wet); strongly calcareous; many very fine vertical and oblique discontineous inped pores.

AP1.18 KARNAL UPLAND PLAIN

Pedon # R3
Classification : Coarse loamy Typic Ustochrepts.
Location : Gudah village (Karnal)
Date of examination: 7/4/86
Landform : Upland plain
Landuse : Peddy,Sugarcane, pulses
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Good;
(b) Depth of groundwater= 15-20m.
Moisture condition in profile : Slightly moist
Evidence of erosion : Nil
Presence of salt/alkali: Non-saline
Human influence : Cultivated land

Horizon	Depth cm)	Morphological description
AP	0-10	Light yellowish brown (10YR 6/3, m); sandy loam ; subangular blocky, non-sticky, plastic (wet); slightly friable (moist); common medium to fine interstatial pores; common fine roots; moderate effervescence; gradual wavy boundary.
AB	10-45	Light yellowish brown (10YR 6/3, m); sandy- loam; subangular blocky; non-sticky, slightly plastic (wet); few fine interstatial pores; few very fine roots; moderate effervescence; gradual wavy boundary.
B	45-110	Light yellowish brown (10YR 6/3, m);snady loam; non-sticky, slightly-plastic (wet); slightly friable (moist); subangular blocky; fine interstital pores; sand pockets after 80 cm depth; few very fine roots; medium calcareous carbonate concretions; gradual wavy boundary.
C	110-180	Light yellowish brown (10YR 6/3, m), sandy loam; subangular blocky; non-sticky and slightly- plastic (wet), common fine to very fine interstatial pores; strong effervescence; gradual wavy boundary.

AP1.19 KARNAL UPLAND PLAIN

Pedon # R4
Classification : Coarse loamy Typic Ustochrepts.
Location : Village Bailana, 14 km from Panipat on

Panipat-Kohand(Karnak) road.
Date of examination: 8/4/86
Landform : Upland plain
Landuse : Barren land
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Good;
(b) Depth of groundwater= 35-40 m.
Moisture condition in profile : Moist
Evidence of erosion : Nil
Presence of salt/alkali: Saline
Human influence : Nil

Horizon	Depth cm)	Morphological description
A	0-10	Light whitish gray (10YR 7/3, d), sandy loam; subangular blocky/ structureless; non-sticky, slightly plastic (wet); friable (moist); common medium to fine interstatial pores; few fine roots; strong effervescence; gradual wavy boundary.
AC	10-42	Dark yellowish brown (10YR 4/3, m); loam; subangular blocky/structureless; non-sticky, slightly plastic (wet); few fine interstatial pores; strong effervescence; gradual wavy boundary.
C1	42-150	Dark yellowish brown (10YR 4/4, m); sandy loam; non-sticky, slightly-plastic (wet); friable (moist); subangular blocky; fine interstital pores; some sandy pockets; strong effervescence; gradual wavy boundary.
C2	150-180	Dark yellowish brown (10YR 4/4, m), sandy loam; subangular blocky; non-sticky and slightly- plastic (wet), common fine interstatial pores; strong effervescence; gradual wavy boundary.

AP1.20 KARNAL UPLAND PLAIN

Pedon # R5
Classification : Coarse loamy Typic Ustochrepts.
Location : 1/2 km from pedon # R4 and south of G.T.road.
Date of examination: 8/4/86
Landform : Upland plain
Landuse : Peddy,Sugarcane, wheat.
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Good;
(b) Depth of groundwater= 40-45 m.
Moisture condition in profile : Moist
Evidence of erosion : Nil
Presence of salt/alkali: Non-saline

Human influence : Cultivated land

Horizon	Depth cm)	Morphological description
AP	0-20	Whitish gray (10YR 6/3, m), silt loam; slightly hard (dry); subangular blocky, non- sticky, slightly plastic (wet); friable (moist); common medium interstatial pores; many medium roots; strong effervescence; gradual wavy boundary.
B1	20-90	Light yellowish brown (10YR 5/3, m); silt- loam; subangular blocky; non-sticky, slightly plastic (wet); medium iterstatial pores; many medium roots; strong effervescence; gradual wavy boundary.
B21	90-152	Dark yellowish brown (10YR 4/4, m);silt loam; non-sticky, slightly-plastic (wet); friable (moist); subangular blocky; fine interstital pores; many very fine roots; strong effervescence; gradual wavy boundary.
C	152-180	Dark yellowish brown (10YR 4/4, m), sandy loam; subangular blocky; non-sticky and slightly- plastic (wet), common fine to very fine interstatial pores; strong effervescence; gradual wavy boundary.

AP1.21 KARNAL UPLAND PLAIN (Rb)

Pedon # R6
Classification : Coarse loamy Udic Ustochrepts.
Location : Dhigal on Jhagger-Rohtak road.
Date of examination: 4/4/86
Landform : ------
Landuse : Nil
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Good;
(b) Depth of groundwater= 10 m.
Moisture condition in profile : Slightly moist
Evidence of erosion : Nil
Presence of salt/alkali: Slightly saline
Human influence : Nil

Horizon	Depth cm	Morphological description
AP11	0-20	Light yellowish brown (10YR 6/3, m), loam; subangular blocky, non-sticky, slightly plastic (wet); friable (moist); common coarse interstatial pores; common fine roots; strong effervescence; gradual wavy boundary.

A12	20-50	Brown (10YR 5/3, m); loamy sand; subangular blocky; non-sticky, slightly plastic (wet); friable (moist); coarse interstatial pores; common fine roots; strong effervescence and presence of calcium carbonate concretions; gradual wavy boundary.
B2	50-102	Brown (10YR 5/3, m);loam; non-sticky, slightly-plastic (wet); friable (moist); subangular blocky; common fine roots; common coarse to fine interstital pores; strong effervescence; gradual wavy boundary.
B3	102-140	Yellowish brown (10YR 5/4, m), sandy loam; subangular blocky; non-sticky and slightly- plastic (wet), common coarse to fine interstatial pores; strong effervescence; gradual wavy boundary.
C	140-180	Yellowish brown (10YR 5/4, m); silt loam; subangular blocky; non-sticky and slightly plastic (wet); friable (moist), very few medium roots; fine interstitial pores; strong effervescence.

AP 1.22 KARNAL UPLAND PLAIN (Rb)

Pedon # R6
Classification : Coarse loamy Udic Ustochrepts.
Location : Dhigal on Jhagger-Rohtak road (1/2 km from pedon # R6.
Date of examination: 4/4/86
Landuse : Peddy, sugarcane and wheat.
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Good;
(b) Depth of groundwater= 5 m.
Moisture condition in profile : Moist
Evidence of erosion : Nil
Presence of salt/alkali: Non - saline
Human influence : Cultivated land

Horizon	Depth	Morphological description
AP	0-10	Light yellowish brown (10YR 6/3, m), clay loam; subangular blocky, non-sticky, slightly plastic (wet); friable (moist); common medium interstatial pores; few fine roots; moderate effervescence; gradual wavy boundary.
AB	10-30	Brown (10YR 4/3, m); sandyloam; subangular blocky; non-sticky, slightly plastic (wet); friable (moist); common medium interstatial pores; few fine roots; moderate effervescence, gradual wavy boundary.
B21	30-107	Brown (10YR 4/3, m);loam; non-sticky, slightly-

		plastic (wet); friable (moist); subangular blocky; very few fine roots; medium coarse to fine interstital pores; moderate effervescence; gradual wavy boundary.
B22	107-162	Yellowish brown (10YR 5/4, m), sandy clay loam; subangular blocky; non-sticky and slightly- plastic (wet), common fine oxidation motteling; fine to very fine interstatial pores; strong effervescence; gradual wavy boundary.
C	162-180	Yellowish brown (10YR 5/4, m); loam; subangular blocky; non-sticky and slightly plastic (wet); friable (moist), very few very fine roots; fine to very fine interstitial pores; yellowish brown (10YR 4/4) medium, medium to fine oxidation mottling, distinct;strong effervescence.

AP 1.23 KARNAL UPLAND PLAIN (Rb)

Pedon # R7
Classification : Coarse loamy Udic Ustochrepts.
Location : 1/2 km from Badli bus stand (Jhajjar)
Date of examination: 5/4/86
Landuse : Peddy, sugarcane and wheat.
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Good;
(b) Depth of groundwater= 10 m.
Moisture condition in profile : Moist below 20 cm.
Evidence of erosion : Nil
Presence of salt/alkali: slightly - saline
Human influence : Cultivated land

Horizon	Depth	Morphological description
AP	0-15	Light yellowish brown (10YR 6/3, m), and Brown (10YR 4/3, m), sandy loam; subangular blocky, non-sticky, slightly plastic (wet); slightly friable (moist); fine interstatial pores; common fine roots; strong effervescence; gradual wavy boundary.
B2	15-50	Brown (10YR 4/3, m); sandyloam; subangular blocky; non-sticky, slightly plastic (wet); friable (moist); fine interstatial pores; common very fine roots; strong effervescence, gradual wavy boundary.
B3	50-100	Dark yellowish brown (10YR 4.5/3.5, m); sandyloam; non-sticky, slightly-plastic (wet); friable (moist); subangular blocky; common fine roots; common fine to very fine interstital pores; strong effervescence; gradual wavy boundary.
C	100-140	Whitish gray (10YR 6/3, m), silt loam;coarse to

medium calcium carbonate concretions; strong effervescence;

AP 1.23 KARNAL UPLAND PLAIN (Rb)

Pedon # R9
Classification : Coarse loamy Udic Ustochrepts.
Location : Village Murthal (6 km from Sonipat on Panipat - Sonipat road.
Date of examination: 8/4/86
Landuse : Peddy, sugarcane and pulses.
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Good;
(b) Depth of groundwater= 7-9 m.
Moisture condition in profile : Slightly moist
Evidence of erosion : Nil
Presence of salt/alkali: Nil
Human influence : Cultivated land

Horizon	Depth	Morphological description
AP	0-15	Light yellowish brown (10YR 6/2, m), loamy; subangular blocky, non-sticky, slightly plastic (wet); slightly friable (moist); common medium interstatial pores; medium fine roots; weak effervescence; gradual wavy boundary.
AC	15-70	Brown to dark brown (10YR 4/3, m); sandyloam; subangular blocky; non-sticky, slightly plastic (wet); friable (moist); few fine interstatial pores; no effervescence, gradual wavy boundary.
C1	70-108	Dark yellowish brown (10YR 4/4, m);loamy sand ; non-sticky, slightly-plastic (wet); friable (moist); subangular blocky; common fine to very fine interstital pores; no effervescence; gradual wavy boundary.
C2	108-180	Dark brown to brown (10YR 4/3, m), sandy loam; friable (moist), subangular blocky; non-sticky and slightly- plastic (wet), common fine interstatial pores; no effervescence; gradual wavy boundary.

AP1.25 DRISHADVATI PLAIN

Pedon # D1
Classification : Coarse loamy Udic Ustochrepts.
Location : 1/2 km north of village Bastali on Karnal-Kaithal road.
Date of examination: 3/1/87
Landform : Chataug river system
Landuse : Gram,peddy, sugarcane and wheat.

Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - medium
(b) Depth of groundwater= 13 m.
Moisture condition in profile : Slightly moist below 20 cm.
Evidence of erosion : Nil
Presence of salt/alkali: Non-saline
Human influence : Cultivated land

Horizon	Depth	Morphological description
AP	0-21	Very pale brown (10YR 7/4, d) and light yellowish brown (10YR 6/4, m); loam; hard (dry), friable (moist); angular blocky; slightlt-sticky, slightly plastic (wet); common coarse tubular pores and fine interstatial pores; few medium , common fine fibrous roots; moderate effervescence; gradual wavy boundary.
B1	21-59	Light yellowish brown (10YR 6/4, m); silt loam; subangular blocky to angular blocky; slightly-sticky, slightly plastic (wet); slightly friable (moist); common medium to fine interstatial pores; common fine roots; moderate effervescence; clear smooth boundary.
B21	59-72	Yellowish brown (10YR 5/4, m);silt loam; slightly-sticky, slightly-plastic (wet); slightly friable (moist); subangular blocky; common fine fine roots; medium fine interstital pores; moderate effervescence; clear smooth boundary.
B22	72-125	Yellowish brown (10YR 5/4, m), silt loam; subangular blocky; slightly-sticky and slightly-plastic (wet),firm (moist); common fine to very fine interstatial pores; common fine roots;common medium, dark brown (10YR 4/3) oxidation mottles, distinct, about 7% by volume; moderate effervescence; clear smooth boundary.
B23	125-152	Yellowish brown (10YR 5/4, m); clay loam; subangular blocky; sticky and slightly plastic (wet); firm (moist), common fine interstitial pores; very few very fine roots; few fine dark brown (10 YR 4/3) oxidation mottling, distinct; and about 7% by volume Fe/Mn concretions ; strong effervescence.
C	152-180	Varigated colours of soil-matrix, pale brown (10YR 6/3) patches and brownish yellow patches (10YR 6/8); silt loam; massive tending to subangular blocky; common fine to very fine interstital pores; about 7% by volume Fe/Mn concretions; moderately to strongly calcareous.

AP1.26 DRISHADVATI PLAIN

Pedon # D2
Classification : Coarse loamy Udic Ustochrepts.
Location : 1/2 km from Nisang bus stand on Nisang-Kaithal road.
Date of examination: 3/1/87
Landform : Chataug river system
Landuse : Gram, sugarcane and wheat.
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Good
(b) Depth of groundwater= 13 m.
Moisture condition in profile : Slightly moist below 10 cm.
Evidence of erosion : Nil
Presence of salt/alkali: Non-saline
Human influence : Cultivated land

Horizon	Depth	Morphological description
AP	0-10	Light yellowish brown (10YR 6/4, d) and dark yellowish brown (10YR 4/6, m); silt loam; friable (dry), friable (moist); angular blocky; sticky, non- plastic (wet); common fine interstitial pores , few medium and many fine roots; moderate effervescence; clear smooth boundary.
AB	10-39	Dark brown to brown (10YR 4.5/3, m); loam; subangular blocky ; slightly-sticky, slightly plastic (wet); firm (moist); common fine to very fine discontineous random and interstatial pores; very few fine roots; moderate effervescence; clear smooth boundary.
B11	39-61	Dark brown (10YR 3/3, m);silt loam; slightly-sticky, slightly-plastic (wet); slightly friable (moist); subangular blocky; very few very fine roots; few coarse, common medium and common fine interstital pores; moderate effervescence; clear smooth boundary.
B21	61-102	Brown to dark brown (10YR 4/3, m), sandy clay loam; subangular blocky; slightly-sticky and slightly-plastic (wet),friable (moist); common medium to fine interstatial pores; common medium, dark brown (10YR 4/3) oxidation mottles, distinct, moderate effervescence; clear smooth boundary.
B22	102-123	Brown to dark brown (10YR 4/3, m); loam; subangular blocky; sticky and slightly plastic (wet); friable (moist), common medium to fine interstitial pores; very few very fine roots; few fine dark brown (10 YR 4/3) oxidation mottling,

		faint; moderat effervescence; clear smooth boundary.
B3	123-180	Dark brown (10YR 4/4, m); silt loam; subangular blocky ; common fine to very fine interstital pores; moderately calcareous.

AP1.27 DRISHADVATI PLAIN

Pedon # D3
Classification : Coarse loamy Aquic Ustochrepts.
Location : 1/2 km from Jind on Jind-Hansi road.
Date of examination: 23/3/86
Landform : Relict Chataug river system
Landuse : Peddy, sugarcane and wheat.
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Poor
(b) Depth of groundwater= 17-20 m.
Moisture condition in profile : Slightly moist.
Evidence of erosion : Nil
Presence of salt/alkali: Non-saline
Human influence : Cultivated land

Horizon	Depth	Morphological description
AP	0-12	Dark greyish brown (10YR 5/2, m) sandy loam; friable (moist); subangular bocky; sticky, slightly- plastic (wet); common fine and very fine interstitial pores , common fine roots; week effervescence; gradual wavy boundary.
B1	12-31	Dark brown (10YR 4/3, m); loam; subangular blocky ; slightly-sticky, slightly plastic (wet); friable (moist); common fine to very fine interstatial pores; few fine roots; weak effervescence; gradual wavy boundary.
B21	31-70	Dark brown (10YR 4/2, m), loam; subangular blocky; slightly-sticky and slightly- plastic (wet),friable (moist); common fine to very fine interstatial pores; very few fine roots; weak effervescence; gradual wavy boundary.
B22	70-160	Dark brown (10YR 4/1.5, m); sandy loam; subangular blocky; sticky and slightly plastic (wet); friable (moist), common fine to very fine interstitial pores; few fine dark brown (10 YR 4/3) oxidation mottling, faint and medium coarse distinct; weak effervescence; clear smooth boundary.
B3	123-180	Brown to dark brown (10YR 4/3, m); silt; (Auger sample)

AP1.28 DRISHADVATI PLAIN

Pedon # D4
Classification : Coarse loamy Calcareous Natric Ustochrepts.
Location : 1/2 km from Narnound towards 35 ^{0}EW.(Jind)
Date of examination:22/3/86
Landform : Plain
Landuse : Sugarcane, maize and wheat.
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Poorly drained
(b) Depth of groundwater= 2 m.
Moisture condition in profile : Moist.
Evidence of erosion : Nil
Presence of salt/alkali: Non-saline
Human influence : Cultivated land

Horizon	Depth	Morphological description
AP	0-12	Light yellowish brown (10YR 6/3, m) sandy loam; slightly friable (moist); subangular bocky; non-sticky, non- plastic (wet); common fine and very fine interstitial pores , common fine roots; week effervescence; gradual wavy boundary.
B21	12-30	Dark yellowish brown (10YR 4/3, m); silt loam; subangular blocky with some part of platy structure; slightly-sticky, slightly plastic (wet); slightly friable (moist); common fine to very fine interstatial pores; few fine roots; moderate effervescence; gradual wavy boundary.
B22	30-110	Yellowish brown (7.5YR 4/3, m);silt loam; slightly-sticky, slightly-plastic (wet); slightly friable (moist); platy structure; few medium roots; common fine interstital pores; strong effervescence; clear smooth boundary.
B31	110-150	Brown (7.5YR 4/2, m), sandy loam; platy structure; slightly-sticky and slightly- plastic (wet), slightly friable (moist); common fine to very fine interstatial pores; very few fine roots; about 10% by volume calcium carbonate concretions; strong effervescence; gradual wavy boundary.
B33	150-180	Yellowish brown (7.5YR 4/3, m); sandy loam; platy structure; slightly-sticky and slightly plastic (wet); friable (moist), common fine to very fine interstitial pores; strong effervescence; clear smooth boundary.

AP1.29 DRISHADVATI PLAIN

Pedon # D5
Classification : Coarse loamy Calcareous Natric Ustochrepts.
Location : 2.5 km from Narnound towards west.
Date of examination: 19/3/86
Landform : Plain
Landuse : Nil
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Poorly drained
(b) Depth of groundwater= 2 m.
Moisture condition in profile : Moist throughout (2-115 cm) and wet within last sub-horizon (115-140cm).
Evidence of erosion : Nil
Presence of salt/alkali: Saline
Human influence : Barren land

Horizon	Depth	Morphological description
A11	0-2	Light whitish gray (2.5YR 7/1, m) loam; platy structure; friable (moist);non-sticky,non-plastic; common fine and very fine interstitial pores, violent effervescence; smooth boundary.
A12	2-19	Dark yellowish brown (10YR 4/3, m); loam; subangular blocky ; slightly-sticky, slightly plastic (wet); friable (moist); medium fine to very fine interstatial pores; strong effervescence; gradual wavy boundary.
B1	19-50	Light yellowish brown (10YR 5/4, m);sandy loam; slightly-sticky, slightly-plastic (wet); slightly friable (moist); subangular blocky; medium fine and very fine interstital pores; violent effervescence; many moderately hard calcium carbonate concretions; gradual wavy boundary.
B21	50-95	Dark yellowish brown (10YR 5/3.5, m), loam; subangular blocky; non-sticky and slightly- plastic (wet), slightly friable (moist); common fine to very fine interstatial pores; weak effervescence; gradual wavy boundary.
B22	95-115	Dark yellowish brown (10YR 5/3, m); silt loam; subangular blocky; non-sticky and slightly plastic (wet); slightly friable (moist), common fine to very fine interstitial pores; very few coarse roots; strong effervescence; gradualar wavy boundary.
C	115-140	Darkish reddish brown (2.5YR 5/3, m); loam; massive; non-sticky and slightly plastic (wet), common fine to very fine interstital pores; wetness in soil; strong effervescence.

AP1.30ADRISHADVATI PLAIN

Pedon # D6
Classification : Coarse loamy Udic Ustochrepts.
Location : 2.5 km before Chanaut on Hansi-Barwala road
Date of examination: 30/12/86
Landform : Plain
Landuse : wheat, mustard and Bajra.
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - moderately well drained
(b) Depth of groundwater= 7 m.
Moisture condition in profile : slightly moist below 10 cm.
Evidence of erosion : Nil
Presence of salt/alkali: Non-saline
Human influence : Cultivated land

Horizon	Depth	Morphological description
AP	0-20	Light yellowish brown (10YR 6/4, d) and dark brown (10YR 4/3, m); loam; slightly hard (dry); angular bocky; slightly- sticky, slightly- plastic (wet); few medium and common fine and very fine interstitial pores , many fine roots; week effervescence; gradual wavy boundary.
B21	20-27	Yellowish brown (10YR 5.5/4, m); sandy loam; subangular blocky ; slightly-sticky, slightly plastic (wet); slightly hard (moist); few medium and common fine to very fine interstatial pores; few fine roots; weak effervescence; gradual wavy boundary.
B22	27-68	Yellowish brown (10YR 5.5/4, m);sandy loam; slightly-sticky, slightly-plastic (wet); slightly friable (moist); subangular blocky; few fine roots; few medium and common fine interstital pores; weak effervescence; gradual wavy boundary.
B31	68-105	Dark brown (10YR 4/3, m) sandy loam; subangularblocky; slightly-sticky and slightly-plastic (wet), slightly friable (moist); common fine to very fine interstatial pores; few fine roots; gradual wavy boundary.
B32	105-150	Dark brown (10YR 4/3, m); sandy loam; subangular blocky; sticky and plastic (wet); common medium and fine interstitial pores; few very fine roots; slightly calcareous.

AP1.31 DRISHADVATI PLAIN

Pedon #D_7

Classification : Coarse loamy Typic Ustochrepts.
Location : 300 m (45° W from village Bhiwani-Rohila
Date of examination: 20/3/86
Landform : Aeolian-plain
Landuse : Bajra, gram and mustard.
Climate : Semi-arid
Present material : Alluvium
Hydrology:Drainage - Well drained
Moisture condition in profile : Slightly moist
Evidence of erosion : Nil
Presence of salt/alkali: Non-saline
Human influence : Cultivated land

Horizon	Depth	Morphological description
AP	0-18	Light yellowish brown (10YR 6/3, d); sandy loam; subangular blocky; non-sticky, non-plastic (wet), slightly friable (moist), medium interstitial pores; very few fine roots; violent effervescence; abrupt boundary..
C1	18-45	Dark yellowish brown (10YR 5/3, m); sandy loam; subangular blocky; non-sticky, non-plastic (wet), slightly friable (moist); medium interstitial pores; common fine roots; violent effervescence; gradual wavy boundary.
C2	45-50	Dark yellowish brown (7.5YR 4/4, m); sandy loam; subangular blocky; non-sticky, non-plastic (wet), slightly friable (moist); common medium interstatial pores; more than 50% by volume, calcaium carbonate concretions.

AP1.32 DRISHADVATI PLAIN

Pedon # D8
Classification : Coarse loamy Typic Ustochrepts.
Location : Village Karori (8 km from Hissar on Hissar-Balsamund road.
Date of examination: 2/1/87
Landform : Plain
Landuse : Wheat, gram and sugarcane
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Good
(b) Depth of groundwater= 5-6 m.
Moisture condition in profile : Moist after 25 cm
Evidence of erosion : Nil
Presence of salt/alkali: Non-saline
Human influence : Cultivated land

Horizon	Depth	Morphological description

AP	0-15	Pale brown (10YR 6/3, d) and brown to dark brown (10YR 4/3, m); sandy loam; massive tending to subangular blocky; hard (dry),friable (moist);slightly-sticky,non-plastic; common fine and many very fine interstitial pores; many fine roots; slight effervescence; smooth boundary.
A12	15-29	Yellowish brown (10YR 5/4, d) and dark yellowish brown (10YR 4/4, m); loamy sand; subangular blocky; hard (dry), friable (moist) ; slightly-sticky, slightly plastic (wet); many very fine discontineous random, vertical and some horizontal pores; slight effervescence; clear smooth boundary.
B21	29-57	Brown to dark brown (10YR 4/3, m);sandy loam; slightly-sticky, slightly-plastic (wet); slightly friable (moist); subangular blocky; many fine and very fine discontineous and random pores; common very fine fibrous roots; slight effervescence; clear smooth boundary.
B22	57-80	Brown to dark brown (10YR 4/3, d) and yellowish brown (10YR 5/4, m), sandy loam; subangular blocky; non-sticky and slightly- plastic (wet), slightly friable (moist); slightly calcareous; sand pockets of light yellowish brown colour; few very fine medium fibrous roots; many fine and very fine discontineous, random and vertical pores; clear smooth boundary.
B23	80-103	Brown to dark brown (10YR 4/3, m); sandy loam; subangular blocky; non-sticky and slightly plastic (wet); firm (moist), common fine to very fine discontineous, random and vertical pores; very few fine fibrous roots; strong effervescence; clear smooth boundary.
B31	103-127	Brown to dark brown (10YR 4/3, m); silt loam; subangular blocky; non-sticky and slightly plastic (wet), common fine to very fine interstital pores; moderately calcareous; clear smooth boundary.
B32	127-160	Varigsted colours i.e brown to dark brown (10YR 4/3, m) and dark yellowish brown (10YR 4/4, m); silt loam; subangular blocky; friable (moist), slightly sticky, slightly plastic (wet); very few very fine roots; moderately calcareous.

AP1.33 FLUVIO-AEOLIAN PLAIN

Pedon : #F1
Classification : Coarse loamy Typic Ustochrepts.
Location : Mithathal (Bhiwani)
Date of examination: 30/12/86
Landform : Plain

Landuse : Nil
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Moderately well drained
(b) Depth of groundwater= 10 m.
Moisture condition in profile : slightly moist
Evidence of erosion : Nil
Presence of salt/alkali: Nil
Human influence : An arachaeological site

Horizon	Depth	Morphological description
A	0-26	Light brownish gray (10YR 6/2, d); loam; firable (dry); subangular blocky; non-sticky, non-plastic; few medium and common fine interstitial pores; many medium and fine roots; no effervescence; gradual wavy boundary.
AC	26-58	Pale brown (10YR 6/3, d); loam; weak subangular blocky ; non- sticky, slightly plastic (wet); friable (moist); common fine interstatial pores; common fine roots; strongly calcareous; gradual wavy boundary.
C1	58-96	Brown (10YR 5/3, m); silt loam; structureless; non-sticky, slightly-plastic (wet); slightly firm (moist); common coarse, few medium and common fine interstital pores; moderate effervescence; common medium and fine roots; gradual wavy boundary.
C2	96-115	Grayish brown (10YR 5/2, m),silt loam; structureless, loose grains; non-sticky and slightly- plastic (wet), friable (moist); common fine to very fine interstatial pores; common medium and fine roots; strongly calcareous, gradual wavy boundary.
C3	115-168	Grayish brown (10YR 5/2, m); loam; subangular blocky; slightly-sticky and slightly plastic (wet); slightly friable (moist), few coarse to medium and common fine interstitial pores; strongly calcareous ; clear smooth boundary
C4	168-203	Dark brown (10YR 4/3, m); silt loam; platy structure; plastic; few coarse and medium and common fine interstitial pores; few medium roots; strongly calcareous; clear smooth boundary.
C5	203-231	Dark brown (10YR 4/3, m); silt loam; subangular blocky; slightly sticky, plastic; common fine, few medium interstitial pores; strongly calcareous.
C6	231-286	Auger sample (Silt-loam)

C7 286-306 Auger sample (Clay loam).

AP1.34 FLUVIO-AEOLIAN PLAIN

Pedon : #F2
Classification : Coarse loamy Udic Ustochrepts.
Location : 8.3 km from Bhiwani on Bhiwani-Tosam road.
Date of examination: 31/12/86
Landform : Plain
Landuse : Sugarcane and mustard.
Climate : Semi-arid
Present material : Alluvium
Hydrology (a) Drainage - Well drained
(b) Depth of groundwater= 20 m.
Moisture condition in profile : Moist
Evidence of erosion : Nil
Presence of salt/alkali: Nil
Human influence : Brick-klin

Horizon	Depth	Morphological description
A	0-30	Dark brownish (10YR 4/3, m); sandy loam; hard (dry); subangular blocky; sticky, slightly-plastic; few medium and common fine interstitial pores; common fine roots; no effervescence; gradual wavy boundary.
B1	30-50	Dark brown (10YR 3/4, m); sandy loam; medium subangular blocky ; sticky, slightly plastic (wet); friable (moist); few coarse and common medium and fine interstatial pores; very few very fine roots; slight effervescence; gradual wavy boundary.
B21	50-90	Dark brown (10YR 4/3, m); silt loam; sticky, slightly-plastic (wet); slightly firm (moist); subangular blocky; few fine interstital pores; moderate effervescence; gradual wavy boundary.
B22	90-145	Dark brown (10YR 4/4, m),silt loam; subangular blocky; slightly-sticky and slightly- plastic (wet), slightly friable (moist); common fine to very fine interstatial pores; strongly calcareous, about 20% by volume calcium carbonate concretions; gradual wavy boundary.
C1	145-170	Yellowish brown (10YR 5/4, m); loam; subangular blocky; non-sticky and slightly plastic (wet); slightly friable (moist), few fine interstitial pores; few medium brown (10YR 5/4) oxidation mottles; strongly calcareous.

APPENDIX III

	HORIZON SYMBOL	DEPTH (CM)	SAND	TOTAL SILT	CLAY	TEXTURAL CLASS
BASIN WITH MARL M1	AP	0-25	64.12	32.87	3.01	Sandy loam
	C1	25-50	60.03	33.86	6.11	Sandy loam
	C2	50-75	47.85	37.43	14.72	Loam
	C3	75-150	MARL			
M2	AP	0-10	42.94	36.31	20.75	Loam
	C1	10-45	45.95	46.58	7.47	Loam
	C2	45-100	70.45	18.97	10.58	Sandy loam
		100+	MARL			
OLDER PIEDMONT P1	A	0-18	49.92	37.44	12.64	Loam
	B11	18-58	16.20	70.52	13.28	Silt loam
	B12	58-102	24.00	67.52	8.48	Silt loam
	B21	102-155	11.20	70.72	18.08	Silty clay loam
	B22	155-175	13.60	68.16	18.24	Silty clay loam
	B3	175-187	46.56	43.20	10.24	Loam
	C	187-202	76.96	16.32	6.72	Sandy loam
P2	A	0-10	61.49	31.72	6.79	Sandy loam
	B21	10-33	33.12	45.44	21.44	Loam
	B22	33-120	29.92	49.28	20.80	Sandy loam
	B31	120-155	59.36	28.50	11.84	Sandy loam
	B32	155-180	67.52	17.92	14.56	Sandy loam
	C	180-210	75.20	14.08	10.72	Sandy loam
P3	A	0-18	75.20	10.56	14.24	Sandy loam
	B1	18-46	46.56	40.32	13.12	Loam
	B2	46-89	51.68	31.36	16.96	Loam
	B3	89-108	62.88	28.00	9.12	Sandy loam
	C	108-150	67.20	23.36	9.44	Sandy loam
YOUNGER PIEDMONT YP1	AP1	0-8	52.16	47.84	11.20	Sandy loam
	AP2	8-25	58.88	30.88	10.24	Sandy loam
	B21	25-53	50.40	35.16	14.44	Sandy loam
	B22	53-72	50.88	35.36	13.76	Sandy loam
	B31	72-122	50.56	39.36	10.08	Sandy loam
	B32	122-170	45.28	46.56	8.16	Loam
YAMUNA FLOOD-PLAIN Y1	AP	0-8	43.04	40.16	16.80	Loam
	AB	8-33	46.16	38.50	15.34	Loam
	B3	33-73	60.00	29.08	10.92	Sandy loam
	C1	73-140	76.64	16.16	7.20	Sandy loam
	C2	140-150	74.72	20.00	5.28	Sandy loam

	HORIZON SYMBOL	DEPTH (CM)	SAND	TOTAL SILT	CLAY	TEXTURAL CLASS
Y2	AP1	0-10	65.76	28.28	5.96	Sandy loam
	AP2	10-20	69.71	25.62	4.67	Sandy loam
	B	20-90	43.64	54.34	2.02	Silt loam
	C1	90-152	23.54	69.12	7.34	Silt loam
	C2	152-180	83.94	14.38	1.68	Loamy sand
Y3	AP	0-15	81.37	15.73	2.90	Loamy sand
	AC	15-70	69.73	29.10	1.17	Sandy loam
	C1	70-108	77.17	21.15	1.68	Loamy sand
	C2	108-180	63.10	35.90	1.00	Sandy loam
GHAGGER FLOOD PLAIN G1	AP	0-10	54.08	37.18	8.74	Sandy loam
	AB	10-40	41.76	48.20	10.04	Loam
	B21	40-63	38.72	49.28	12.00	Loam
	B22	63-121	35.52	49.12	15.36	Loam
	C	121-180	47.68	43.36	8.96	Loam
G2	AP	0-26	40-64	45.60	13.76	Loam
	B21	26-66	40-00	44.66	15.34	Loam
	B22	66-102	30.17	56.32	13.51	Silt loam
	C	102-127	21.6	71.36	7.04	Silt loam
KAITHAL UPLAND PLAIN K1	A11	0-07	43.68	47.84	8.48	Loam
	A12	7-29	38.32	52.40	9.28	Silt loam
	B21	29-43	31.84	56.00	12.16	Silt loam
	B22	43-60	31.52	54.72	13.76	Silt loam
	B31	60-102	39.68	51.04	9.28	Silt loam
	B32	102-153	29.60	55.52	14.88	Silt loam
	C	153-170	20.32	61.12	18.56	Silt loam
K2	AP	0-10	28.70	54.44	16.86	Silt loam
	B1	10-38	49.36	41.60	9.04	Loam
	B21	38-78	43.30	45.09	11.61	Loam
	B22	78-115	44.34	27.83	27.83	Clay loam
	B3	115-180	44.12	45.97	9.91	Loam
	C	180-250	35.12	36.16	28.72	Clay loam
K3	AP	0-10	76.00	17.22	6.78	Sandy loam
	AC	10-30	66.88	27.52	5.60	Sandy loam
	C1Ca	30-65	78.28	15.68	6.08	Loamy sand
	C2Ca	65-100	60.53	25.53	13.94	Sandy loam
	C3Ca	100-135	77.60	11.84	10.56	Sandy loam
	C4Ca	135-160	67.68	69.16	8.48	Sandy loam
	C5Ca	160-185	70.56	24.96	4.48	Sandy loam

	HORIZON SYMBOL	DEPTH (CM)	SAND	TOTAL SILT	CLAY	TEXTURAL CLASS
K4	A	0-11	59.88	24.60	15.52	Sandy loam
	AC	11-45	52.64	36.02	11.34	Sandy loam
	C1	45-100	48.64	36.16	15.20	Loam
	C2	100-147	52.96	35.52	11.52	Sandy loam
	C3	147-247	72.80	23.04	4.16	Sandy loam
	C4	247-285	64.32	25.60	10.08	Sandy loam
	C5	285-306	52.00	31.12	6.88	Sandy loam
	C6	306-400	56.72	32.56	10.72	Sandy loam
	C7	400-450	60.80	31.52	7.68	Sandy loam
	C8	450-500	49.60	42.40	8.88	Loam
KARNAL UPLAND PLAIN R1	AP	0-10	35.97	12.99	51.22	Clay
	B1	10-60	41.49	51.59	6.92	Silt loam
	B2	60-225	50.26	39.65	10.09	Loam/S.loam
	C	225-300	73.74	24.06	2.20	Sandy loam
R2	A11	0-05	34.24	53.60	12.16	Silt loam
	A12	05-24	23.04	62.08	14.88	Silt loam
	B1	24-41	25.76	57.28	16.96	Silt loam
	B21	41-81	30.56	51.84	17.60	Silt loam
	B22	81-104	32.64	57.28	10.08	Silt loam
	B3Ca	104-117	21.12	61.76	17.12	Silt loam
	CCa	117-150	17.92	70.74	11.34	Silt loam
R3	AP	0-10	56.41	38.28	5.31	Sandy loam
	AB	10-45	55.08	31.25	13.67	Sandy loam
	B	45-110	54.00	31.93	14.07	Sandy loam
	C	110-180	54.08	28.75	17.17	Sandy loam
R4	A	0-10	58.20	34.48	7.32	Sandy loam
	AC	10-42	47.09	46.04	6.87	Loam
	C1	42-150	56.03	41.97	2.00	Sandy loam
	C2	150-180	55.32	43.00	1.98	Sandy loam
R5	AP	0-20	28.51	68.31	3.18	Silt loam
	B1	20-90	34.64	53.40	11.96	Silt loam
	B2	90-152	47.01	51.04	10.95	Loam
	C	152-180	41.03	57.97	1.00	Silt loam
R6	A11	0-20	42.69	29.97	27.34	Loam
	A12	20-50	79.98	13.82	6.20	Loamy sand
	B2	50-102	45.77	45.65	8.58	Loam
	B3	102-140	51.24	40.25	8.21	Sandy loam
	C1	140-180	22.16	50.86	18.98	Silt loam
	C2	180-280	74.00	23.82	2.18	Loamy sand

	HORIZON SYMBOL	DEPTH (CM)	SAND	TOTAL SILT	CLAY	TEXTURAL CLASS
R7	AP	0-10	30.41	32.38	37.21	Clay loam
	AB	10-30	53.50	40.76	5.74	Sandy loam
	B21	30-107	48.93	46.83	4.24	Loam
	B22	107-162	69.97	8.42	21.61	Sandy clay loam
	B3	162-180				Loam
R8	AP	0-15	62.53	34.65	2.82	Sandy loam
	B21	15-50	68.06	15.49	16.45	Sandy loam
	B3	50-100	66.15	22.85	11.00	Sandy loam
	C	100-140	37.89	57.55	4.56	Silt loam
R9	AP	0-10	60.00	31.84	8.16	Sandy loam
	AB	10-35	54.24	38.72	7.04	Sandy loam
	B2	35-70	48.96	31.52	19.52	Loam
	B3	70-120	51.04	40.08	8.88	Sandy loam
	C1	120-140	54.40	38.63	6.97	Sandy loam
<u>DRISHADVATI PLAIN</u> D1	AP	0-21	35.45	47.30	17.25	Loam
	B1	21-59	25.12	62.08	12.80	Silt loam
	B21	59-72	26.24	55.84	17.92	Silt loam
	B22	72-125	20.80	63.92	16.00	Silt loam
	B23	125-152	34.88	45.44	19.68	Clay loam
	C	152-180	30.24	62.08	7.68	Silt loam
D2	AP	0-10	21.76	60.80	17.44	Silt loam
	AB	10-39	28.00	46.88	25.12	Loam
	B11	39-61	31.52	64.96	3.52	Silt loam
	B21	61.102	48.80	25.92	25.28	Sandy clay lo
	B22	102-123	45.12	50.56	4.32	Loam
	B3	123-180	21.37	68.18	10.45	Silt loam
D3	AP	0-12	51.49	46.96	1.55	Sandy loam
	B21	12-31	46.67	50.68	2.65	Loam
	B22	31-70	47.86	48.88	3.26	Loam
	C1	70-160	55.17	40.36	4.47	Sandy loam
	C2	160-250	64.72	31.56	3.72	Sandy loam
D4	AP	0-12	54.32	32.53	13.15	Sandy loam
	B21	12-30	42.26	53.49	4.25	Silt loam
	B22	30-110	39.52	57.59	2.89	Silt loam
	B31	110-150	75.19	17.54	7.29	Sandy loam
	B33	150-180	62.65	34.45	2.90	Sandy loam

	HORIZON SYMBOL	DEPTH (CM)	SAND	TOTAL SILT	CLAY	TEXTURAL CLASS
D5	A11	0-02	43.76	49.26	6.98	Loam
	A12	02-19	41.20	51.00	7.80	Loam
	B1	19-50	50.53	31.63	17.84	Sandy loam
	B21	50-95	41.50	61.32	19.82	Loam
	B22	95-115	31.27	62.09	6.64	Silt loam
	C	115-140	45.18	36.28	18.54	Loam
D6	AP	0-20	49.28	40.16	10.56	Loam
	B21	20-27	61.76	30.24	8.00	Sandy loam
	B22	27-68	63.84	23.04	13.12	Sandy loam
	B31	68-105	60.48	30.72	8.80	Sandy loam
	B32	105-150	64.00	27.04	8.96	Sandy loam
D7	A	0-18	63.10	18.20	18.70	Sandy loam
	C1	18-45	73.76	20.84	5.40	Sandy loam
	C2	45-50	74.11	20.22	5.67	Sandy loam
	C3	50-75	57.88	31.65	10.47	Sandy loam
D8	AP	0-15	76.64	14.08	9.28	Sandy loam
	A12	15-29	79.04	13.12	7.84	Loamy sand
	B21	29-57	52.80	33.60	13.60	Sandy loam
	B22	57-80	54.72	36.00	9.28	Sandy loam
	B23	80-103	52.00	40.00	8.00	Sandy loam
	B32	103-127	41.60	48.00	10.40	Silt loam
	B3/C	127-160	41.28	48.64	10.08	Silt loam
<u>FLUVIO-AEOLIAN</u> <u>PLAIN</u> F1	AP	0-26	42.72	42.56	14.72	Loam
	AC	26-58	36.13	49.12	14.72	Loam
	C1	58-56	32.26	51.00	16.74	Silt loam
	C2	96-115	31.99	56.54	11.47	Silt loam
	C3	115-168	42.71	50.51	6.78	Loam
	C4	168-203	33.12	63.54	7.34	Silt loam
	C5	203-231	27.02	51.41	21.57	Silt loam
	C6	231-286	26.88	51.84	21.28	Silt loam
	C7	286-306	20.32	48.00	31.68	Clay loam
F2	A	0-30	59.68	32.98	7.34	Sandy loam
	B1	30-50	52.00	41.28	6.72	Sandy loam
	B21	50-90	39.68	52.00	8.32	Silt loam
	B22	90-145	39.84	54.56	5.60	Silt loam
	C1	145-170	28.80	48.16	23.04	Loam

APPENDIX IV

PEDON Nos.	HORIZON SYMBOL	SiO_2	AL_2O_3	Fe_2O_3	CaO	MgO	K_2O	NA_2O	P_2O^5	CO_2
M1	AP	81.09	8.36	4.86	0.29	0.65	1.63	0.96	.028	0.23
	C1	45.97	10.15	5.12	17.66	2.78	1.34	0.57	.001	13.90
	C2	54.42	14.69	6.57	11.08	1.86	1.42	0.05	.001	8.72
M2	AP	61.00	18.90	5.92	5.87	0.90	1.47	0.98	.029	4.62
	C1	59.80	10.35	6.01	10.82	1.09	1.42	0.74	.022	9.31
	C2	29.00	2.17	2.26	35.37	0.22	1.32	0.70	.018	27.87
P1	A	59.38	26.74	10.77	0.23	0.18	1.56	0.06	.001	0.18
	B11	56.30	28.34	12.02	0.18	0.34	1.73	0.06	.001	0.14
	B12	50.55	31.36	12.99	0.26	0.89	1.94	0.06	.001	0.20
	B21	55.28	28.53	12.07	0.27	0.55	1.95	0.06	.001	0.21
	B22	55.32	29.15	12.04	0.24	1.03	1.78	0.06	.001	0.19
	B3	63.03	24.09	8.88	0.23	0.37	1.49	0.06	.001	0.18
	C	84.00	9.68	4.02	0.21	0.40	1.04	0.10	.001	0.16
P2	A	70.77	17.90	6.09	0.36	2.16	1.24	0.14	.001	0.28
	B21	56.63	27.68	10.72	0.20	1.06	1.70	0.09	.01	0.16
	B22	50.95	31.22	11.88	0.13	1.12	1.70	0.10	.001	0.10
	B31	65.78	21.02	7.77	0.20	1.95	1.32	0.25	.008	0.16
	B32	71.50	18.85	6.30	0.14	1.09	1.14	0.23	.001	0.11
	C	74.07	16.06	5.23	0.21	1.06	0.93	0.12	.003	0.16
P3	A	80.10	13.50	4.16	0.18	0.14	0.83	0.27	.003	0.14
	B1	65.50	21.82	8.96	0.18	1.12	1.35	0.25	.001	0.14
	B2	70.20	18.66	7.40	0.18	1.23	1.20	0.12	.001	0.14
	B3	75.93	13.60	5.48	0.16	1.54	1.09	0.12	.007	0.13
	C	72.36	17.57	6.07	0.14	1.74	1.19	0.30	.005	0.11
YP1	AP1	72.86	18.80	5.56	0.15	0.03	1.20	0.06	.006	0.11
	AP2	73.77	17.71	5.15	0.16	0.06	1.14	0.06	.004	0.12
	B21	71.95	18.52	6.24	0.28	0.23	1.31	0.06	.004	0.22
	B22	68.25	21.59	7.36	0.36	0.22	1.45	0.06	.001	0.28
	B31	68.19	21.30	7.86	0.16	0.53	1.48	0.06	.004	0.12
	B32	66.10	23.67	7.69	0.15	0.15	1.35	0.06	.003	0.11
Y1	AP	49.36	33.95	10.10	0.32	1.09	2.18	0.29	.001	0.25
	AB	59.68	25.79	10.93	0.27	0.29	2.15	0.15	.001	0.21
	B3	63.88	22.91	9.57	0.27	0.71	1.89	0.13	.001	0.21
	C1	64.00	23.71	9.02	0.23	0.73	1.75	0.16	.001	0.18

APPENDIX IV (Contd)

PEDON Nos.	HORI -ZON	SiO_2	AL_2O_3	Fe_2O_3	CaO	MgO	K_2O	NA_2O	P_2O_5	CO_2
Y2	AP1	61.06	23.47	7.80	1.08	1.32	1.70	0.65	.010	0.85
	AP2	63.34	21.39	6.68	1.91	1.45	1.46	0.58	.007	1.50
	B	50.95	25.41	10.20	3.37	3.50	1.85	0.39	.006	2.65
	C1	42.90	34.48	13.72	1.14	3.22	1.95	0.38	.014	1.13
	C2	61.20	23.05	9.09	0.92	1.71	1.94	0.47	.006	0.73
Y3	AP	69.66	19.32	5.90	0.85	0.77	1.41	0.66	.008	0.67
	AC	68.29	22.34	5.36	0.62	0.53	1.33	0.50	.010	0.49
	C1	60.09	24.85	9.18	0.69	1.50	1.54	0.44	.003	0.54
	C2	64.89	20.45	7.43	0.76	1.51	1.46	0.50	.006	0.60
G1	AP	67.35	25.50	5.12	0.02	0.05	1.15	0.06	.001	NIL
	AB	70.30	18.66	6.96	0.14	0.12	1.38	0.06	.001	0.11
	B21	65.63	22.30	8.68	0.15	0.28	1.49	0.06	.001	0.11
	B22	57.96	25.84	11.41	0.17	0.66	1.85	0.06	.001	0.13
	C	60.00	25.60	10.84	0.24	0.40	1.71	0.06	.001	0.19
G2	AP	62.90	18.52	7.56	2.13	3.58	1.80	0.89	.007	1.67
	B21	54.75	25.18	10.28	2.54	1.33	1.95	0.80	.008	2.00
	B22	55.80	24.75	9.59	2.32	1.83	1.90	0.84	.014	1.83
	C	36.62	17.76	8.49	13.94	2.38	1.64	0.40	.001	13.90
K1	A11	69.35	15.97	5.49	1.62	2.48	1.63	1.15	.039	1.27
	A12	63.00	19.37	8.68	0.97	3.31	1.81	1.05	.016	0.76
	B21	58.78	21.02	9.82	1.41	2.75	1.98	1.12	.009	1.11
	B22	54.95	22.49	10.16	3.02	3.10	1.95	1.03	.001	2.37
	B31	51.40	23.43	11.71	2.34	0.08	2.16	0.98	.001	1.84
	B32	51.25	18.61	9.55	7.66	2.93	1.88	0.76	.001	6.03
	C	21.10	26.08	9.69	16.81	9.50	1.89	0.68	.016	13.22
K2	AP	58.52	28.86	7.94	0.57	0.20	1.78	0.50	.004	0.44
	B1	62.54	23.15	7.70	0.50	0.59	1.63	0.25	.001	0.39
	B21	52.90	34.20	9.66	0.10	0.70	1.93	0.37	.001	0.08
	B22	60.66	18.56	9.42	3.56	1.77	1.68	0.37	.001	2.80
	B3	49.34	13.65	10.00	9.76	4.05	1.75	0.20	.030	7.68
	C	56.07	18.14	9.32	4.65	3.41	1.96	0.39	.019	3.66
K3	AP	71.34	16.96	6.38	0.74	0.28	1.60	1.20	.001	0.58
	AC	69.72	19.65	5.53	0.62	0.35	1.44	1.18	.001	0.48
	C1Ca	57.25	18.04	7.01	7.23	0.70	1.54	1.00	.001	5.69
	C2Ca	38.93	16.77	7.28	18.50	1.57	1.28	0.52	.001	14.56
	C3Ca	55.45	16.20	6.88	9.29	0.50	1.38	1.13	.001	7.32
	C4Ca	49.32	21.54	7.00	9.73	1.05	1.30	1.01	.008	7.66
	C5Ca	55.00	22.58	6.95	5.37	0.91	1.32	1.19	.009	4.22

APPENDIX IV (Contd.)

PEDON Nos.	HORI -ZON	SiO_2	AL_2O_3	Fe_2O_3	CaO	MgO	K_2O	NA_2O	P_2O_5	CO_2
K4	A	67.10	16.11	6.67	2.50	1.36	1.96	0.83	.040	1.96
	AC	50.35	28.72	8.66	1.29	5.65	1.89	0.98	.026	1.01
	C1	56.26	25.89	8.93	1.31	1.36	2.40	1.08	.039	1.03
	C2	57.83	20.78	7.48	4.30	1.99	2.29	1.11	.024	3.38
	C3	61.00	17.05	12.28	2.91	0.59	1.63	1.10	.025	2.29
	C4	53.20	20.50	9.27	5.82	2.75	1.99	0.70	.019	4.58
	C5	37.84	41.05	9.47	3.12	0.04	1.89	3.37	.002	2.45
	C6	43.98	35.89	8.93	2.88	1.74	1.81	1.07	.006	2.26
	C7	56.60	18.90	7.60	6.73	2.20	1.73	0.90	.014	5.29
	C8	42.94	21.40	9.50	11.15	2.83	1.89	0.74	.011	8.78
R1	AP	65.06	19.93	6.68	2.57	0.34	1.57	0.81	.017	2.02
	B1	50.63	25.65	9.94	1.85	3.37	1.68	1.26	.003	1.46
	B2	49.19	28.39	11.84	1.39	2.28	2.01	1.21	.011	1.09
	C	55.19	21.30	8.38	7.45	1.88	1.60	0.85	.010	5.85
R2	A11	62.50	21.92	7.02	0.95	1.39	1.92	2.25	.025	0.75
	A12	58.10	23.52	9.38	1.08	2.99	2.01	1.27	.001	0.85
	B1	42.50	26.08	10.86	6.97	4.45	1.96	0.90	.001	5.49
	B21	49.60	29.38	11.20	0.74	3.78	2.16	1.14	.001	0.58
	B22	48.60	30.04	12.74	1.12	2.51	2.08	0.89	.001	0.88
	C3Ca	16.00	22.39	8.14	23.24	9.52	1.40	0.35	.002	18.30
	CCa	28.15	19.18	8.79	19.52	5.94	1.42	0.39	.002	15.37
R3	AP	56.10	27.35	10.64	1.13	1.36	1.76	0.66	.009	0.31
	AB	59.71	22.63	9.47	2.06	2.06	1.89	0.65	.022	0.44
	B	56.80	24.14	8.48	1.25	1.71	1.75	3.75	.002	0.98
	C	61.10	22.63	8.09	1.35	2.07	1.80	0.71	.001	1.06
R4	A	59.95	23.10	8.41	0.94	1.56	2.00	2.12	.029	0.24
	AC	53.32	27.44	10.09	1.97	1.89	1.95	0.91	.007	0.42
	C1	48.30	31.74	12.85	0.93	1.29	1.90	0.85	.005	0.73
	C2	49.60	28.81	10.01	2.59	2.75	1.96	0.96	.006	2.07
R5	AP	54.14	26.73	9.43	1.89	2.03	1.83	0.72	.001	1.49
	B1	51.32	29.15	10.40	1.68	2.36	2.03	0.66	.004	1.32
	B2	49.31	29.38	12.05	2.00	2.45	2.22	0.41	.010	1.57
	C	41.25	23.00	10.36	10.69	2.05	1.84	0.31	.001	8.42
R6	A11	61.93	15.25	7.45	5.60	2.22	1.76	0.75	.001	4.40
	A12	38.99	13.93	8.99	16.73	4.44	0.57	0.39	.001	13.17
	B2	50.80	21.44	9.86	5.13	3.55	2.22	0.88	.030	4.03
	B3	51.08	20.93	9.01	6.47	3.60	2.08	1.21	.001	5.49
	C1	47.74	20.55	10.30	7.17	3.59	2.16	0.78	.018	5.64
	C2	43.72	21.54	10.70	9.57	2.10	2.20	0.58	.002	7.53

APPENDIX IV (Contd.)

PEDON Nos.	HORI-ZON	SiO_2	AL_2O_3	Fe_2O_3	CaO	MgO	K_2O	NA_2O	P_2O_5	CO_2
R7	AP	58.10	24.56	10.08	1.30	1.12	2.22	0.78	.001	1.02
	AB	51.31	28.44	12.51	1.28	1.53	2.27	0.58	.001	1.00
	B21	56.40	25.13	12.10	0.13	1.18	2.10	0.65	.009	0.10
	B22	37.25	23.14	12.37	9.76	4.29	2.30	0.56	.009	7.69
R8	AP	70.85	16.63	4.89	1.97	0.85	1.68	1.01	.001	0.53
	B21	66.46	18.09	6.24	1.57	2.60	1.64	0.96	.009	0.42
	B3	39.11	12.19	7.42	20.11	2.92	1.41	0.35	.001	15.92
	C	45.50	20.45	9.66	9.62	3.58	2.18	0.75	.014	7.57
R9	AP	63.38	22.81	7.09	1.04	1.21	1.57	0.80	.003	0.81
	AB	63.45	22.91	7.42	0.41	0.70	1.71	1.11	.001	0.32
	B2	57.39	26.74	10.19	0.25	1.07	2.01	0.96	.001	0.19
	B3	54.10	28.25	10.90	0.21	0.48	2.01	1.02	.001	0.16
	C1	56.88	27.44	11.20	0.15	0.47	2.15	1.20	.001	0.11
D1	AP	63.80	23.15	8.30	0.26	0.38	1.83	0.30	.010	0.20
	B1	53.25	26.22	11.56	1.47	1.02	1.91	0.30	.003	1.15
	B21	44.09	34.06	14.17	1.38	1.66	2.12	0.30	.002	1.08
	B22	43.35	35.90	14.21	0.51	1.96	1.98	0.39	.001	0.40
	B23	48.93	30.94	11.54	1.47	1.64	2.00	0.53	.001	1.15
	C	50.00	32.78	13.90	0.33	0.19	1.71	0.76	.004	0.25
D2	AP	51.00	31.79	12.70	0.28	1.29	2.28	0.23	.004	0.22
	AB	48.63	33.54	13.58	0.31	0.57	2.18	0.10	.008	0.24
	B11	55.73	28.11	10.80	0.58	0.87	1.79	0.51	.003	0.20
	B21	53.20	28.25	12.20	1.12	1.30	2.02	0.50	.003	0.88
	B22	51.75	31.55	12.01	0.52	0.62	2.10	0.52	.001	0.48
	B3	52.09	29.19	13.32	0.78	0.96	2.19	0.46	.001	0.61
D3	AP	68.30	17.15	8.06	1.01	1.15	2.00	0.70	.014	0.22
	B21	65.96	16.86	7.60	1.09	1.36	1.99	1.13	.019	0.86
	B22	65.10	18.32	7.71	1.65	0.74	2.12	1.06	.021	1.33
	C1	64.63	19.60	9.92	0.22	0.77	2.27	0.76	.022	0.17
	C2	66.70	17.29	8.12	1.67	0.82	1.82	1.12	.008	1.31
D4	AP	69.38	17.52	7.26	0.69	0.35	1.71	0.43	.022	0.54
	B21	67.64	18.37	7.89	0.49	1.26	1.75	0.50	.022	0.38
	B22	58.60	17.85	7.36	6.89	1.12	1.55	0.62	.008	5.42
	B31	55.50	23.19	8.19	5.53	0.35	1.43	0.37	.050	4.35
	B33	54.40	28.53	9.70	1.11	2.29	1.75	0.13	.040	0.87

APPENIX IV (Contd.)

PEDON Nos.	HORI -ZON	SiO_2	AL_2O_3	Fe_2O_3	CaO	MgO	K_2O	NA_2O	P_2O_5	CO_2
D5	A11	67.08	14.97	4.99	1.70	0.96	1.75	5.38	.053	1.33
	A12	64.54	18.33	6.27	2.07	2.98	1.82	0.83	.040	1.63
	B1	60.70	17.71	6.61	3.74	4.24	1.70	0.68	.028	3.11
	B21	58.54	19.65	7.82	5.34	1.37	1.73	0.75	.002	4.20
	B22	45.20	17.90	7.68	12.52	4.02	1.51	0.18	.004	9.86
	C	70.60	18.66	5.40	1.00	0.34	1.47	0.75	.007	0.78
D6	AP	49.90	32.55	9.94	0.67	2.98	1.69	0.79	.001	0.53
	B21	54.25	28.86	9.38	0.70	2.48	1.80	0.89	.001	0.55
	B22	50.12	26.40	8.14	4.82	3.24	2.21	0.78	.001	3.79
	B31	55.35	27.54	9.93	0.83	1.28	1.78	0.81	.001	0.65
	B32	56.10	26.97	10.12	1.33	1.49	2.04	0.78	.001	1.04
D7	A	68.90	17.00	6.08	1.40	2.45	1.54	0.72	.004	1.10
	C1	71.52	14.27	5.40	2.16	0.70	1.46	0.22	.009	1.70
	C2	63.50	19.98	5.96	3.87	0.83	1.65	0.50	.014	2.38
	C3	54.38	19.59	7.76	7.07	3.23	1.95	0.44	.018	5.55
D8	AP	67.00	21.68	6.38	1.14	0.36	1.53	1.25	.008	0.89
	A12	64.93	23.43	6.17	1.09	0.52	1.46	1.20	.001	0.85
	B21	53.10	28.96	9.56	0.72	1.38	1.84	1.23	.001	0.56
	B22	55.48	27.73	10.23	0.64	1.54	1.88	0.95	.001	0.50
	B23	52.58	28.75	10.28	0.89	1.59	1.89	1.16	.001	0.70
	B32	50.05	31.08	11.19	0.98	2.10	1.90	0.95	.001	0.70
	B3/C	51.34	29.62	11.17	1.22	1.21	1.83	1.22	.001	0.96
F1	AP	41.50	24.51	10.03	8.00	4.70	2.51	1.08	.025	6.29
	AC	49.15	27.78	10.11	2.90	3.34	2.44	0.96	.029	2.28
	C1	46.92	24.84	10.19	4.64	4.52	2.87	1.01	.042	3.66
	C2	55.84	21.26	10.82	1.43	4.50	2.37	0.90	.005	1.12
	C3	50.67	24.17	10.98	2.13	5.74	2.45	0.84	.004	1.67
	C4	53.55	23.38	9.17	2.57	2.64	2.27	1.22	.001	2.02
	C5	49.90	25.42	10.79	2.36	4.73	2.75	0.91	.009	1.85
	C6	40.10	30.89	12.76	2.33	7.99	2.50	1.02	.001	1.83
	C7	49.55	24.52	10.28	5.82	2.29	2.15	0.58	.001	4.58
F2	A	55.30	27.06	8.57	0.80	2.10	1.68	1.20	.001	0.62
	B1	56.95	26.55	9.12	0.70	1.75	1.74	1.12	.001	0.55
	B21	57.14	26.40	11.19	0.70	0.86	1.76	0.82	.002	0.55
	B22	42.59	27.44	11.27	6.57	3.67	1.70	0.40	.002	5.17
	C1	46.90	24.72	10.67	5.67	4.33	1.81	0.51	.002	4.46

APPENDIX V

PEDON	HORI-	pH	EC	ORGANIC	SULPHUR	Cu	Mn	Zn
Nos.	ZON		mmhos/cm	CARBON(%)			(ppm)	
M1	AP	8.54	0.109	0.73	0.0031	53.75	470.00	77.50
	C1	8.29	0.088	0.17	0.0251	65.00	595.00	56.25
	C2	8.28	0.065	0.10	0.0571	53.75	757.50	21.25
M2	AP	7.40	5.230	0.27	0.0171	2515.00	606.25	5.00
	C1	7.68	2.310	0.25	0.0242	405.00	596.00	10.00
	C2	8.03	1.500	0.21	0.1727	540.00	380.00	11.25
P1	A	8.72	0.207	0.29	0.0037	35.00	583.65	46.25
	B11	8.53	0.184	0.17	0.0038	10.00	628.75	46.25
	B12	8.57	0.201	0.12	0.0030	18.75	651.25	47.50
	B21	8.58	0.216	0.10	0.0037	21.25	630.00	47.50
	B22	8.59	0.214	0.10	0.0052	42.50	672.50	47.50
	B3	8.60	0.081	0.10	0.0036	7.50	467.50	46.25
	C	8.62	0.056	0.10	0.0976	65.00	301.25	20.00
P2	A	8.84	0.038	0.32	0.0095	95.00	258.75	67.50
	B21	9.05	0.018	0.32	0.0058	108.75	513.75	42.50
	B22	9.26	0.063	0.23	0.0036	168.75	567.50	30.00
	B31	9.34	0.138	0.13	0.0019	98.25	735.00	27.50
	B32	9.51	0.109	0.16	0.0682	103.75	495.00	27.50
	C	9.53	0.426	0.13	0.0547	163.75	462.50	27.50
P3	A	9.10	0.426	0.22	0.0032	228.75	615.00	27.50
	B1	9.90	0.883	0.20	0.0020	200.00	920.00	28.75
	B2	9.97	0.567	0.18	0.0018	198.75	590.00	27.50
	B3	9.94	0.546	0.10	0.0040	13.75	437.50	47.50
	C	9.63	0.376	0.10	0.0011	2.50	396.25	47.50
YP1	AP1	7.83	0.288	0.54	0.0033	30.00	318.75	46.25
	AP2	7.90	0.013	0.41	0.0041	35.00	288.75	47.50
	B21	8.17	0.084	0.23	0.0046	61.25	348.75	67.50
	B22	8.37	0.093	0.22	0.0029	32.50	345.00	46.25
	B31	8.27	0.053	0.22	0.0038	22.50	407.50	52.50
	B32	8.48	0.043	0.10	0.0021	45.00	1161.25	52.50
Y1	AP	8.41	0.259	0.88	0.0087	33.75	530.00	46.25
	AB	8.43	0.104	0.37	0.0057	31.25	521.25	46.25
	B3	8.38	0.059	0.30	0.0064	20.00	757.50	46.25
	C1	8.44	0.060	0.16	0.0063	28.75	740.00	47.50
	C2	8.28	0.063	0.15	0.0057	31.25	687.50	46.25
Y2	AP1	8.50	0.455	0.32	0.0184	228.75	438.75	31.25
	AP2	8.35	0.455	0.27	0.0084	295.00	425.00	28.75
	B	8.84	0.522	0.26	0.0043	126.25	587.50	30.00
	C1	8.89	0.781	0.25	0.0099	98.75	1015.00	32.50
	C2	9.05	0.640	0.24	0.0099	111.25	496.25	27.50

APPENDIX V (Continued)

PEDON Nos.	HORIZON	pH	EC mmhos/cm	ORGANIC CARBON(%)	SULPHER(%)	Cu	Mn	Zn
						------	(ppm)	---------
Y3	AP	8.60	0.094	0.33	0.0115	198.75	313.75	28.75
	AC	8.53	0.136	0.10	0.0519	207.50	295.00	28.75
	C1	8.50	0.151	0.10	0.0052	378.75	555.00	28.75
	C2	8.50	0.933	0.10	0.0036	422.50	370.00	27.50
G1	AP	8.05	0.017	0.25	0.0042	22.50	355.00	46.25
	AB	8.38	0.047	0.20	0.0046	18.75	465.00	47.50
	B21	8.55	0.051	0.19	0.0052	1.25	870.00	47.50
	B22	8.65	0.069	0.15	0.0042	117.50	778.75	47.50
G2	AP	8.30	0.320	0.21	0.0430	7.50	433.75	48.25
	B21	8.64	0.315	0.10	0.0051	33.75	601.25	51.25
	B22	9.02	0.427	0.10	0.0053	33.75	575.00	52.50
	C	8.83	0.559	0.10	0.0042	23.75	573.75	52.50
K1	A11	9.19	2.710	0.69	0.1242	25.00	390.00	48.75
	A12	8.72	3.640	0.39	0.0003	16.25	480.00	46.25
	B21	8.75	4.400	0.29	0.3001	10.00	495.00	48.25
	B22	8.80	3.320	0.27	0.2765	25.00	563.75	50.00
	B31	9.30	1.120	0.31	0.1320	13.75	613.75	47.50
	B32	8.82	0.660	0.13	0.0073	46.25	602.50	50.00
	C	8.84	0.423	0.10	0.0107	31.25	575.00	48.25
K2	AP	8.48	0.526	0.66	0.0173	1.25	661.25	11.25
	B1	8.49	0.223	0.32	0.0063	1.25	575.00	11.25
	B21	8.49	0.124	0.13	0.0048	1.25	652.50	41.25
	B22	8.27	0.129	0.19	0.0046	77.50	930.00	13.75
	B3	8.25	0.116	0.14	0.0083	87.50	1391.25	71.25
	C	8.29	0.162	0.15	0.0037	75.00	595.00	6.25
K3	AP	8.30	0.238	0.53	0.0042	70.00	501.25	56.25
	AC	8.46	0.198	0.26	0.0026	52.50	428.75	53.75
	C1Ca	8.49	0.149	0.42	0.0041	42.50	527.50	55.00
	C2Ca	8.48	0.168	0.24	0.0061	100.50	600.00	53.75
	C4Ca	8.49	0.168	0.22	0.0045	45.00	533.75	48.75
	C5Ca	8.51	0.174	0.10	0.0049	60.00	522.50	50.00
K4	A	8.37	3.240	0.66	0.1213	2.50	576.25	46.25
	AC	8.70	3.660	0.19	0.0043	2.50	573.75	52.50
	C1	8.74	7.730	0.28	0.0985	1.25	558.75	47.50
	C2	8.45	11.900	0.27	0.0625	22.50	551.25	53.75
	C3	8.61	0.620	0.30	0.0115	347.50	415.00	62.50
	C4	8.63	0.523	0.20	0.0141	17.50	635.00	47.50
	C5	8.66	0.450	0.20	0.0108	30.00	640.00	55.00
	C6	8.70	0.471	0.18	0.0082	41.25	597.75	47.50
	C7	8.72	0.446	0.16	0.0113	16.25	637.50	47.50
	C8	8.73	0.649	0.11	0.0126	128.75	717.50	46.25

APPENDIX V (CONTINUED)

PEDON Nos.	HORI- ZON	pH	EC mmhos/cm	ORGANIC CARBON(%)	SULPHER(%)	Cu(ppm)	Mn(ppm)	Zn(ppm)
R1	AP	8.73	2.620	0.58	0.0055	141.25	550.00	28.75
	B1	9.80	4.730	0.37	0.0240	75.00	376.25	31.25
	B2	10.30	0.170	0.10	0.0716	113.75	658.75	46.25
	C	9.36	0.020	0.10	0.0048	157.50	442.50	28.75
R2	A11	10.25	11.560	0.21	0.1826	2.50	413.75	50.00
	A12	10.25	7.570	0.17	0.0488	30.00	507.50	18.75
	B1	9.65	3.150	0.27	0.0116	21.25	628.75	23.75
	B21	9.36	1.660	0.12	0.0089	30.00	563.75	52.50
	B22	9.10	0.710	0.10	0.0067	41.25	673.75	72.50
	B3Ca	9.10	1.050	0.10	0.0090	56.25	557.50	30.00
	CCa	9.10	1.110	0.10	0.0122	32.50	646.25	65.00
R3	AP	8.76	0.196	0.15	0.0052	1025.00	475.00	63.75
	AB	8.49	0.332	0.10	0.0066	1306.25	528.75	40.00
	B	8.66	0.653	0.10	0.0096	313.75	432.50	27.50
	C	8.77	0.635	0.10	0.0042	1735.00	408.75	42.50
R4	A	9.84	20.040	0.24	0.2051	1541.25	502.50	46.25
	AC	9.06	1.610	0.13	0.0262	855.00	528.75	31.25
	C1	9.22	0.852	0.12	0.0079	208.75	1576.25	35.00
	C2	8.93	0.698	0.10	0.0125	563.75	475.00	30.00
R5	AP	8.53	0.441	0.42	0.0146	843.75	547.50	38.75
	B1	8.72	0.290	0.14	0.0125	1435.00	575.00	40.00
	B2	8.70	0.287	0.10	0.0768	251.25	646.25	31.25
	C	8.46	0.158	0.10	0.0424	335.00	957.50	33.75
R6	A11	7.97	6.450	0.92	0.0434	2081.25	686.25	27.50
	A12	7.89	5.160	0.81	0.0358	565.00	647.50	26.25
	B2	8.13	3.180	0.42	0.1281	592.50	507.50	13.75
	B3	8.21	1.870	0.17	0.0547	482.50	643.75	27.50
	C1	8.16	1.880	0.35	0.0563	545.00	550.00	30.00
	C2	8.26	1.580	0.32	0.0406	533.75	566.25	11.25
R7	AP	8.05	1.640	0.28	0.1518	671.25	592.50	36.25
	AB	8.10	0.770	0.24	0.0795	470.00	601.25	37.50
	B21	8.33	0.512	0.22	0.0037	513.75	632.50	32.50
	B22	8.43	0.421	0.20	0.1144	1132.50	643.75	36.25
R8	AP	8.14	0.515	0.25	0.0078	905.00	360.00	50.00
	B21	8.60	0.433	0.10	0.1030	481.25	406.25	30.00
	B3	8.35	0.660	0.10	0.0120	280.00	798.75	35.00
	C	8.80	1.110	0.10	0.0134	1598.75	463.75	33.75
R9	AP	8.67	0.264	0.22	0.0031	130.00	422.50	52.50
	AB	8.55	0.205	0.20	0.0056	328.75	520.00	55.00
	B2	8.52	0.187	0.18	0.0026	122.50	317.52	53.75
	B3	8.35	0.253	0.18	0.0032	56.25	647.50	55.00
	C1	8.62	0.223	0.15	0.0031	168.75	616.25	55.00

APPENDIX V (CONTINUED)

PEDON Nos.	HORI-ZON	pH	EC mmhos/cm	ORGANIC CARBON(%)	SULPHER(%)	-----(ppm)-------		
						Cu	Mn	Zn
D1	AP	8.50	0.396	0.82	0.0063	13.75	546.25	46.25
	B1	9.03	0.632	0.30	0.0069	32.50	685.00	46.25
	B21	9.28	1.116	0.51	0.0153	41.50	648.75	47.25
	B22	9.15	0.945	0.28	0.0064	37.50	706.25	50.00
	B23	9.19	0.869	0.27	0.0072	41.50	463.75	48.75
	C	9.17	0.747	0.12	0.0060	153.75	530.00	81.25
D2	AP	8.50	0.400	0.57	0.0599	58.75	687.50	47.50
	AB	8.03	0.261	0.10	0.0725	26.25	687.50	47.50
	B11	8.50	0.194	0.10	0.0722	38.75	917.50	51.25
	B21	8.56	0.134	0.10	0.0020	51.25	951.25	60.00
	B22	8.60	0.118	0.10	0.0038	41.25	753.75	47.50
	B3	8.63	0.128	0.10	0.0035	32.50	747.50	73.75
D3	AP	8.41	0.218	0.50	0.0173	83.75	486.25	6.25
	B21	8.53	0.140	0.32	0.1090	96.25	496.25	63.75
	B22	8.52	0.102	0.20	0.0044	88.75	440.00	36.25
	C1	8.36	0.081	0.19	0.0049	92.50	586.25	43.75
	C2	8.53	0.081	0.15	0.0029	98.75	530.00	73.75
D4	AP	8.51	0.620	1.03	0.0114	2.50	493.75	62.50
	B21	8.56	0.610	0.88	0.0181	8.75	533.75	61.25
	B22	8.40	10.150	0.63	0.0222	17.50	533.75	63.75
	B31	8.53	1.750	0.25	0.0292	38.75	551.25	41.25
	B33	8.60	0.900	0.24	0.0403	65.00	610.00	30.00
D5	A11	8.63	51.500	0.40	0.4846	51.25	423.75	22.50
	A12	8.60	2.500	0.39	0.0827	41.25	490.00	27.50
	B1	8.69	0.602	0.57	0.0173	38.75	508.75	23.75
	B21	8.75	0.843	0.16	0.0152	18.75	486.25	13.75
	B22	8.83	0.588	0.39	0.0169	33.75	498.75	10.00
	C	8.65	0.620	0.27	0.0249	11.25	425.00	11.25
D6	AP	8.62	0.203	0.18	0.0078	26.25	630.00	46.25
	B21	8.54	0.168	0.40	0.0048	32.50	605.00	47.50
	B22	8.40	0.181	0.10	0.0306	15.00	650.00	47.50
	B31	8.37	0.194	0.10	0.0027	15.00	623.75	46.25
	B32	8.17	0.198	0.09	0.1779	21.25	681.25	48.75
D7	A	8.70	0.320	0.13	0.0413	1.25	447.50	78.75
	C1	8.42	0.876	0.12	0.0369	7.50	396.25	57.50
	C2	8.45	0.165	0.10	0.3830	25.00	483.75	106.25
	C3	8.00	2.810	0.10	0.0645	8.75	526.25	62.50

APPENDIX V (CONTINUED)

PEDON	HORI	pH	EC	ORGANIC	SULPHER(%)	-----(ppm)------		
Nos.	-ZON		mmhos/cm	CARBON(%)		Cu	Mn	Zn
D8	AP	8.64	7.460	0.73	0.1908	66.25	441.25	50.00
	A12	8.60	1.340	0.27	0.0285	50.00	487.50	50.00
	B21	8.50	2.930	0.24	0.1157	52.50	760.00	50.00
	B22	8.54	1.730	0.18	0.0789	76.25	592.50	46.25
	B23	8.56	2.630	0.10	0.1134	85.00	568.75	51.25
	B32	8.44	1.420	0.10	0.0504	81.25	613.75	52.50
	B3/C	8.58	6.850	0.10	0.1313	88.75	541.25	51.25
F1	AP	8.19	8.410	0.45	0.2309	105.00	622.50	50.00
	AC	8.20	7.900	0.23	0.8281	1271.25	675.00	50.00
	C1	8.28	4.610	0.20	0.7615	887.50	713.75	50.00
	C2	8.04	4.600	0.59	0.0002	28.75	652.50	58.75
	C3	8.11	4.600	0.55	0.7163	30.00	533.75	46.25
	C4	8.18	6.130	0.40	0.7705	22.50	518.75	46.25
	C5	8.28	8.620	0.33	0.3781	20.00	438.75	46.25
	C6	8.35	7.800	0.32	0.1449	63.75	455.00	46.25
	C7	8.45	6.160	0.10	0.1604	242.50	766.25	55.00
F2	A	7.96	11.660	0.26	0.0977	3906.25	573.75	48.75
	B1	7.90	9.810	0.10	0.0643	5931.25	626.25	47.50
	B21	8.13	5.760	0.10	0.0258	645.00	630.00	47.50
	B22	8.63	1.710	0.10	0.0217	973.75	642.50	48.75
	C1	8.30	0.330	0.10	0.0073	470.00	631.25	50.00

APPENDIX VI

PEDON Nos.	HORIZON		CLAY MINERAL PERCENTAGES		
		VERMICULITE	CHLORITE	KAOLINITE	ILLITE
M1	AP	6.12	14.29	36.63	42.86
	C1	6.12	14.29	36.63	42.86
	C2	4.91	11.48	32.79	42.63
M2	AP	3.70	12.35	34.57	49.38
	C1	0.00	16.66	33.34	50.00
	C2	3.70	9.26	24.08	62.96
P1	A	11.11	0.00	38.89	50.00
	B11	19.35	0.00	38.70	41.95
	B12	19.65	0.00	42.43	37.88
	B21	16.95	0.00	38.98	44.07
	B22	14.58	0.00	37.50	47.92
	B3	15.91	0.00	38.64	45.45
	C	16.13	0.00	32.36	51.61
P2	A	7.83	0.00	56.52	35.65
	BP21	8.64	4.94	30.86	55.56
	B22	6.49	12.98	32.46	48.05
	B31	7.25	7.25	33.33	52.17
	B32	17.33	0.00	30.67	52.00
	C	4.17	0.00	39.50	58.33
P3	A	9.40	0.00	28.21	62.39
	B1	2.82	4.93	30.98	61.27
	B2	5.26	5.26	30.27	59.21
	B3	4.08	6.12	23.47	66.33
	C	3.66	6.10	21.95	68.29
YP1	AP1	0.00	0.00	0.00	100.00
	AP2	0.00	0.00	0.00	100.00
	B21	0.00	0.00	28.57	71.43
	B22	0.00	0.00	32.00	68.00
	B31	0.00	0.00	0.00	100.00
	B32	13.51	0.00	21.62	64.87
Y1	AP	12.50	0.00	30.35	57.15
	AB	2.47	8.64	35.80	53.09
	B3	2.81	9.85	36.61	52.11
	C1	9.26	11.11	0.00	79.63
	C2	0.00	0.00	0.00	0.00
Y2	AP1	5.83	6.66	24.15	63.30
	AP2	1.74	6.96	23.48	67.82
	B	1.23	12.35	27.78	58.64
	C1	0.00	13.17	38.46	48.35
	C2	0.00	5.32	23.40	71.28

APPENDIX VI (CONTINUED)

PEDON Nos.	HORIZON		CLAY MINERAL PERCENTAGES		
		VERMICULITE	CHLORITE	KAOLINITE	ILLITE
Y3	AP	6.01	7.52	22.56	63.91
	AC	2.92	5.11	24.09	67.88
	C1	10.97	25.60	25.60	58.53
	C2	0.00	0.00	0.00	0.00
G1	AP	22.73	0.00	0.00	77.27
	AB	21.05	0.00	0.00	78.95
	B21	16.67	0.00	0.00	83.33
	B22	19.23	0.00	0.00	80.77
G2	AP	0.00	12.19	31.71	56.10
	B21	6.55	6.56	29.51	57.37
	B22	8.57	7.14	27.14	57.15
	C	7.94	6.35	34.92	50.79
K1	A11	8.11	5.40	28.38	58.11
	A12	3.28	6.56	29.51	60.65
	B21	5.26	8.77	31.58	54.39
	B22	6.55	6.58	29.51	57.38
	B31	5.71	8.57	28.57	57.15
	B32	4.44	8.89	28.89	57.78
	C	8.57	5.70	28.58	57.14
K2	AP	0.00	0.00	21.74	78.26
	B1	0.00	0.00	30.00	70.00
	B21	0.00	0.00	22.50	77.50
	B22	0.00	0.00	30.77	69.23
	B3	0.00	0.00	34.00	66.00
	C	0.00	0.00	30.00	70.00
K3	AP	9.26	0.00	29.63	61.11
	AC	18.52	0.00	35.18	46.30
	C1Ca	12.96	0.00	25.92	61.12
	C2Ca	16.94	0.00	28.81	49.15
	C3Ca	11.86	0.00	27.12	61.02
	C4Ca	5.45	9.09	30.91	54.55
	C5Ca	5.45	9.09	30.91	54.55
K4	A	2.98	7.46	22.39	67.17
	AC	6.25	3.75	25.00	65.00
	C1	4.61	4.62	26.15	64.62
	C2	5.19	6.49	31.17	57.15
	C3	1.78	8.93	30.36	58.93
	C4	6.98	6.97	34.88	51.17
	C5	5.48	5.47	31.50	57.55
	C6	8.10	6.76	35.14	50.00
	C7	6.67	8.33	35.00	50.00
	C8	0.00	10.00	46.00	44.00

APPENDIX VI (CONTINUED)

PEDON Nos.	HORI-ZON	CLAY MINERAL PERCENTAGES VERMI-CULITE	CHLORITE	KAOLINITE	ILLITE
D7	A	0.00	0.00	0.00	100.00
	C1	0.00	0.00	0.00	100.00
	C2	0.00	0.00	0.00	100.00
	C3	0.00	0.00	48.57	31.43
D8	AP	9.80	0.00	27.45	62.75
	A12	7.27	7.27	25.46	60.00
	B21	10.34	6.90	25.86	56.90
	B22	4.16	8.34	31.25	56.25
	B23	11.33	0.00	32.07	50.94
	B32	12.24	0.00	26.53	61.23
	B3/C	14.58	0.00	27.08	58.34
F1	AP	0.00	5.45	21.82	72.73
	AC	0.00	12.50	25.00	62.50
	C1	0.00	11.66	21.67	66.67
	C2	3.64	9.09	23.64	63.63
	C3	4.65	11.63	32.56	51.16
	C4	3.28	8.20	22.95	65.57
	C5	0.00	13.16	26.31	60.63
	C6	3.13	10.94	35.93	50.00
	C7	5.97	11.94	32.84	49.25
F2	A	0.00	11.36	34.09	54.55
	B1	0.00	15.15	21.21	63.64
	B21	0.00	10.34	24.14	65.52
	B22	0.00	0.00	29.17	70.83
	C1	0.00	11.11	22.22	66.67

APPENDIX VI (CONTINUED)

PEDON Nos.	HORIZON	CLAY MINERAL PERCENTAGES			
		VERMICULITE	CHLORITE	KAOLINITE	ILLITE
R1	AP	0.00	0.00	18.60	81.40
	B1	0.00	0.00	0.00	100.00
	B2	0.00	0.00	22.64	77.36
	C	3.38	3.39	10.17	83.05
R2	A11	4.35	5.80	28.98	60.87
	A12	3.08	9.23	27.69	60.00
	B1	6.76	9.46	36.48	47.30
	B21	5.45	5.45	27.28	61.82
	B22	2.50	8.75	31.25	57.50
	B3Ca	7.86	11.24	30.34	50.56
	CCa	5.13	10.26	28.20	56.41
R3	AP	5.08	8.48	23.73	26.71
	AB	3.66	6.10	25.60	64.64
	B	1.54	10.77	26.15	61.54
	C	0.00	0.00	25.00	75.00
R4	A	4.49	3.37	22.47	69.67
	AC	1.78	8.93	30.36	58.93
	C1	0.00	9.59	21.92	68.49
	C2	0.00	10.81	30.63	58.56
R5	AP	0.00	9.80	27.45	62.75
	B1	0.00	9.43	24.53	66.24
	B2	0.00	11.47	26.23	62.30
	C	0.00	0.00	23.80	76.20
R6	A11	2.70	7.20	18.02	72.08
	A12	2.00	7.70	32.69	57.61
	B2	2.00	8.33	25.00	64.67
	B3	2.94	11.76	22.06	63.24
	C1	2.17	2.17	19.57	76.09
	C2	1.10	6.04	25.82	67.04
R7	AP	4.54	0.00	0.00	95.46
	AB	4.60	0.00	0.00	95.40
	B21	12.87	0.00	0.00	87.13
	B22	3.07	6.15	30.70	60.00
R8	AP	2.00	6.00	26.00	68.00
	B21	11.42	0.00	0.00	88.58
	B3	1.65	6.61	27.27	64.47
	C	6.25	7.03	29.69	57.03

APPENDIX VI (CONTINUED)

PEDON	HORI-		CLAY MINERAL PERCENTAGES		
		VERMI-CULITE	CHLORITE	KAOLINITE	ILLITE
R9	Ap	0.00	11.36	22.73	65.91
	AB	2.00	6.00	26.00	66.00
	B2	2.33	9.30	18.60	69.77
	B3	2.50	10.00	25.00	62.50
	C1	1.85	7.41	18.52	72.20
D1	AP	4.35	10.14	33.33	47.83
	B1	4.28	10.00	32.86	47.14
	B21	5.88	7.84	32.35	47.05
	B22	0.00	14.49	21.57	29.41
	B23	2.43	10.98	31.70	52.25
	C	5.55	10.00	31.11	47.78
D2	AP	10.00	0.00	30.00	55.71
	AB	11.94	0.00	29.85	53.73
	B11	12.76	0.00	23.40	57.45
	B21	13.55	0.00	23.73	59.32
	B22	10.71	0.00	32.14	53.57
	B3	13.33	0.00	25.00	61.67
D3	AP	0.00	0.00	23.40	76.60
	B21	0.00	0.00	16.28	83.72
	B22	0.00	0.00	14.63	85.37
	C1	0.00	0.00	0.00	100.00
	C2	0.00	0.00	17.50	82.50
D4	AP	6.00	6.00	22.67	65.33
	B21	4.26	6.38	27.66	61.70
	B22	7.69	11.54	26.92	53.85
	B31	3.70	6.17	12.35	77.78
	B33	1.94	7.77	24.27	66.02
D5	A11	4.88	4.87	24.39	65.86
	A12	2.24	3.73	19.40	74.63
	B1	2.78	5.55	13.89	77.78
	B21	2.78	5.55	13.89	77.78
	B22	0.00	0.00	25.00	75.00
	C	0.00	0.00	15.79	84.21
D6	AP	8.88	8.89	22.23	60.00
	B21	6.98	6.98	23.25	62.79
	B22	16.13	0.00	16.13	67.74
	B31	13.95	0.00	18.60	58.15
	B32	15.00	0.00	15.00	70.00

APPENDIX VII

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1 PCA OF DATA OF SINGHAI

 CORRELATION MATRIX

 SILT.1              1.000
 CLAY.2             0.1385E-01  1.000
 SIO2.3            -0.3855    -0.1164       1.000
 AL2O3.4            0.3706     0.1001    -0.3952       1.000
 FE2O3.5            0.4913     0.1402    -0.5175     0.7669       1.000
 TIO2.6             0.2321E-01 0.9858E-01 0.1313E-01 0.6865E-02 0.5658E-01  1.000
 CAO.7              0.2795E-02 0.1748E-01-0.6361    -0.4156    -0.2199    -0.4868E-01  1.000
 MGO.8              0.2618     0.1470    -0.6085     0.3792E-01 0.2039     0.1624E-01 0.4396       1.000
 K2O.9              0.3700     0.1732    -0.3857     0.4973     0.6412     0.1300    -0.1567     0.3035       1.000
 NA2O.10           -0.2781E-01-0.9400E-01-0.5637E-01 0.2497E-01-0.9043E-01 0.9298E-02-0.1895E-01 0.6202E-01 0.2316       1.000
 P2O5.11           -0.5172E-01-0.4251E-01 0.9000E-01-0.2666    -0.2129     0.3380     0.7341E-01 0.1206     0.1754     0.3028
 CU.12             -0.6178E-02 0.1041    -0.1348     0.2042E-02 0.5128E-01-0.9483E-01 0.9578E-01 0.2124     0.2650     0.1085
 MN.13              0.2110     0.1067    -0.3459     0.2854     0.4797     0.1190     0.7041E-01 0.1166     0.2360    -0.1663
 ZN.14              0.6711E-01-0.1037     0.2052E-01 0.1518     0.1578    -0.1782    -0.1580    -0.6910E-01 0.1170     0.5170E-02
 SI+CL.15           0.9081     0.4314    -0.3965     0.3765     0.5020     0.6224E-01 0.9844E-02 0.2978     0.4064    -0.6446E-01
 SI/AL16           -0.3932    -0.1188     0.5033    -0.8042    -0.7400    -0.5437E-01 0.2028    -0.2998    -0.4729    -0.2180E-01
 SIO2/FE2O3.17     -0.4810    -0.1380     0.7917    -0.6687    -0.8649    -0.5528E-01-0.1543    -0.4183    -0.6156     0.1099E-01
 SI/AL+FE.18       -0.4295    -0.1285     0.6184    -0.8143    -0.7957    -0.4989E-01 0.1012    -0.3393    -0.5252    -0.1735E-01
 CAMGNAK/AL.19     -0.9409E-01-0.3917E-02-0.3280    -0.3739    -0.3076    -0.8877E-01 0.6886     0.8394E-01-0.1257     0.1301E-01
 PH.20              0.1162    -0.7144E-02 0.6334E-02 0.1378     0.1121    -0.5998E-01-0.1480     0.6760E-01-0.9736E-01 0.7930E-01
 EC.21              0.9153E-01 0.1614E-01-0.3471E-04-0.6857E-01-0.8859E-01 0.1001    -0.6746E-02 0.1125     0.1646     0.6590
 OR.CAR.22         -0.2819E-01 0.7572E-01 0.2064    -0.1874    -0.1464     0.1540    -0.7974E-01-0.7054E-01 0.1346E-01 0.1822E-01
 SULPHUR.23         0.9686E-01 0.4751E-01-0.9012E-01-0.9003E-02 0.1368E-01-0.7522E-01 0.2168E-01 0.2317     0.3902     0.3111
 AV.DEP.24          0.1357E-01-0.4322E-01-0.3185     0.1277     0.2297    -0.1119     0.2008     0.1938     0.1259    -0.2940E-02
 VERMI.25           0.4870E-01 0.1901E-01 0.4295E-01 0.1373     0.6585E-01-0.1643    -0.9360E-01-0.2182    -0.1531    -0.1689
 CHLORITE.26        0.7061E-01-0.2669E-01-0.2341     0.9013E-01 0.9366E-01-0.7728E-01 0.1256     0.2250     0.1320     0.1800
 KAOLINITE.27       0.1665     0.4478E-01-0.2441     0.7869E-01 0.1473    -0.1290     0.1557     0.1845     0.2336E-01 0.3994E-01
 ILLITE.28         -0.1037     0.7102E-01 0.2181    -0.1690    -0.1898     0.1605    -0.8747E-01-0.9440E-01 0.1064E-01 0.1997E-01


 P2O5.11             1.000
 CU.12              0.2045       1.000
 MN.13             -0.9741E-01-0.5550E-02  1.000
 ZN.14             -0.6616E-01-0.1198     0.3246E-01  1.000
 SI+CL.15          -0.6447E-01 0.3804E-01 0.2351     0.1713E-01  1.000
 SI/AL16            0.2232    -0.5096E-01-0.3125    -0.1191    -0.4045       1.000
 SIO2/FE2O3.17      0.1601    -0.9519E-01-0.4702    -0.8533E-01-0.4918     0.7899       1.000
 SI/AL+FE.18        0.2189    -0.6639E-01-0.3624    -0.1098    -0.4414     0.9841     0.8791       1.000
 CAMGNAK/AL.19      0.1079     0.5840E-01-0.5167E-01-0.1747    -0.8653E-01 0.5490     0.8526E-01 0.4124       1.000
 PH.20             -0.4913E-01-0.1821    -0.4021E-02-0.2196E-01 0.1018    -0.1055    -0.4588E-01-0.8779E-01-0.1271       1.000
 EC.21              0.4019     0.1862    -0.8963E-01-0.6870E-01 0.8935E-01 0.2185E-01 0.6025E-01 0.3340E-01 0.1601E-01 0.1775E-01
 OR.CAR.22          0.2161     0.5215E-01-0.8101E-01-0.4180E-01 0.6286E-02 0.1798     0.1694     0.1915    -0.2341E-01-0.1697
 SULPHUR.23         0.2980     0.3981    -0.1616E-01 0.7570E-01 0.1073    -0.9012E-02-0.3850E-01-0.1939E-01 0.7726E-01-0.1318
 AV.DEP.24         -0.7460E-01-0.8024E-01 0.2182     0.3638E-01-0.5865E-02-0.1756    -0.2822    -0.2088     0.2592E-01 0.8227E-01
 VERMI.25          -0.2500    -0.2013     0.1035     0.1660     0.5190E-01-0.4147E-01 0.2177E-01-0.3105E-01-0.6216E-01 0.1321E-01
 CHLORITE.26        0.4654E-01 0.1354     0.6470E-01-0.2657E-01 0.5253E-01-0.7838E-01-0.1766    -0.1089     0.8546E-01-0.3847E-02
 KAOLINITE.27      -0.2930E-01-0.1697E-01 0.1013    -0.8229E-02 0.1690    -0.7321E-01-0.1737    -0.9875E-01 0.4447E-01 0.1729
 ILLITE.28          0.1288     0.3668E-01-0.1109    -0.3599E-01-0.6377E-01 0.1188     0.2027     0.1432    -0.1987E-01-0.1165


 EC.21               1.000
 OR.CAR.22          0.1508       1.000
 SULPHUR.23         0.4550     0.8542E-01  1.000
 AV.DEP.24         -0.1146    -0.3348     0.3837E-02  1.000
 VERMI.25          -0.1074    -0.7827E-01-0.1238    -0.1027E-02  1.000
 CHLORITE.26        0.1252     0.2947E-01 0.1514     0.1895E-01-0.2085       1.000
 KAOLINITE.27       0.4309E-01 0.1296E-01-0.2817E-01 0.1897     0.4731E-01 0.2193       1.000
 ILLITE.28          0.1921E-02 0.8401E-01 0.5231E-01-0.2058    -0.2228    -0.4043    -0.5743       1.000
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