A HOLOCENE SOIL-CHRONOASSOCIATION OF THE GANGETIC PLAINS BETWEEN RAMGANGA AND RAPTI RIVERS

A THESIS

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requirements for the award of the degree
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By

PANKAJ SRIVASTAVA

Professor and Head
Department of Earth Sciences
University of Roorkee
ROORKEE

7-9-92

DEPARTMENT OF EARTH SCIENCES
UNIVERSITY OF ROORKEE
ROORKEE-247 667 (INDIA)

JULY, 1992


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to amma and papa

CANDIDATE'S DECLARATION

I hereby certify that the work, which is being presented in the thesis entitled **"A HOLOCENE SOIL-CHRONOASSOCIATION OF THE GANGETIC PLAINS BETWEEN RAMGANGA AND RAPTI RIVERS"** 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 *June*, 1988 to September 1992 under the supervision of **Dr. B. Parkash** and **Dr. J.L. Sehgal.**

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

Pankaj Srivastava

PANKAJ SRIVASTAVA

Candidate's Signature

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

Signature of Supervisors

JLSehgal

Dr. J.L. SEHGAL
Director,
National Bureau of Soil Survey
and Land Use Planning,
Amravati Road,
NAGPUR- 440 010

B Parkash

Dr. B. PARKASH
Professor of Geology,
Department of Earth Sciences,
University of Roorkee,
ROORKEE- 247 667

The Ph.D. Viva-Voce examination of **Mr. Pankaj Srivastava**, Research Scholar was held on 19.8.93.

JLSehgal 19/8/93

Signature of Guides

B M Singh 19/8/93

Signature of External Examiner

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Pankaj Srivastava

(PANKAJ SRIVASTAVA)

ABSTRACT

Fourteen soil-geomorphic units have been delineated from the Gangetic plains between the Ramganga and Rapti rivers. The units delineated are based on remote sensing studies and field checks. One additional unit immediately east of the study area, described earlier by Mohindra et al. (in press), and named here as the Lower Deoha/Ganga-Ghaghra unit also has been included. On the basis of degree of soil profile development, these units have been grouped into five members (QGH1 to QGH5, QGH5 being the oldest) of a soil chronoassociation. The member QGH1 (age < 500 yrs. B.P.) includes soils of floodplains of the Ghaghra and Rapti, Kosi-Gola Piedmont, Gholia-Dhobania-Bhambhar Piedmont and Young Sihali-Mohan-Kandra Piedmont. QGH2 member (age > 500 yrs. B.P.) comprises soils of the Upper Kosi-Gola Plain, Old Ghaghra Plain and Old Sihali-Mohan-Kandra Piedmont. Soils of the Lower Kosi-Gola Plain, Upper Rapti-Ghaghra Interfluve, Upper Deoha/Ganga-Ghaghra Interfluve and Old Ghaghra Bar are included in QGH3 member (age > 2500 yrs. B.P.). The QGH4 member (age > 6500 yrs. B.P.) includes soils of the Lower Deoha/Ganga-Ghaghra Interfluve. Soils Of the Middle Deoha/Ganga-Ghaghra Interfluve and Lower Rapti-Ghaghra Interfluve are included in the QGH5 member (age 9000 to 11000 yrs. B.P.).

Pedological studies suggest that conditions favourable for formation of pedogenic calcrete in the Gangetic Plains prevailed from 11000 to 6500 yrs. B.P. Amelioration of climate and improved drainage resulted in large scale to complete removal of calcrete

from soil profile in some areas or its dissolution and reprecipitation in lower horizons in other areas.

Neotectonics seems to have played a significant role in evolution of morphology and soils of the study area. It determined areas of active sedimentation and pedogenesis (in upland areas). It led to tilting and sagging of large blocks. Tectonic slopes/faults determined direction of courses of large rivers.

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1.1 INTRODUCTION

The Indogangetic Plains need to be studied in depth for the following reasons:

i. The Indogangetic Basin is a typical foredeep basin formed due to collision of India and China plates. The present pedogenic and sedimentation processes in this basin are essentially the continuation of those prevailing since Mid. Miocene (Parkash et al., 1980). Thus, the study of these processes in the Indogangetic Plains may help to understand the genesis of the older rocks such as the Siwalik Supergroup (Mid Miocene to Lower Pleistocene), thought to be of similar origin.

ii. The Indogangetic Plains support about 1/3 population of the country with basically an agricultural economy. Any understanding of the soils in these plains should provide ideas for better management of this important resource.

iii. These plains have been affected by neotectonism (Parkash and Kumar, 1991). The Plains must have witnessed climatic changes during the Holocene Period similar to those recorded from the adjoining areas of Rajasthan (Singh, 1971; Singh et al., 1974). Effect of neotectonism and climatic changes on evolution of morphology and soils of Indogangetic Plains need to be understood.

Keeping the above points in view, in the present study an attempt has been made to work out evolution of morphology and soils of the Gangetic Plains between the Ramganga and Rapti rivers in the eastern Uttar Pradesh. The study area covers a major part of the Upper and a small part of the Middle Gangetic Plains (Singh and Singh, 1971). For this purpose regional mapping of soil-geomorphic units was undertaken using remote sensing techniques and field checks. The degree of soil profile development was determined on the basis of field characteristics and laboratory analysis of soils. Using these data, a soil chronoassociation has been constructed for the study area. Role of climatic changes and neotectonic activity during Holocene Period in development of morphology and soils in the study area has also been worked out. An attempt has been made to work out genesis of calcrete of the area.

1.2 GENERAL DESCRIPTION OF THE AREA

1.2.1 Location and Extent

The area under investigation is a part of the vast Gangetic Plains and lies between Latitudes 26° N to 29° 30' N and longitudes 78° E to 82° E and is covered by Survey of India toposheets 53K, 53O, 53L, 53P, 62D, 62H, 54M, 63A, 63B, 63E 63F, 63G, 63I and 64J on 1:250,000 scale. The area covers most of the parts of the state of Uttar Pradesh in central region. (Fig. 1.1). This area includes a major part of the Upper Ganga Plain and also some part of Middle Ganga Plain (Singh and Singh, 1971).

1.2.2. Physiography

The study area is monotonous seemingly featureless and lacks

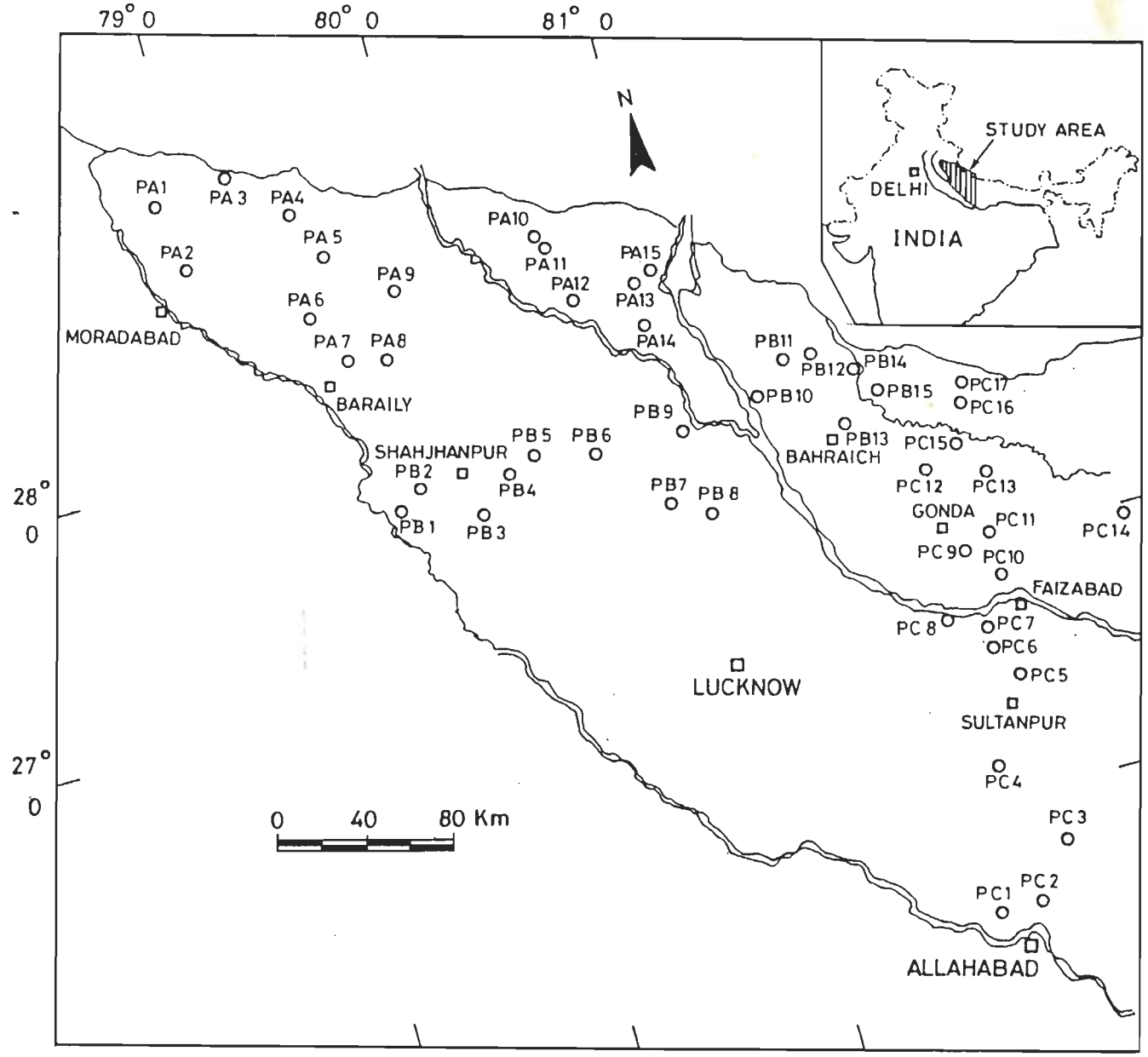

Fig. 1.1 Location and extent of the study area and location ofthe soil profiles from traverse 'PA' (PA1 to PA15), 'PB' (PB1 to PB15), PC (PC1 to PC16).

topographic prominence. The monotony of this physical landscape is broadly broken by Bhabhar-Tarai submontane belt in north and locally by river channels, levees, oxbow lakes and paleochannels. The axis of the physiographic trough probably lies along the river Ganga which traverses the area in a south-westerly direction with an average gradient of 24 cm/km, which is higher in upper reaches. In the north below foothills, where slope is higher, numerous small streams originate and flow in parallel drainage pattern before they cease to exist and deposit their load in the piedmont zone. In south major river systems are sluggish in nature and numerous oxbow and meander scars are observed along the Ramganga and Ganga rivers. The Ghaghra river maintains a braided character for most of the course in the study area. Ganga - Ghaghra interfluve and Rapti - Ghaghra interfluve (called doab locally) exhibit somewhat stable land (Bhangar), which rises 15-20 m above the adjoining floodplains. Throughout the region there is preponderance of regional slopes as many tributaries travel long distances parallel to the master streams before joining them.

Most significant topographic feature in the area is submontane belt, running at the foot of Siwalik hills from west to east along the area on the northern border. This belt consists of two parallel and adjoining strips - the piedmont zone (called the Bhabhar) and gently sloping zone of groundwater seepage (called Tarai belt). The piedmont zone is about 10-30 km wide belt consisting of generally coalescing alluvial fans. The central part of this piedmont zone has been severely dissected due to upliftment. Also several remnants of the Older

Piedmont are seen in this zone. Severe erosion and fast deposition of coarser material in the Piedmont Zone make it unsuitable for agricultural purposes. In the Tarai Zone fine sand silt and clays are deposited by the emerging streams, almost level and fertile soils along with high water table have rendered unique physical and cultural landscape to the belt.

1.2.3 Climate

In the study area climate is mainly controlled by the Himalayas in north and movement of monsoon from east to west. Climate, in general, can be described as sub-humid for most part of study area comprising the Upper Ganga Plain. In the eastern part of study area in the Middle Ganga Plain, the climate generally is humid. Temperature decreases and rainfall increases as one moves towards Himalayas from south (Fig. 1.2).

The average weather conditions emerging out of the combined effect of the various elements lead to the recognition of four well marked seasons i.e., hot summer, wet summer, the pre-winter transition and the winter. The temperature rises gradually from February, and rapidly from March onwards till May/June when it attains as much as 40°C. The Himalayas undoubtedly exerts influence, as the maximum May temperature may remain below 40°C at Gonda (near Himalayas) whereas it exceeds well above 40°C in the southern part i.e., at Allahabad and Kanpur. The rainy season stretches from the later half of the June to late September. These rainy months account for over 90% of the total annual rainfall in the area. The monsoon rainfall and annual rainfall decrease westward as well as southward (Gonda, 113 cm;

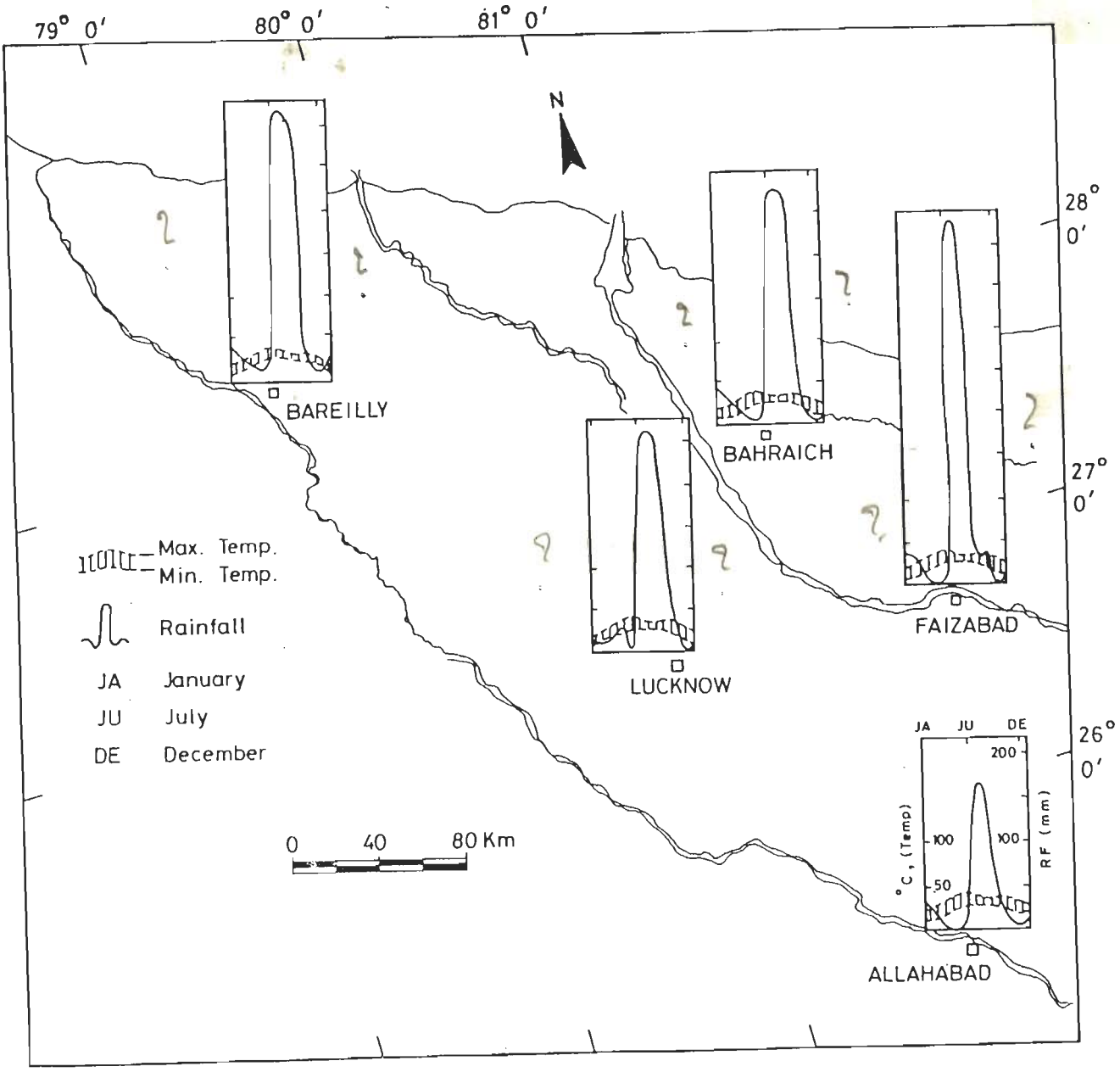

Fig. 1.2 Temperature - precipitation diagram for selected stations for the study area.

- not clear - draw the figure
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-

Bahraich, 100 cm; Allahabad, 90 cm) (Fig. 1.2).

1.2.4 Drainage

The region comprising the study area is a part of the well integrated drainage system of the river Ganga. Important tributaries like the Ramganga, Gomti and Ghaghra and Rapti flow in the region. Almost all the streams follow a NW-SE course concomitant with the regional slope of the land. Extremely gentle gradient over most of the region, restricts the degradational activities of the streams resulting in nearly parallel courses and the acute angle junctions of the tributaries with their master streams at most levels. This feature imparts the region a pinnate drainage, an extreme case of the dendritic pattern on macro level (Fig. 1.3). The Ramganga, Ghaghra and Gomti are braided streams near their sources and change to meandering pattern further away from it. The Ganga has a meandering pattern in the study area. In north, a host of seasonal torrents originating from southern slope of the Siwalik Hills, notably Pilakhar, drain in the area, whereas in south these streams loose their discharge mainly due to percolation and only a few of them continue as distinct entities further south. The Gomti and Sukhata have their source in the Bhabhar and Tarai tracts. Another group of rivers, mainly Sai and Kalayan, are entirely alluvial rivers originating from depressions or tals in the Bhanger tract. In the study area the Ganga and its major tributaries Ramganga and Ghaghra are the only Himalayan rivers, which carry significant discharge throughout the year. The river Ganga commonly shows wide floodplains and high banks along its

course, whereas the Ramganga and Ghaghra have rather ill-defined and frequently changing channels.

1.2.5 Natural Vegetation

Till Protohistoric times, the Ganga Plains were covered with thick forests. The epic Ramayana refers to thick forest of Namisaranya in the Ghaghra-Gomti Doab, now in the Sitapur district, the hermitage of sage Valmiki in a forest on the bank of the Ganga in an area now part of the Unnao district. The Khandav forest of the Mahabharata epic and other such fragmentary references in these epics throw sufficient light on the predominance of natural forest vegetation in the past. During the last about 3,000 years of human occupance in the region, gradual clearing of natural vegetation has continued. Presently the forest are mainly confined to the Tarai region (Lakhimpur, 27.5% ;Pilibhit, 30.7% ;Saharanpur, Bijnor and Baharaich each over 13%), and in plains it varies from 0.1% in Partapgarh district to almost nil at other places.

In the Tarai region the main forest cover of the Sal (Shorea robusta) is seperated by a few tracts of Savannah (Seth, 1954; Singh, 1967). The most common trees in sal forests are simul (Salkamalia malabaria), dhak (Butea monosperma) and khair (acacia catechu). Savannah forests are considered by Puri (1976) to be degraded high forests and not true Savannah. Major vegetation in Savannah forests are tall grasses of various types growing to 3 metre high (Gangwar et al., 1982).

The forest cover in the study area can be grouped as tropical moist deciduous, tropical wet and subtropical dry.

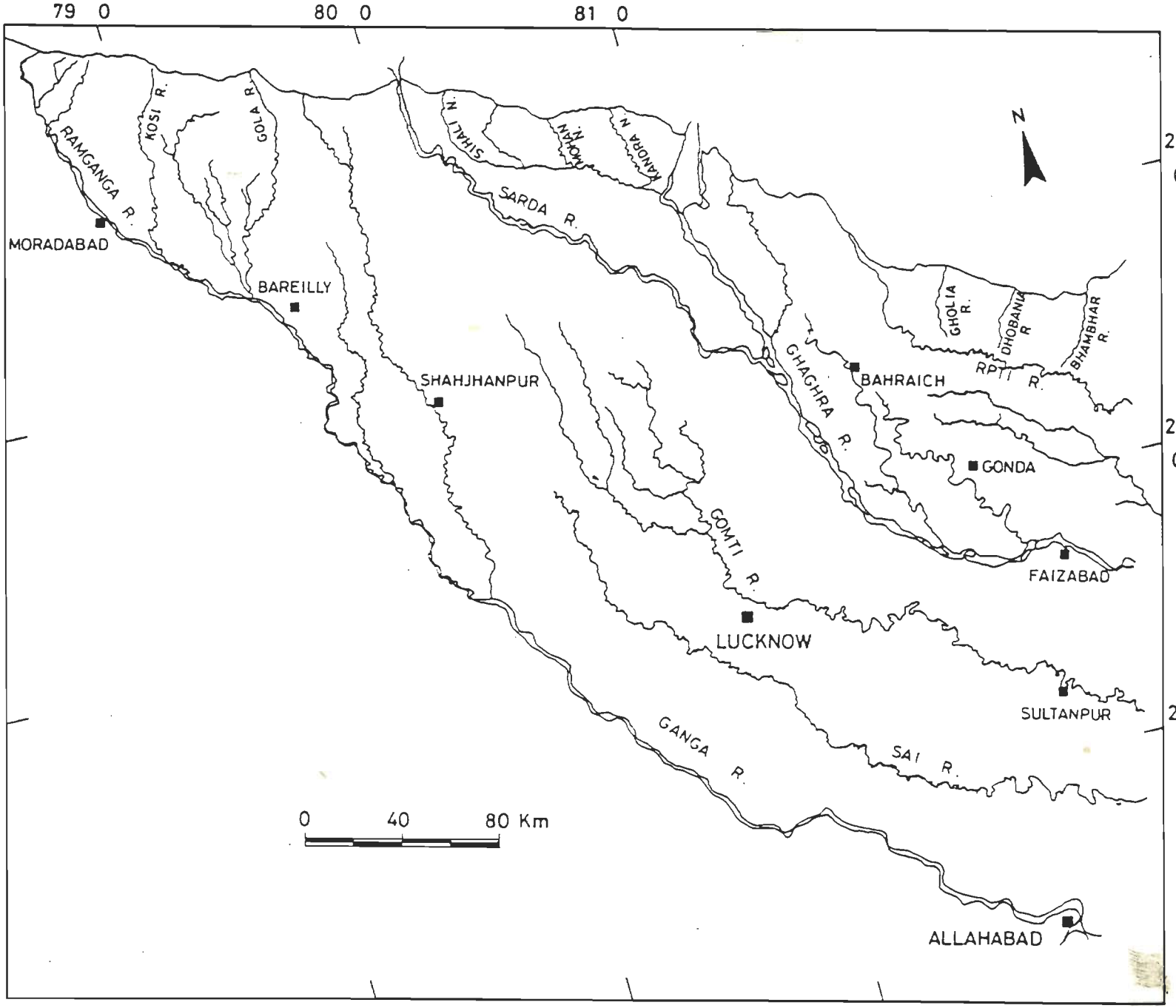


Fig. 1.3 Drainage map of the study area.

Tropical moist deciduous forests area confined to the Tarai region. Tall grass like the elephant grass, kans, munj, etc. are main species of this group. The second group of forest is more open mixed semal type. In subtropical dry areas especially in the western part shisham, babul, khair and semal are the main species.

1.2.6 Ground Water

The region is potentially quite rich in groundwater resource, both free and confined. In the Bhabhar belt, the ground water occurs in water table conditions and water table is generally up to 90 m deep. This is due to high permeability and absence of confining layers at shallow depths. The Tarai region is underlain by well defined alternate clay and sand layers, forming artesian aquifers. The boundary between the Bhabhar and Tarai is marked by a spring line. Towards south the Tarai merges into plains in which the flowing well conditions are practically unknown. In alluvial plain areas, the aquifers consist of sand beds, while the clays with kankar serves as aquitards. Water table in the area is usually 5-12 meters deep.

In general the ground water is fairly deep except in regions close to active river and in the Tarai tract and thus does not influence the pedogenic processes acting in the area.

1.3 GENERAL GEOLOGY AND TECTONIC SETUP

The Indogangetic Plains, lying between Peninsular India and the Extra Peninsular region, constitute a major geologic/geomorphic unit of the Indian subcontinent. To the north they are limited by the outer most Himalayan Ranges i.e., Siwalik Hills

(Frontal Folded Belt) and to the south by the Precambrian rocks (Delhis, Bundelkhand Gneisses, Aravallis and Vindhyans). Geophysical surveys and deep drilling by Oil and Natural Gas Commission (Sastri et al., 1971; Rao, 1973; Raiverman et al., 1983) suggest that the Indogangetic Basin is a vast asymmetric trough with a maximum thickness of Tertiary sediment occurring in the north (about 10,000 m) and that thins out to the south. The Precambrian Formations exposed to the south of the Plains and continue under the Tertiary sediments in the north.

The Precambrian basement underlying the plains can be divided into many depressions and ridges. These structures can be divided into first order or second order depending upon the fact whether their aerial extent is more or less than 6,000 sq km respectively (Fig.1.4) (Eremenko and Negi, 1968).

The study area is marked by the major first order structure of the Faizabad ridge, the Sarda depression and the West Uttar Pradesh shelf. Faizabad ridge, the most important tectonic element, is the northeastward subsurface projection of the Bundelkhand Massif. It differentiates the Ganga basin into East Uttar Pradesh Shelf and West Uttar Pradesh Shelf, occurring on the two sides of the ridge. The Neogene sequence seems to directly overlie this basement ridge. The West Uttar Pradesh Shelf can be broadly divided into two parts by Moradabad fault. In areas west of Moradabad Fault, the Vindhyan Sequence overlies the Aravalli folded basement, while in areas east of Moradabad fault the Neogene sediments directly overlie the Delhi basement. The Pre-Siwalik sequence in West Uttar Pradesh shelf is

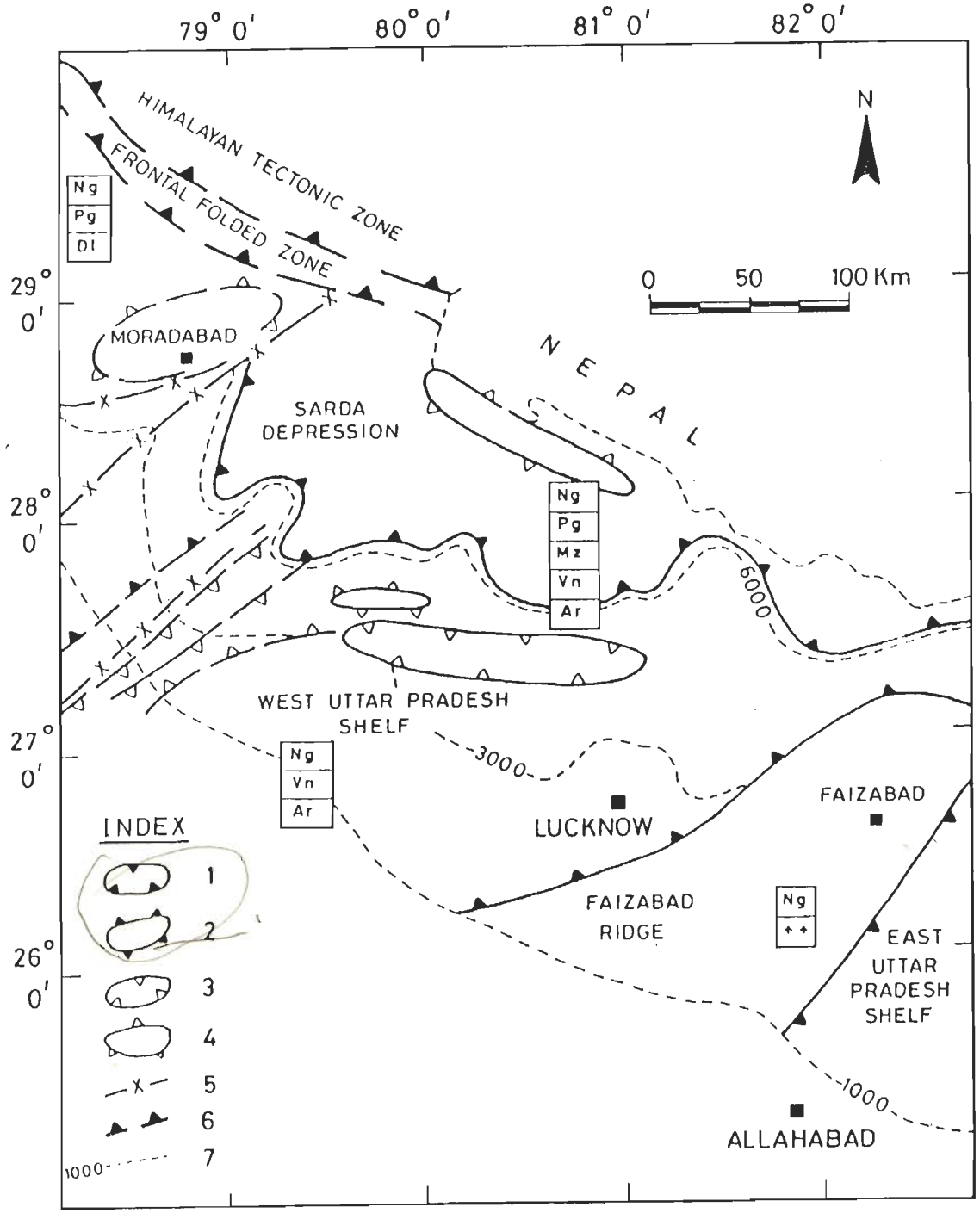


Fig. 1.4 Geological map of the study area.

characterized by development of several second and third order structures. These structures trend mostly NE-SW and E-W. The major faults in this zone strike NE-SW parallel to the strike of Precambrian Aravalli belt. The Moradabad fault striking NE-SW is a tectonic boundary between the Delhi Folded Belt and the Vindhyans.

The Sarda depression represents the northern part of the West Uttar Pradesh Shelf, from which it is tectonically distinguished on the basis of inferred sedimentary thickness of more than 6,000 m and by NW-SE trending structures. The large thickness of sediments in this area may include partly Tertiary and Mesozoic besides the Proterozoic and the Vindhyans.

The surfacial alluvium of the Indogangetic Plains represents alluvium deposited by various rivers emerging out from Himalayas. The alluvium chiefly consists of sand, kankar and clay beds. Besides these, beds of gravel are also found close to northern and southern boundaries of Indogangetic Plains.

The surfacial deposits of the Indogangetic Plains have been classified into (i) Older alluvium 'The Bhangar', (ii) Newer alluvium, 'The Khadar' and (iii) Piedmont deposits, 'The Bhabhar' (Wadia, 1966). The Bhabhar deposits are confined to a narrow zone, about 10 - 30 km wide, between the Siwalik and the alluvial Plains. While the Khadar deposits occupy the riverine tract (Floodplains) and are renewed annually, the Bhangar occupies the interfluvial zones and experiences slow and secular changes. One distinctive character of the Bhangar is formation of kankar in

subsoil. The Older alluvium has been traditionally thought to be of the Late Pleistocene age (Wadia, 1966).

1.4 PREVIOUS WORK

The soils, especially of western Indogangetic Plains, (Panjab, Harayana and western U.P.) have been studied in detail. Excellent reviews on morphology and genesis of soils, clay minerals and micromorphology in 'Review of Soils Research in India' were brought out as part of Proceedings of 12th International Congress of Soil Sciences held in 1982 in New Delhi. Pertinent reviews are presented by Shankaranarayana (1982) on morphology and genesis on soils, Gangwar et al. (1982) on Tarai soils, Bharagava and Bhattacharjee (1982) on saline soils, Sehgal and Raghu Mohan (1982) on micromorphology and Srinivasan (1982) on mapping of soils. In this thesis, only a selective review of the interesting aspects of soils in study area and adjoining areas is presented.

1.4.1 Soil Mapping

Soils of the Indogangetic Plains have been mapped over small areas for agricultural purposes by a number of workers (Karale and Venugopal, 1972; Mahapatra and Saxena, 1970; Jayaraman and Shivprasad, 1971; Verma and Singh, 1971; Karale and Ghosh, 1972; Roy and Jain, 1974; Singh, 1984). Also some attempts at regional mapping of soil-geomorphic units using satellite infra-red imageries indicate that these techniques are very effective in the mapping of soils (Manchanda and Khanna, 1979; Garlapuri et al., 1980; Hilwig, 1976; Mohindra, 1989; Kumar, 1991).

1.4.2 Morphology

Studies on morphology of the Indogangetic Plains are few. Geddes (1960) thought that major sedimentation in these plains (especially the Middle Gangetic Plains) was taking in the form of megacones formed by big rivers debouching into the plains from the Himalayas. Megacones were marked by coarse sediments and interconal areas received mainly finer sediments. Raychaudhri (1964) described the morphology of alluvial soils in Indogangetic Plains and classified them as riverine old, riverine recent and riverine calcareous. As mentioned earlier, Wadia (1966) recognised mainly two major soils/alluvia/surfaces in the Indogangetic Plains i.e. Khadar and Bhangar. Hilwig (1972) found that major geomorphic units in western U.P. were marked by uniformity of soils. Furthermore, different units occurring at higher levels with respect to the floodplains of active rivers had older soils. Singh (1988) recognised three major surfaces i.e. T0, T1 and T2 in these plains and assigned them ages of 15,000 B.P., 25,000-3000 B.P. and 120,000 B.P. respectively. T3 surface was considered to be a planation (erosional) surface. Surfaces T0 and T1 seem to be the same as Khadar and Bhangar of Wadia (1966). Effect of tectonics in the form of uplift of the Older Piedmont and its dissection and formation of a dissected spur north of Roorkee due to a fault was observed by Meijerink (1974). Bajpai and Gokhale (1986) classified the southern marginal alluvial plains of western U.P. into upland tracts, ravine tracts, floodplains and rocky tracts.

1.4.3 Saline Soils

Nearly 3.5 million hectares of the Indogangetic Plains are

salt affected and locally called usar land. These are marked by patchy distribution of salts on the surface and presence of a calcrete horizon at variable depths. The earliest investigations of these soils were made by Medlicott (1863) and Centre (1880) and they attributed salinity to the concentration of salts released from weathering of minerals. More recently Bhargava et al. (1980) and Kapoor et al. (1981b) have suggested that weathering of alumina-silicate minerals through carbonation yields solute of bicarbonates and carbonates of alkalies, in addition to colloids of silica and alumina. Also in an inland area with high rates of evaporation, separation of electrolytes leads to development of sodic soils close to the source (foothills) and non-sodic saline soils far away from the source (Bhargava et al., 1980). Patchy distribution of salts has been attributed to evaporation from shallow microdepressions. Bhargava and Bhattacharjee (1982) showed that shallow water table, low slopes, low rainfall and poor drainage contribute to the saline nature of soils.

Recent work by Kumar (1991) and Mohindra et al. (in press) and suggest that saline soils of the Indogangetic Plains originated due to an arid climate prevailing in the present area during a cold arid phase coinciding with late stage of the last glaciation (with maximum around 18000 B.P.) during the period 9000-11000 B.P. Due to wetter climate since then, these saline soils have been modified extensively at favorable places and they have suffered retrograde pedogenesis leading to removal of salts and leaching of calcrete to deeper levels.

1.4.4 Tarai Soils

Because of their fertility, the Tarai soils attracted attention of many scientists. Usually these are considered to be poorly developed (Despande, 1971a & b) and have been divided into six major series- Phool bagh clay loam, Beni silty clay loam, Haldi loam, Nagla loam, Khamia sandy loam, and Patharchatta sandy loam (Fehrenbacher et al., 1966, Despande et al., 1971b). Typic Euterochrepts, Typic Ustochrepts and Typic Ustorthents, Aeric Haplaquents have been identified from these soils (Despande et al., 1971b; Singh, 1974; Mathur, 1979) These areas are highly vegetated and are swampy in nature.

1.4.5 Clay Mineral Studies

A large number of studies on clay minerals of soils of the Indogangetic Plains are available. Yadav and Gupta (1974) reported widespread occurrence of smectitie in addition to illite, chlorite and kaolinite in some moderately alkaline soils of U.P. Sehgal and de Coninck (1971) and Sehgal (1974) observed that in addition to illite, some kaolinite, intergrade minerals such as chloritised vermiculite or smectite instead of true chlorite occur in soils of Panjab and Haryana. Sidhu and Gilkes (1977) found abundant occurrence of chlorite and occasional occurrence of smectite in alluvial soils of northwest India.

Sehgal (1974) and Kapoor et al. (1981a) reported that illite of alluvial soils in northwest India was a mixture of both octahedral and trioctahedral type, whereas chlorite, smectite and vermiculite were trioctahedral. Sidhu and Gilkes (1977)

reported that illite in these soils are mainly dioctahedral in nature. Singhai et al. (in press) found that illite content decreases with increase in grain size of soils of Haryana. Also, a clay mineral transformation in alkaline soils has been postulated by Kapoor et al. (1980a) i.e. biotite ->mixed layers->vermiculite->smectite. In summary, the major minerals reported from the Western U.P. include illite, chlorite and montmorillonite along with minor amounts of kaolinite, mixed layer and vermiculite.

1.4.6 Micromorphological Studies

Sehgal (1970) described fabric of Camborthids of Rajasthan and Haryana and showed that the soil fabric varied from argilasepic, agglomeratic grading to silasepic and crystic and intertextic. He also observed the frequent occurrence of free grain cutans (argillans and calcitans) in B horzons and common spongy, calcareous nodules in these soils.

Sehgal and Stoops (1972) observed nine forms of calcite accumulations from micro-crystalline calcite to coarsely crystalline crystallaria in soils of Panjab and Haryana. Sehgal and Stoops (1972), and Courty and Federoff (1985) concluded that kankar in Haryana and Panjab was pedogenic in origin and originated by gradual aggradation. However, later Courty (1990) found that local factors affected carbonate accumulation in a significant way.

Other notable studies on micromorphology include Karale et al. (1974), Kooistra (1982), Manchanda and Hilwig (1983). Karale

et al. (1974) observed the presence of moderately to strongly oriented argillans in alfisols of Meerut in Western Uttar Pradesh. Kooistra (1982) described micromorphology of 3 soil series from western U.P. Manchanda and Hilwig (1983) found that clay cutans and matrans increased with the increase in rainfall. They reported several features of carbonate accumulation related to rainfall. Kumar (1991) finds that micromorphological features indicate the degree of soil profile development in different soil-geomorphic units in parts of western U.P..

Sehgal et al. (1980) studied Camborthids of Rajasthan and showed that papule formation was associated with the weathering of mafic mineral. Accumulation of free carbonate and formation of clays were associated with differential weathering of silicate minerals.

The review of the previous work indicates the following:

(i) No detailed work or investigations correlating the development of landforms and soils on a regional scale has been done for the study area.

ii) Neotectonics has controlled the evolution of landforms and soils in a significant way in the adjoining areas of Indogangetic Plain (Kumar, 1991; Mohindra et al., in press; Singhai et al., in press). The present area requires serious attention from this point of view.

iii) Soil stratigraphy has not been attempted for this area.

iv) Though calcretes of Haryana and Panjab have been studied by

a number of workers, little or no work has been on calcretes of the Gangetic Plains.

The present study aims at (i) identification and mapping of various soil-geomorphic units, (ii) determination of degree of soil development on various soil-geomorphic units, using soil morphology, chemical and grain size analyses, (iii) construction of a soil chronoassociation for the area, (iv) elucidiation of role of tectonic and climate changes on development of morphology and soil during Holocene Period and (v) genesis of calcretes of the area.

With the objectives outlined above, different soil-geomorphic units with distinctive landforms and soils have been recognised and delineated using topographic maps, Landsat MSS B & W images, FCC's and IRS-1A's FCC's and subsequent field checks. Field work has been done in transverses to study the amount of maximum variability in soils. Soil samples from 32 typical soil profiles, fairly distributed over different soil-geomorphic units, were collected after studying the detailed morphology of different horizons/subhorizons in the field. The bulk samples collected were analysed for grain size distribution, oxides of major elements, clay mineralogy, stable isotope of oxygen and carbon and quartz/feldspar ratios.

Oriented undisturbed samples were collected for micromorphological studies. The field and laboratory characteristics were used to determine the degree of soil development on different soil-geomorphic units in order to develop a soil chronoassociation and other interpretations. The

methodology and findings of these studies are presented in form of five chapters.

Chapter 1 entitled "Introduction" deals with rationale for selecting the research problem, general description of the study area, physiography, climate, drainage, geology and geotectonic setup, natural vegetation and ground water. This chapter also includes a review of previous work and objectives and scope of the present work.

In chapter 2, a brief account of general morphology of each soil-geomorphic unit is given, which is followed by detailed description of soil profiles. A discussion on the variation of soil characteristics in different soil-geomorphic units is ~~given~~ discussed.

Chapter 3 deals with physical, chemical and mineralogical characteristics of soils of various soil-geomorphic units. Variation of texture, clay mineralogy, ratio of quartz/feldspar, oxides of major elements, and isotopic composition of calcretes in soils of different units are discussed in detail.

Chapter 4 entitled "Micromorphology of Soils", describes the procedure for preparation of large size (5x6x8 cm) thin sections. A detailed description of soil thin sections from various soil-geomorphic units is given. Correlation and comparison of micromorphological characteristics of soils from different soil-geomorphic units has also been included in this chapter.

Chapter 5 the last chapter entitled "Summary, Synthesis and Conclusion" briefly summarizes the morphology, micromorphology and physical, chemical and mineralogical characters of soils of various soil-geomorphic units identified in the study area. A synthesis of data in terms of soil chronoassociation, role of tectonics and climate in evolution of soils and morphology of the area is given. Significant conclusions drawn from the study are included in this chapter.

C H A P T E R 2

GENERAL MORPHOLOGY AND SOILS OF THE AREA

2.1 INTRODUCTION

In order to decipher the geomorphic evolution and to construct a soil-chronoassociation of the Gangetic Plain between the Ramganga and Rapti rivers in eastern Uttar Pradesh, the work has been carried in three stages; (i) Pre-field investigation of the study area: This involved identification of the different soil geomorphic units ~~in the study area~~ using Landsat MSS (Multispectral Scanning System) B&W (Black & White) images , FCC's (False Colour Composits) and IRS (Indian Remote Sensing) FCC's, (ii) Field investigations: This work involved checking and confirming the identified soil geomorphic units by field visits and a record of soil characters. Also the soil samples were collected for laboratory analysis and (iii) Laboratory analysis: In this stage soil samples were analyzed for grain size, clay mineralogy, chemical characteristic, stable isotope characters, Quartz/felspar ratio and micromorphology. Methods and findings of the first two stages are discussed below.

2.2 Identification of the Soil-Geomorphic units by Remote Sensing Techniques

In this study for visual interpretation Landsat black and white images of band 4, 5 and 7 at 1:1000000 scale and FCC's on 1:250,000 scale and Remote IRS FCC's on 1;50,000 scale and topographic sheets were used. Various soil- geomorphic units have been delineated on the basis of important elements such as

color, tone, vegetation, pattern, moisture, texture, drainage etc. Using these techniques a geomorphic map (Fig.2.1) has been prepared. Important characteristics of the geomorphic units interpreted from the Landsat 4 MSS Band 7 of post and pre monsoon period are give in Table (2.1).

2.3 FIELD INVESTIGATIONS

After demarcating different soil geomorphic units fieldwork was carried out to groundcheck and examine characteristics of soils in each soil geomorphic units. The approximate sampling sites were selected, keeping in view that site should represent typical characteristics of that particular soil geomorphic unit. These site selection was done with the help of soil geomorphic map and topographic map of the area. In the field auguring was done at a number of locations in a geomorphic unit and sites for typical soil profile were selected for detailed studies. At the selected site an excavation of size 1m x 1.5 m was made, extending through the solum to the parent material or up to reasonably excavable depth. Different horizons and subhorizons were marked using soil properties (colour, texture, mottling, consistency, clay cutans, kankars, etc) and were designated according to United States Department of Agriculture (USDA) nomenclature (Soil Taxonomy, 1975) as A1, Ap, B1, B2, C etc. Depth of each horizon and subhorizon has been recorded with special attention to following aspects.

2.3.1 Colour

Colour is one of the most useful, important and easily determined soil characteristics. Soil colours were determined by

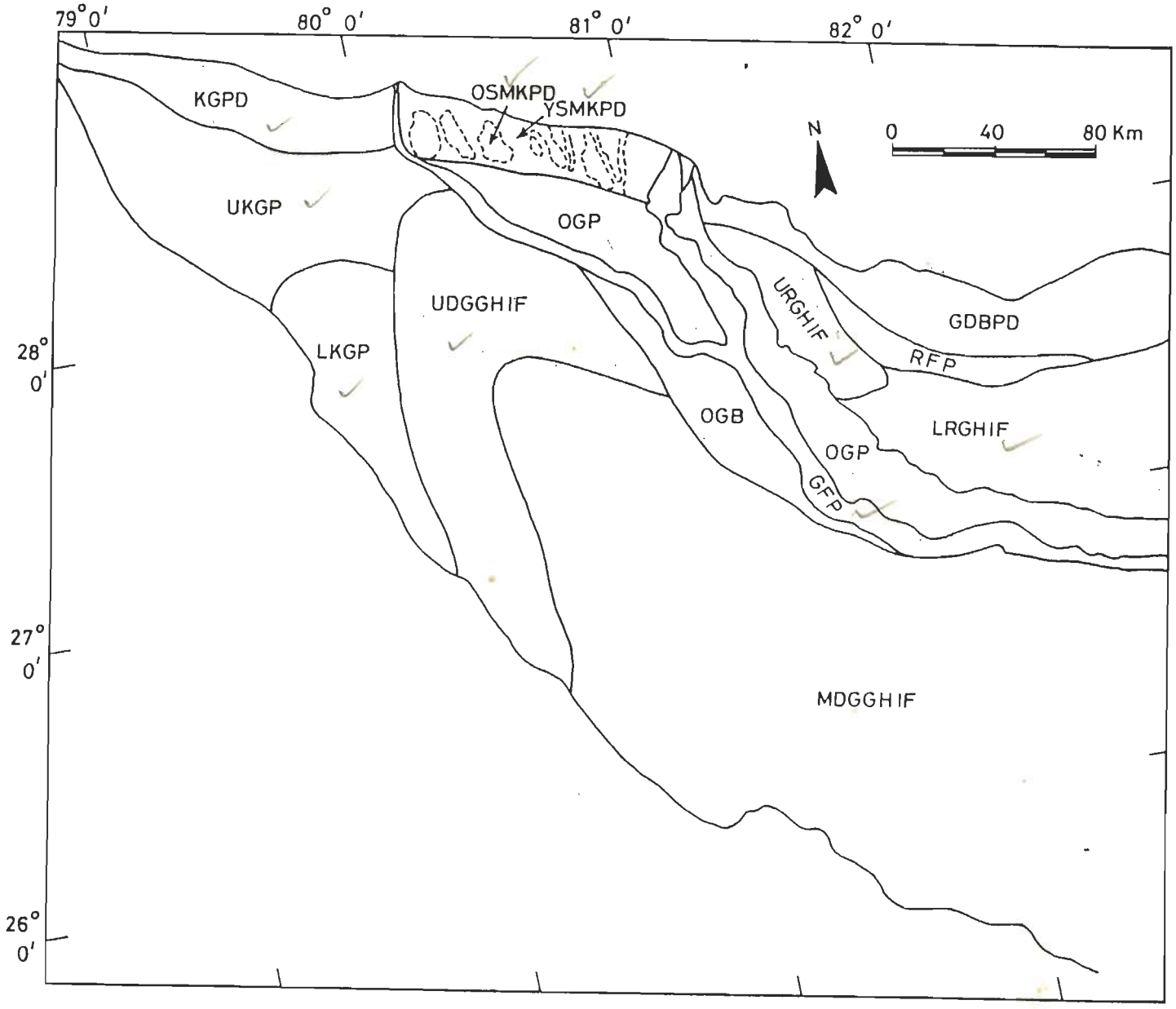


Fig. 2.1 Soil-Geomorphic map of the study area showing fourteen soil-geomorphic units identified using remote sensing techniques. Kosi-Gola Piedmont- KGPD, Upper Kosi-Gola Plain- UKGP, Lower Kosi-Gola Plain- LKGP, Upper Deoha/Ganga-Ghaghra Interfluve- UDGGHIF, Middle Deoha/Ganga-Ghaghra Interfluve- MDGGHIF, Young Sihali-Mohan-Kandra Piedmont- SMKPD, Old Sihali-Mohan-Kandra Piedmont- OSMKPD, Upper Rapti-Ghaghra Interfluve- URGHIF, Lower Rapti-Ghaghra Interfluve- LRGHIF, Ghaghra Floodplain- GFP, Old Ghaghra Plain- OGP, Old Ghaghra Bar- OGB, Rapti Floodplain- RFP, Gholia-Dhobania-Bhambhar Piedmont- GDBPD,

TABLE 2.1 : IMPORTANT CHARACTERISTICS OF SOIL-GEOMORPHIC UNITS BASED ON INFORMATION FROM B & W LANDSAT IMAGES OF BAND 7 OF PRE-MONSOON PERIOD

Soil-Geomorphic unit	Physiography	Characters
KGPD	Slight relief, parallel drainage, well drained	Gray tone with medium texture, uniform dark gray in forested area.
YSMKPD and OSMKPD	Moderate relief, parllel drainage, well drained	Dark gray tone in remnant in excessively vegetated land (OSMKPD) and bright tone in eroded young piedmont (YSMKPD)
GDBPD	Slight relief, parallel drainage	Medium gray with pitted texture.
GFP	Well drained	Uniformly dark gray and extrely dark to black in active channel
OGP	Well drained	Medium gray in general, paleochannels show dark gray tone.
OGB	well drained	Medium gray tone with linear bar type features
UKGP	Very slight relief, moderately drained	Medium gray and dark gray with medium texture and dark gray when moisture and drainage density is high.
LKGP	Moderately drained	Medium gray with sparse motteles, Paleochannels show dark gray tone
UDGGHIF	Moderately drained	Uniform gray, medium texture with a very few bright mottles.
MDGGHIF	Poorly drained	Medium gray tone, coarse texture, highly mottled with white and dark patches in salt affected and water logged areas.
URGHIF	Moderately drained with very slightly relief	Light gray tone with medium texture, sparsely mottled with dark when forested.
LRGHIF	Poorly drained	Medium gray tone with coarse texture, highly mottled with bright and dark in salt affected and water logged part.

comparing with Munsell colour chart. Hue, values and chroma are noted according to the Munsell notations. An accurate and closest match is obtained by holding the soil sample close to the colour chips of Munsell Chart. As soil colour changes with the moisture content, soil colour is noted at field condition and the moisture condition is stated.

2.3.2 Mottles

Mottling in soils is described by noting (i) colour of the matrix and mottles, and (ii) pattern of mottling. Colour of the mottles is also defined by using the Munsell notation. The pattern of mottles is described by its three aspects, contrast (faint, distinct, and prominent), abundance (few, common and many) and size (fine, medium and coarse).

2.3.3 Consistence

This is a measure of the adherence of the soil particles to fingers, the cohesion of the soil particles to one another and the resistance of the soil mass to deformation. The consistence is measured by compressing the soil between thumb and forefinger and noting the adherence of soil upon release of pressure. The classes recognized are sticky, slightly sticky and non-sticky. Plasticity is measured by rolling the wet soil between thumb and forefinger in an attempt to form a thin rod. Several classes are recognized: non plastic - no rod forms; slightly plastic - a weak rod forms that is easily deformed and broken; plastic - a rod forms, which resists moderate deformation and breakage. The consistence helps in determining soil texture also.

2.3.4 Texture

Soil texture refers to the relative proportions of various size groups of individual soil grains in a mass of soil and specially refers to the proportions of clay, silt and sand. Textural classes were noted down by the grittiness and wet consistence. Several textural classes were recognised in field, but these were determined later more accurately in laboratory by grain size analysis.

2.3.5 Structure

Soil structure refers to the aggregation of primary soil particles into compound particles or clusters of primary particles, which are separate from the adjoining aggregates by weak surfaces. Grade of structure is the degree of aggregation and adhesion between aggregates. In the field, grade of structure of aggregates and the proportions between aggregated and non-aggregated material that results, when clods of soil material are displaced or gently crushed, were noted. The terms for grade of structure are: Structureless - without aggregates; weak - a few peds are barely observable, moderate - peds are easily observable and most material is aggregated; strong -mass consists entirely of distinctly visible peds. In field, grade type and size of soil structure are noted and confirmed later with the help of soil micromorphology.

2.3.6 Carbonates

Concretions of carbonates are noted and their size and volume percentage are estimated. Disseminated fine grained carbonate is determined by indication of the effervescence with

dilute HCl as : very slight - few bubbles; slight-bubbles readily observed, strong - bubbles form low foam, and very strong - violent foam is thick and mainly boils appear.

2.3.7 Soil Pores

Soil pores are identified by visual examination in the field. Soil pore size is noted as; coarse, medium, fine and very fine, and their abundance is recorded as few, common and many.

2.3.8 Horizon Boundary

Width of transition zone from the underlying to the overlying horizon (distinctness) and topography of the zone are recorded. Distinct classes based on width of transition are: very abrupt less than 1 mm, abrupt - 1 to 2.5 mm, clear - 2.5 to 6 mm, gradual 6 to 12.5 cm and diffused > 12.5 cm. Topography classes are: smooth, wavy, irregular and broken.

2.3.9 Roots

Size, and abundance and penetration of roots are recorded according to soil survey staff (1951). Different classes of size are very fine - less than 1 mm, fine - 1-2 mm; medium - 2.5 mm, coarse - larger than 5 mm.

After recording various soil characteristics systematically samples from each pedon were collected for laboratory analysis. Grab samples from each horizon/subhorizon and oriented and undisturbed samples in tin boxes for micromorphological studies were collected. Also, calcrete nodules when present were picked up in sufficient amount for stable isotope analysis and dating.

2.4 MORPHOLOGY AND SOILS OF VARIOUS SOIL GEOMORPHIC UNITS

Based on image interpretation and field investigations the study area has been divided into following fourteen soil geomorphic units (Fig. 2.1).

Soil Geomorphic Unit	Abbreviated as
i) Kosi - Gola Piedmont	KGPD
ii) Upper Kosi Gola Plain	UKGP
iii) Lower Kosi Gola Plain	LKGP
iv) Upper Deoha/Ganga Ghaghra Interfluve	UDGGHIF
v) Middle Deoha/Ganga Ghaghra Interfluve	MDGGHIF
vi) Young Sihali-Mohan-Kandra Piedmont	YSMKPD
vii) Old Sihali-Mohan-Kandra Piedmont	OSMKPD
viii) Upper Rapti Ghaghra Interfluve	URGHIF
ix) Lower Rapti Ghaghra Interfluve	LRGHIF
x) Ghaghra Floodplain	GFP
xi) Old Ghaghra Plain	OGP
xii) Old Ghaghra Bar	OGB
xiii) Rapti Flood plain	RFP
xiv) Gholia-Dhobania-Bhambhar Piedmont	GDBPD

Morphology and soils of these geomorphic units are described below.

2.4.1 Kosi-Gola Piedmont ~~Piedmont~~

This unit is a narrow strip of 15-25 km in width extending from the base of the Siwalik Hills. In north this unit is bounded by Himalayan Frontal Fault and in south by Upper Kosi

Gola Plain. Western limit of this piedmont zone is marked by River Ramganga, which originates in Himalaya and follows a fault zone (Ramganga fault) while entering into Gangetic Plain. Eastern limit of this piedmont is marked by another mighty Himalayan river Sarda, flowing along a deep cut following a fault zone (Ghaghra Fault). Major rivers within this unit are river Kosi and Gola. Numerous Siwalik streams are depositing their loads in this unit. These streams are braided in character and shift their course rapidly.

In Landsat MSS 4,5,7 black and white images this unit shows slight relief, parallel drainage and medium gray to gray tone with coarser texture than from adjacent lower units. In Landsat TM and IRS FCC's this unit is marked by red colour with medium to coarse texture and stream dissections are bright and pink.

Pedon PA3 and Pedon PA4 have been studied in detail (Fig. 2.2 a, b, c). Pedological characters of these soils in the field are as follows.

PEDON # PA3

Classification	: Coarse Loamy Typic Ustorthent
Location	: Choi, Ramnagar, Nanital, Uttar Pradesh, (Lat. 29°21', Long. 79°6')
Date of examination	: 24-2-91
Slope	: 1-2% towards south
Landuse	: Wheat cultivation
Parent Material	: Alluvium
Moisture condition	: Moist
Depth of Ground water	: 12m
Drainage class	: well drained
Erosion	: el
Physiography	: Kosi-Gola Piedmont

Ap 0-40 cm; dark olive gray (5Y3/2), loam, granular, hard (dry) frible (moist) slightly plastic and slightly sticky (wet), abundant fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary.

C1 40-70 cm; olive gray to olive (5Y4.5/2), loam, massive, hard (dry) friable (moist) slightly plastic and slightly sticky (wet), few fine fibrous roots, common fine medium pores, non calcareous, gradual smooth boundary

C2 70-103 cm; olive yellow to light olive brown (2.5Y5.5/6), heavy loam, massive, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few fine roots, common fine medium pores, non calcareous, gradual smooth boundary

C3 103-128 cm; olive yellow to light olive brown (2.5Y5.5/6), loam, structureless, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), no roots, common fine medium pores, non calcareous.

PEDON # PA4

Classification	: Fine Loamy Typic Ustorthent
Location	: Lalkuan, Nanital, Uttar Pradesh
Date of examination	: 27-2-91
Slope	: 1-2% towards south
Landuse/Vegetation	: Forested area
Parent Material	: Alluvium
Moisture condition	: Moist
Depth of Ground water	: 10 m
Drainage class	: well drained
Erosion	: el
Physiography	: Kosi-Gola Piedmont

Ap 0-36 cm, Yellowish brown (10YR5/4), silty loam, structureless, hard (dry), friable (moist), slightly plastic and slightly sticky (wet), abundant fine medium fibrous roots, common fine medium pores, non calcareous, gradual smooth boundary

B1 36-50 cm, yellowish brown (10YR5/4), loam, weakly developed subangular blocky structure, hard (dry), firm (moist), slightly plastic and slightly sticky (wet), common fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

C1 50-73 cm, dark yellowish brown (10YR4/4), silty loam, structureless, hard (dry), firm (moist), slightly plastic and slightly sticky (wet), few fine medium fibrous roots, common fine medium pores, non calcareous, gradual smooth boundary

C2 73-110 cm, dark yellowish brown (10YR4/4), sandy loam, structureless, hard (dry), friable (moist), slightly plastic and slightly sticky (wet), no roots, common fine medium pores, non calcareous,

The soils of this piedmont zone are coarse textured (sandy loam). These shows gradational change in development of soil from North to South. The soils show A/C type boundaries and ABC type boundaries in northern and southern parts respectively. Thickness of solum (A+B) varies from 40 - 50 cm.

(a)

PEDON # PA3

(b)

PEDON # PA4

(c)

Fig. 2.2 (a) Field View And (b, c,) Typical Soil-Profiles Of The Kosi-Gola Piedmont.

Soils of A horizon have 30-40 cm thickness and an coarse sandy loam to silty loam in texture. Colour varies from dark olive gray to dark grayish brown due to excess of humus content. It is friable when moist and slightly sticky and plastic when wet. The soils are non-calcareous and show clear smooth boundary with underlying subhorizons. Thickness of B horizon varies from nil in north to 14 cm in south of this soil geomorphic unit. These B horizon soils show heavy sandy loam texture and very weakly developed subangular blocky structure. They are non-calcareous and show clear smooth boundary with C horizon.

Soils in C horizon are coarse sandy loam to loam in texture. Their colour varies from olive brown to olive. They are very friable when moist and non-sticky and non-plastic when wet.

2.4.2 Upper Kosi-Gola Plain

This soil-geomorphic unit occurs in north western part of study area below Kosi-Gola piedmont. Western extremity of this unit is limited by the river Ramganga and in east by the river Deoha and southern boundary is marked by the Lower Kosi-Gola Plain.

In Landsat black and white images this unit is picked up by uniformly medium gray tone with medium texture and dark gray tone when the moisture and drainage density is high. In FCC's and in IRS FCC's this unit shows uniformly pink colour and occasionally red colour mottles with medium texture.

Major morphological features of this unit are two medium

sized fans- Kosi fan of about 30 km and Gola fan with a diameter of about 55 km. These fans, especially the Gola fan are inferred from a few streams originating in the plains and forming a dichotomic pattern, because their channels are confined to older courses of master streams.

PEDON # PA5

Classification	: Coarse Loamy Udic Ustochrept
Location	: Sitarganj, Kitcha, Nanital, U.P., (Lat. 28°55', Long. 79°42')
Slope	: 1% towards south
Landuse/Vegetation	: Cultivation of wheat
Parent Material	: Alluvium
Moisture condition	: Moist below 60Cm from surface
Depth of Ground water	: 10m
Drainage class	: well drained
Erosion	: el
Human influence	: Nil
Physiography	: Upper Kosi-Gola Plain

Ap 0-25 cm, Pale yellow (2.5Y 7/4), sandy loam, structureless, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), abundant fine medium fibrous roots, common fine medium pores, strongly calcareous, gradual smooth boundary

B1 25-40 cm, Pale yellow (2.5Y 6/4), sandy loam, weakly developed subangular blocky soil structure, slightly hard (dry) friable (moist) slightly plastic and slightly sticky (wet), few fine medium fibrous roots, common fine medium pores, non calcareous, gradual smooth boundary

B21 40-60 cm, Light yellowish brown (2.5Y 5/4), loam, weakly to moderately developed subangular blocky structure, slightly hard (dry) friable (moist) slightly plastic and slightly sticky (wet), few fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

B22 60-85 cm, Light olive brown (2.5Y 5/4), silty loam, moderately developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few thin clay cutans along pores, very few fine fibrous roots, common fine medium pores, weakly calcareous, clear smooth boundary

C1 85-130 cm, Olive yellow (2.5Y 6/5), silty loam, very weakly developed subangular blocky soil structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), very few fine fibrous roots, common fine medium pores, strongly calcareous (kankars about 10%), gradual smooth boundary

C2 130-190 cm, Olive yellow (2.5Y 6/5), silty loam, massive, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), no roots, common fine medium pores, strongly calcareous (kankars about 15%).

PEDON # PA0

Classification	: Coarse Loamy Udic Haplustalf
Location	: Thakurdwara, Moradabad, U.P., (Lat. 29°10',Long.78°52')
Date of examination	: 25-2-91
Slope	: 1% towards south
Landuse/Vegetation	: Cultivation, Presently quarried for brick kiln
Parent Material	: Alluvium
Moisture condition	: Moist
Depth of Ground water	: 6m
Drainage class	: well drained
Erosion	: Nil
Physiography	: Upper Kosi-Gola Plain

Ap 0-20 cm, light yellowish brown (2.5Y 6/4), few fine distinct mottles of dark yellowish brown (10YR 4/6), silty loam, structureless, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), common fine medium fibrous roots, common fine pores, non calcareous, clear smooth boundary,

B1 20-38 cm, Light yellowish brown to light olive brown (2.5Y 5.5/4), few fine distinct mottles of dark yellowish brown (10YR 4/6) , silty loam, weakly developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary,

B21 38-81 cm, light olive brown (2.5Y 5/4), few fine distinct mottles of dark yellowish brown (10YR4/6) , silty loam, weakly developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few fine medium fibrous roots, common fine medium pores, non calcareous, gradual smooth boundary,

B22t 81-110 cm, light olive brown(2.5Y 5/4), few fine distinct mottles of dark yellowish brown (10YR 4/6), loam, moderately developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few clay cutans along pores, few fine medium fibrous roots,common fine medium pores, non calcareous, gradual smooth boundary,

B3 110-128 cm, Olive yellow (2.5Y6/6), common medium coarse distinct mottles of very dark grayish brown (10YR 3/2) and strong brown (7.5YR 4/6) color, moderately developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), no roots, common fine medium pores, non calcareous, clear smooth boundary,

C 128-150 cm, Olive yellow (2.5Y 6/6), common medium coarse distinct mottles of very dark grayish brown (10YR 3/2) and strong brown (7.5YR 4/6) color with Fe Mn concretions , silty loam, massive, hard (dry) friable (moist) slightly plastic and slightly sticky (wet), no roots, common fine medium pores, non calcareous.

PEDON # PA2

Classification	: Coarse Loamy Udic Ustochrept
Location	: Tanda, Rampur, U.P., (Lat.28°58', Long. 78°57')
Slope	: 1% towards SE

Landuse/Vegetation : Cultivation, Presently quarried as brick klin
Parent Material : Alluvium
Moisture condition : Moist
Depth of Ground water : 6m
Drainage class : well drained
Erosion : Nil
Physiography ; Upper Kosi-Gola plain

Ap 0-18 cm, grayish brown to light olive brown (2.5Y 5/3), common medium coarse distinct mottles of strong brown (7.5YR 5/6), silty loam, structureless, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary,

B21 18-32 cm, grayish brown (2.5Y 5/2), common medium coarse distinct mottles of strong brown (7.5YR 5/6), silty loam, weakly developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few fine medium fibrous roots, common fine medium pores, non calcareous, gradual smooth boundary,

B22 32-63 cm, grayish brown (2.5Y 5/2), common medium coarse distinct mottles of strong brown (7.5YR 5/6), silty loam, moderately developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few clay cutans along pores, few fine medium fibrous roots, common fine medium pores, non calcareous, gradual smooth boundary,

B3 63-90 cm, grayish brown to light olive brown (2.5Y 5/3), common medium coarse distinct mottles of strong brown (7.5YR 5/6) with few Fe Mn concretions, silt loam, weakly developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), very few fine fibrous roots, common fine medium pores, non calcareous, clear smooth boundary,

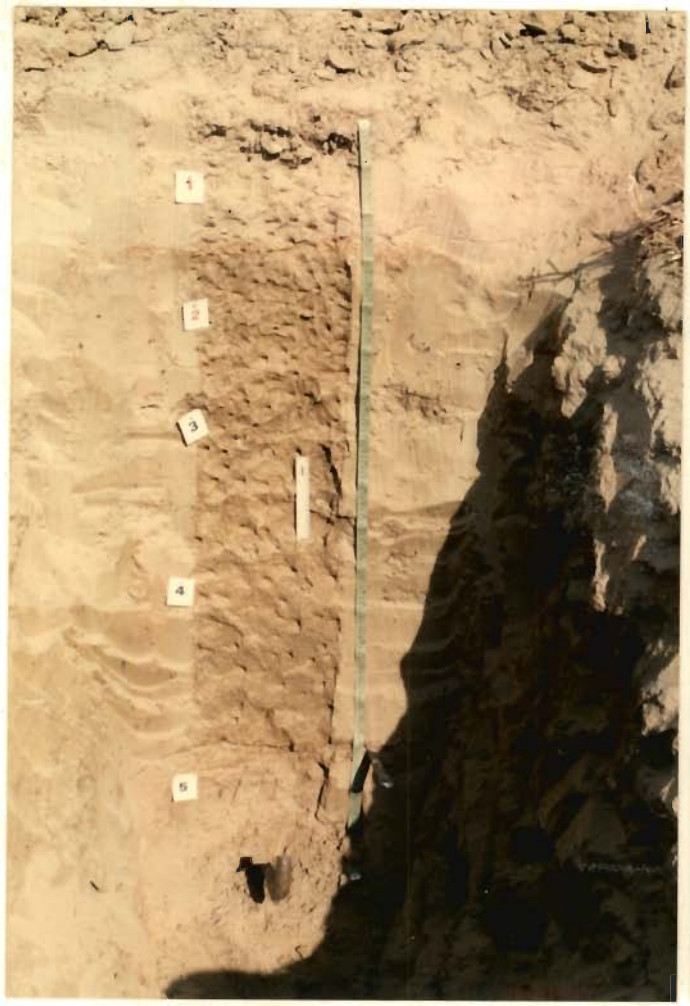
C 90-110 cm, grayish brown to light olive brown (2.5Y 5/3), common medium coarse distinct mottles of strong brown (7.5YR 5/6) with few Fe Mn concretions, silty loam, weakly developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), no roots, common fine medium pores,strongly calcareous.

PEDON # PA6

Classification : Fine Loamy Udic Ustochrept
Location : Baheri, Bareilly, U.P., (Lat.28°47', Long. 79°30')
Slope : 1% towards south
Landuse/Vegetation : Cultivation, Presently quarried as brick kiln
Parent Material : Alluvium
Moisture condition in pedon: Moist
Depth of Ground water : 6m
Drainage class : well drained
Erosion : Nil
Physiography : Upper Kosi-Gola Plain

Ap 0-30 cm, olive gray (5Y 5/2), few medium coarse distinct mottles of dark yellowish brown (10YR 4/4), sandy loam, structureless, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), common fine medium pores, non calcareous, clear smooth boundary

PEDON # PA 0



(a)

PEDON # PA6

(b)

Fig. 2.3 (a, b)) Typical Soil-Profiles Of The Upper Kosi-Gola Plain.

B1 30-70 cm, olive (5Y 5/3), common medium distinct mottles of dark yellowish brown (10YR 4/4), silty loam, moderately developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), common fine fibrous roots, common fine medium pores, strongly calcareous, clear smooth boundary

B21 70-80 cm, olive gray to olive (5Y 5/2.5), common medium distinct mottles of dark yellowish brown (10YR4/4), silt loam, moderately developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few fine fibrous roots, common fine medium pores, strongly calcareous (kankars up to 5mm about 2%), gradual smooth boundary

B22 80-97 cm, olive gray to olive (5Y 5/2.5), many medium distinct mottles of dark yellowish brown (10YR 4/4), silty loam, weakly developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), common fine fibrous roots, common fine medium pores, strongly calcareous (kankars up to 5mm about 2%), clear smooth boundary

C 97-127 cm, Olive (5Y 5/3), many medium distinct mottles of dark yellowish brown (10YR 4/4), silt loam, no developed structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), no roots, common fine medium pores, strongly calcareous (kankars up to 2 cm about 5%), gradual smooth boundary.

The soils in this soil geomorphic unit are weakly developed and coarse to medium in texture. Two typical soil-profiles of this unit are shown in (Fig. 2.3a, b). Thickness of solum varies from 73 to 97 cm. B horizon thickness range from 45 cm to 67 cm. A horizon thickness is from 18 to 30 cm. In this horizon, texture varies from sandy loan to loam and show light colours such as pale yellow to light olive brown with a 2.5 Y hue and chroma 5 to 7 and 3 to 4 value. They are generally friable to firm when moist and slightly stick-y and plastic when wet.

B horizon thickness varies from 45 to 67 m in general and is 90 cm rarely, subangular blocky structure is weakly developed. A few thin clay cutans are seen in pores of B2 horizon. These soils are firm when moist and sticky and plastic when wet. They have generally gradational boundary with underlying subhorizons Colour in B2 horizon is dark and varies with 2.5 Y hue and Chroma 5 to 6 and values 2 to 5. Oxidation mottles of reddish brown colour are common.

C horizon of these soils is generally light coloured. Iron

manganese concretions occur along with oxidation mottles, soils of this unit are sometimes moderately to strongly calcareous with irregular shaped CaCO3 modules disseminated in the subhorizons of soils. They may constitute 10-15% of the soil matter by volume.

2.4.3 Lower Kosi-Gola Plain

This unit is triangular in shape, occurring below Upper Kosi Gola Plain, in between the Ramganga Ganga and Deoha rivers. This unit is defined by a few streams with entrenched courses. In Landsat black and white images, this soil geomorphic unit shows light gray to medium gray tone, with sparse mottles of 'slightly brighter tone, and in FCC's it shows dull pink colour with sparse faint mottles.

River Ramganga flowing in western most part of this soil geomorphic unit have shifted its course in south westerly direction as evidenced by several meander scars (filled with sandy stretches) near Moradabad, also few stabilised point bars (with Vegetation) have been observed in south of Moradabad. General slope of the land surface in this soil geomorphic unit is in NS and SSE direction, suggested by the rivers flowing in this unit. Land surface in this soil geomorphic unit is nearly level, other major tributary of Ramganga is river Deoha following straight course in NS direction along Deoha fault before meeting the master stream.

PEDON # PA7

Classification : Coarse Loamy Typic Haplustalf
Location : Ummedpur Bhuta, Bareilly, U.P., (Lat.28°20'. Long.79°38')

Date of examination	: 28-2-91
Slope	: <1%
Landuse/Vegetation	: Cultivation
Parent Material	: Alluvium
Moisture condition	: Moist throughout pedon
Depth of Ground water	: 6m
Drainage class	: well drained
Erosion	: Nil
Physiography	: Lower Kosi-Gola Plain

Ap 0-26 cm, Grayish brown (2.5Y 5/2), common medium distinct mottles of strong brown brown (7.5YR5/6), silty loam, structureless, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), common fine medium fibrous roots,common fine medium pores, non calcareous, clear smooth boundary

B1 26-42 cm, grayish brown (2.5Y 5/2), common medium distinct mottles of strong brown (7.5YR5/6), silty loam, weakly developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few fine fibrous roots, common fine medium pores, non calcareous, gradual smooth boundary

B21t 42-66 cm, grayish brown to light olive brown (2.5Y 5/3), very few medium distinct mottles of strong brown (7.5YR5/6), silty loam, moderately developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few clay cutans along pores, few fine fibrous roots, common fine medium pores, non calcareous, gradual smooth boundary

B22t 66-94 cm, grayish brown to light olive brown (2.5Y 5/3), very few medium distinct mottles of strong brown (7.5YR 5/6), silt loam, moderately to strongly developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), clay cutans along pores, few fine fibrous roots, common fine medium pores, non calcareous, gradual smooth boundary

B3 94-110 cm, grayish brown to light olive brown (2.5Y 5/3), very few medium distinct mottles of strong brown (7.5YR 5/6), silty loam, weakly developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), no roots, common fine medium pores, strongly calcareous (kankars about 2%,of less than 1 cm) clear smooth boundary

C 110-128 cm, light olive brown (2.5Y 5/4), common medium distinct mottles of strong brown (7.5YR 5/6) and very dark grayish brown (10YR 3/2) with Fe Mn concretions, silt loam, structureless, firm (moist) slightly plastic and slightly sticky (wet), no roots, common fine medium pores, strongly calcareous (kankars about 2% of less than 1 cm).

PEDON # PB2

Classification	: Fine Loamy Typic Haplustalf
Location	: Kant, 10km from Jalalabad, Shahjhanpur-Jalalabad Road, Shahjhanpur, U.P., (Lat. 27°48', Long. 79°48')
Date of examination	: 7-12-89
Slope	: <1%
Landuse/Vegetation	: Cultivation of wheat
Parent Material	: Alluvium
Moisture condition	: Moist throughout pedon
Depth of Ground water	: 6 m

Drainage class : well drained
Erosion : Nil
Physiography : Lower Kosi-Gola Plain

Ap 0-30 cm, Brownish yellow (10SYR 6/6), few medium distinct mottles of strong brown (7.5YR 5/6), silty loam, structureless, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), common fine medium fibrous roots, common fine medium pores, non calcareous, gradual smooth boundary

B21t 30-54 cm, Brown (10SYR 5/3), common medium distinct mottles of strong brown (7.5YR 5/6), silty loam, moderately developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few clay cutans, few fine medium fibrous roots, common fine medium pores, non calcareous, gradual smooth boundary

B22t 54-90 cm, Brown (10SYR 5/3), common medium distinct mottles of strong brown (7.5YR 5/6), silty loam, moderately developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few clay cutans, few fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

C 90-140 cm, Brown (10SYR 5/3), common medium distinct mottles of strong brown (7.5YR5/6), silty loam, structureless, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), very few fine medium fibrous roots, common fine medium pores, non calcareous.

Soils of the unit are medium textured and moderately developed (Fig. 2.4a, b, c). Thickness of solum varies from 90 to 110 cm. B2 horizon is well developed and ranges from 52 cm to 60 cm. A horizon generally shows light colour of grayish brown to brownish yellow, with silty loam texture. It is usually friable when moist and slightly sticky and plastic when wet, A horizon usually shows clear and smooth boundary with the underlying subhorizon.

Soils in B2 horizon show moderately developed subangular blocky structure, colour is darker as compared to the upper horizons and ranges from grayish brown to olive brown with 2.5 Y hue and chroma 4 to 5 and values 2 to 3. These soils are firm when moist, very hard when dry and sticky and plastic when wet. B2 horizon soil often shows reddish brown to strong brown oxidation mottles. These soils grade into C horizon with a transitional B3 horizon, which shows very weakly developed subangular blocky structure, lighter colour as compared to the

(a)

PEDON PA2

(b)

PEDON PA7

(c)

Fig. 2.4 (a) Field View And (b, c) Typical Soil-Profiles Of The Lower Kosi-Gola Plain.

upper B2 horizon.

Soils of C horizon are structureless, and massive friable, silty loams. Colour is light olive brown 2.5 Y 5/4. Oxidation mottles are prominent along with Iron and Mn concretions.

Calcium carbonate accumulation in these soils is not a common phenomena, only in northern part of the unit, a few Kankars (2-3% of soil matter) are present in lower B3 or C horizons.

The three soil-geomorphic units- Kosi-Gola Piedmont and Upper and Lower Kosi-Gola Plains seem to be genetically related. The drainage density is highest in the north (Kosi-Gola Piedmont) and it decreases to the south. The streams are braided in the piedmont zone and they change to meandering nature in the Lower Kosi-Gola Plain. They changes their courses rapidly in the piedmont zone and gradually change to entrenched nature in the south in Lower Kosi-Gola Plain. Also the rate of sedimentation is highest in the north and it decreases gradually to the south.

2.4.4 Gholia-Dhobania-Bhambhar Piedmont

This is a narrow strip of land (20-30 km in width) occurring at the base of the Siwalik Hills and bounded by the Rapti river floodplain in the south. This unit is characterised by numerous small alluvial fans which have merged to form the piedmont.

In Landsat black and white images this unit shows gray tone with medium texture and in Landsat TM and in IRS FCC's it shows pink colour with dense fine mottles of bright.

PEDON # PC16

Classification	: Fine Loamy typic Ustorthent
Location	: Maharajpur, Balrampur, Gonda, U.P., (Lat. 27°33', Long. 82°18')
Slope	: 1-2% towards south
Landuse/Vegetation	: Cultivation
Parent Material	: Alluvium
Moisture condition	: Moist throughout pedon
Depth of Ground water	: 13 m
Drainage class	: Well drained
Erosion	: Nil
Physiography	: Gholia-Dhobania-Bhambhar Piedmont

A 0-34 cm, very dark grayish brown (2.5Y 3/2), silty loam, structureless, hard (dry) very firm (moist) very plastic and very sticky (wet), few fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

C1 34-66 cm, light olive brown to olive brown (2.5Y 4.5/4), silty loam, structureless, hard (dry) firm (moist) slightly plastic and sticky (wet), few fine medium fibrous roots, common fine medium pores, non calcareous, gradual smooth boundary

C2 66-99 cm, light olive brown (2.5Y 5/4), few medium distinct mott-les of very dark grayish brown (10YR 3/2) colour, structureless, hard (dry) firm (moist) plastic and sticky (wet), few fine medium fibrous roots, common fine medium pores, very strongly calcareous (kankars about 10% of 1-2 cm dia), gradual smooth boundary

C3 99-120 cm, light olive brown (2.5Y 5/4), few medium distinct mottles of very dark grayish brown (10YR 3/2), silty loam, massive, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few fine roots, common fine medium pores, very strongly calcareous (kankars about 2% of 1-2 cm dia), gradual indistinct boundary

C4 120-150 cm, light olive brown (2.5Y 5/4), few medium distinct mottles of very dark grayish brown (10YR 3/2), silty loam, massive, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), no roots, common fine medium pores, very strongly calcareous (kankars about 10% of 1-2 cm dia).

Soils of this piedmont zone typically show A/C type horizonation. Thickness of A horizon is 34 cm, and shows dark grayish brown (2.5Y 3/2) colour. It is silty loam in nature. Usually the soils are structureless, but sometimes very weakly developed peds can be seen. These A horizon soils grades to coarse textured light coloured soils of C horizons. Soils in the lower part of C horizon are highly calcareous with irregular shaped concretions (2-3 cm) constituting from 2 to 10% of soil matter by volume.

2.4.5 Young and Old Sihali-Mohan-Kandra Piedmont

These two soil-geomorphic units are intimately related and are confined to the geomorphic unit of piedmont zone, occuring north of the Ghaghra Plains. This geomorphic unit has undergone severe dissection in the recent past as a result of which two soil-geomorphic units are recognised. (i) the area marked by young soils when numerous Siwalik streams are active which is called as Young Sihali-Mohan-Kandra Piedmont, and (ii) the areas still not affected by erosion and representing remnant older piedmont and has been named as Old Sihali-Mohan-Kandra Piedmont.

In Landsat black and white images, this soil geomorphic unit shows dark tone in old remanent part (Old Sihali-Mohan-Kandra Piedmont), showing indicating excessive vegetation and high moisture, and brighter tone where dissection and erosion has occurred. In landsat TM, IRS FCC's it shows dark brownish red colour in excessively vegetated remnant part of piedmont where as bright pink colour in dissected /eroded younger piedmont (Sihali-Mohan-Kandra Piedmont).

On either side of these units two major rivers Sarda and Ghaghra enters from Himalayas and do not form any alluvial fan, since they are flowing through deep cuts.

PEDON # PA10

Classification	: Coarse Loamy Typic Usto-rthent
Location	: Gorifanta, Lakhimpur, U.P., (Lat.28°39', Long.80°31')
Slope	: 1-2% towards south
Landuse/Vegetation	: Cultivation of wheat
Parent Material	: Alluvium
Moisture condition	: Moist throughout pedon

Depth of Ground water : 12 m
Drainage class : well drained
Erosion : el
Physiograph-y : Young Sihali-Mohan-Kandra Piedmont

Ap 0-18 cm, dark grayish brown to olive brown (2.5Y 4/3), common fine medium distinct mottles of reddish brown (5YR 4/4) color, silty loam, structureless, hard (dry) friable (moist) slightly plastic and slightly sticky (wet), abundant fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

C1 18-75 cm, dark olive brown (2.5Y 4/4) common fine medium distinct mottles of reddish brown (5YR 4/4) color, silty loam, very weakly developed subangular blocky structure, hard (dry) fragile (moist) slightly plastic and slightly sticky (wet), common fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

C2 75-120 cm, light olive brown (2.5Y 5/5), common fine medium distinct mottles of reddish brown (5YR 4/4) color, silty loam, structureless, hard (dry) friable (moist) slightly plastic and slightly sticky (wet), common fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

Soils in the Young Sihali-Mohan-Kandra Piedmont ~~piedmont~~ are coarse textured, and poorly developed, and show A/C type horizons. Soil profiles in this unit show Ap horizon or ploughed layer up to 20 cm. Soils are dark grayish brown 2.5 Y 4/3 and fine to medium sized reddish brown mottles are common. These are sandy loam om textured soils they are friable and slightly plastic and slightly sticky when wet.

PEDON # PA13

Classification : Fine Loamy Typic Ustochrept
Location : Belryan, Lakhimpur, U.P.,
: (Lat. 28°21', Long. 80°53')
Slope : 1-2% towards south
Landuse/Vegetation : Cultivation of sugar cane
Parent Material : Alluvium
Moisture condition : Moist throughout pedon
Depth of Ground water : 12 m
Drainage class : well drained
Erosion : el
Physiograph-y : Old Sihali-Mohan-Kandra Piedmont

Ap 0-29 cm, dark grayish brown (2.5Y 4/2), many fine medium distinct mottles of strong brown (7.5YR 5/8) color, loam, structureless, slightly hard (dry) firm (moist) slightly plastic and slightly sticky (wet), abundant fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

B21 29-62 cm, olive yellow (2.5Y 6/6), common fine medium distinct mottles of strong brown (7.5YR 5/8) color, silty loam, weakly developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few fine fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

B22 62-89 cm, olive yellow (2.5Y 6/6), common fine medium distinct mottles of strong brown (7.5YR 5/8) color, silty loam, weakly developed structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few fine fibrous roots, common fine medium pores, weakly calcareous, gradual smooth boundary

B23 89-110 cm, grayish brown to light olive brown (2.5Y 5/3), common fine medium distinct mottles of strong brown (7.5YR 5/8) color, silty loam, weakly to moderately developed structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few clay cutans, no roots, common fine medium pores, strongly calcareous (kankars), gradual smooth boundary

C1 110-135 cm, light yellowish brown (2.5Y 5/4), common fine medium distinct mottles of strong brown (7.5YR 5/8) color, silty loam, structureless, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), no roots, common fine medium pores, strongly calcareous(kankars), clear smooth boundary

C2 135-200 cm, light yellowish brown (2.5Y 5/4), many fine medium distinct mottles of strong brown (7.5YR5/8) color, silty loam, structureless, friable (moist) slightly plastic and slightly sticky (wet), no roots, common fine medium pores, strongly calcareous(kankars)

PEDON # PA15

Classification	: Coarse Loamy Typic Ustochrept
Location	: Tikunia, Lakhimpur, U.P.,
	: (Lat. 28°11', Long. 80°57')
Slope	: 1-2% towards south
Landuse/Vegetation	: Cultivation of wheat
Parent Material	: Alluvium
Moisture condition	: Moist throughout pedon
Depth of Ground water	: 12 m
Drainage class	: well drained
Erosion	: el
Physiography	: Old Sihali-Mohan-Kandra Piedmont

Ap 0-18 cm, gray to grayish brown (2.5Y 5/1), few fine medium distinct mottles of strong brown (7.5YR 5/7) color, loam, structureless, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), abundant fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

B21 18-47 cm, dark gray to dark grayish brown (2.5Y 4/1), few fine medium distinct mottles of strong brown (7.5YR 5/7) color, silty loam, weakly developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few fine fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

B22 47-82 cm, light olive brown (2.5Y 5.5/6), silty loam, weakly to moderately developed subangular blocky soil structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few fine fibrous roots, common fine medium pores, weakly calcareous, gradual smooth boundary

C 82-107 cm, light olive brown (2.5Y 5.5/6), silty loam, structureless, hard (dry) friable (moist) slightly plastic and slightly sticky (wet), no roots, common fine medium pores, strongly calcareous (kankars).

In the Old Sihali-Mohan-Kandra Piedmont the soils have 75 to 110 cm thick solum. In this soil-geomorphic unit, the soils are weakly developed with a thin B2 horizon. Ap horizon is 18 to 30 cm thick, these are high in humus and show grayish brown to dark grayish brown colour, with 2.5Y hud and chroma values 1 - to 2. These soils show loamy texture and lack the development of pedality. B horizon thickness varies from 57 to 81 cm of which B2 horizon is 21 to 27 cm thick. In this part, the soils are dark ~~are~~ coloured than from overlying and underlying horizons, and show weakly to moderately developed subangular blocky structure. The soils are firm when moist and sticky and plastic when wet, indicating higher content clays. Texturally these consist of heavy sandy loam. These heavy textured dark coloured soils merge with clear smooth boundaries to light coloured and light textured sandy loam to loamy sand of C horizon.

Upper horizons are almost free of CaCo3 accumulations, but lower parts of B3 horizons and in C horizons medium sized (1-2 cm) calcium carbonate concretions occur in disseminated form and range from 10 to 15% of soil matter by volume.

2.4.6 Rapti Floodplain:

This soil-geomorphic unit occur in north western part of the study area. In north this unit is bounded by aggrading piedmont and in south by Rapti - Ghaghra interfluve. In landsat black and white images, this unit shows uniform dark gray tone, and in landsat TM and IRS FCC's it shows uniform dark red colour.

The river Rapti originates in Siwalik, and takes an incised course in the plains and does not form any fan. The

floodplains. The floodplain formed by this river is arc shaped, with a maximum width in central part and then narrows both in upstream and downstream direction.

Pedon # PB14

Classification	: Coarse loamy Fluventic Ustorthent
Location	: Patna, Bahraich, Uttar Pradesh, (Lat. Lat. 27°50', Long.81°47')
Slope	: 1% towards from south
Landuse/Vegetation	: Cultivation of rice
Parent Material	: Alluvium
Moisture condition	: Moist throughout pedon
Depth of Ground water	: 6 m
Drainage class	: well drained
Erosion	: Nil
Physiography	: Rapti Floodplain

Ap 0-45 cm, dark grayish brown (2.5Y 4/2), few medium distinct mottles of yellowish brown to dark yellowish brown (10YR 3.5/6), silt loam, structureless, firm (moist) slightly plastic and slightly sticky (wet), common fine medium fibrous roots, common fine medium pores, strongly calcareous, clear smooth boundary

C1 45-74 cm, light olive brown to live brown (2.5Y 4.5/4), common medium distinct mottles of yellowish brown to dark yellowish brown (10YR 3.5/6) and strong brown (7.5YR 4/6), silty loam, structureless, firm (moist) slightly plastic and slightly sticky (wet), few fine roots, common fine medium pores, strongly calcareous (kankars up to 3 cm about 10%), clear smooth boundary

C2 74-82 cm, dark grayish brown (2.5Y 4/2), common medium distinct mottles of yellowish brown to dark yellowish brown (10YR 3.5/6) and strong brown (7.5YR 4/6), silty loam, structureless, firm (moist) slightly plastic and slightly sticky (wet), few fine roots, common fine medium pores, moderately calcareous, clear smooth boundary

C3 82-100 cm, light olive brown (2.5Y 5/4), common medium distinct mottles of yellowish brown to dark yellowish brown (10YR 3.5/6) and strong brown (7.5YR 4/6), silty loam, structureless, friable (moist) slightly plastic and slightly sticky (wet), no fibrous roots, common fine medium pores, moderately calcareous.

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PEDON # PB15

Classification	: Loamy Fluventic Ustortnent
Location	: Khargura, Bhinga, (Bahraich, U.P. (Lat. 27°42', Long.81°54')
Slope	: <1%
Landuse/Vegetation	: Cultivation presently as brick klin
Parent Material	: Alluvium

Moisture condition : Moist throughout pedon
Depth of Ground water : 8 m
Drainage class : well drained
Erosion : Nil
Physiography : Rapti Floodpain

Ap 0-40 cm, light yellowish brown (2.5Y 5/4), few medium faint mottles, silty loam, structureless, firm (moist) slightly plastic and slightly sticky (wet), common fine medium fibrous roots, common fine medium pores, strongly calcareous, clear smooth boundary

C1 40-75 cm, grayish brown (2.5Y 5/2), few medium coarse faint mottles, silty loam, very weakly developed subangular blocky structure, firm (moist) slightly plastic and slightly sticky (wet), few fine roots, few fine medium pores, weakly calcareous, gradual smooth boundary

C2 75-115 cm, olive (5Y 5/4), few medium coarse faint mottles, silty loam, very weakly developed subangular blocky structure, firm (moist) slightly plastic and slightly sticky (wet), few fine medium fibrous roots, few fine medium pores, strongly calcareous, gradual smooth boundary

C3 115-140 cm, olive gray to olive (5Y 5/4) few medium coarse faint mottles, massive,silty loam, firm (moist) slightly plastic and slightly sticky (wet), no roots, few fine medium pores, strongly calcareous.

This geomorphic unit does not show soil development, and show A/C type boundaries (Fig. 2.5a). Thickness of A horizon varies from 35 to 40 cm and the colour is light yellowish brown (2.25 Y 5/4), texture is silty loam. Peds have not developed, and if developed, are very weak. These A horizon soils generally changes to light coloured, coarse textured friable brittle soils of C horizon.

2.4.7 Ghaghra Plains- Ghaghra Floodplain, Old Ghaghra Pain, Old Ghaghra Bar

The geomorphic unit of the Ghaghra Plains is a vast plain, formed by mighty river, the Ghaghra and its tributary Sarda in north. In west this unit is bounded by Deoha/Ganga-Ghaghra Interfluve and in eastern part by Rapti-Ghaghra Interfluve. These plains are incised into the Deoha/Ganga-Rapti structural block, discussed later and as a result both eastern and western boundaries are marked by a series of cliff with a relief of 10-15 m. This vast plain has been subdivided into three subunits

(a)

PEDON # PB 10

PEDON # PB 14

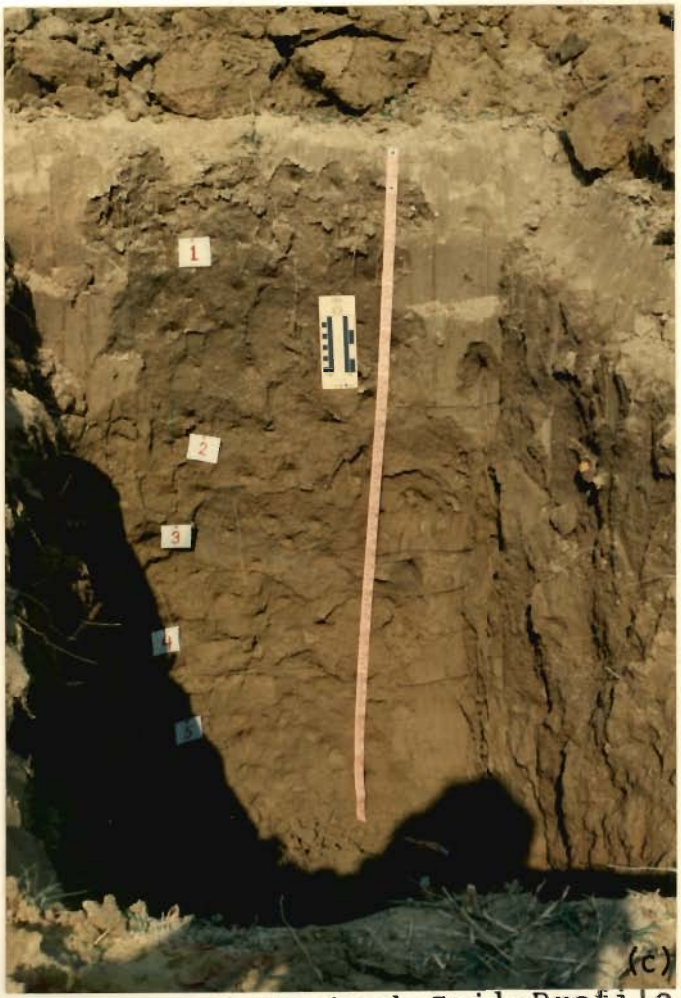

Fig. 2.5 (a) Field View And (b, c) Typical Soil-Profile Of The Ghaghra Floodplain (Pedon # PB10) And Rapti Floodplain (PEDON # PB14).

based on their distinct characteristics in landsat images and soil development features (i) Ghaghra Floodplain- In landsat black and white images, this unit shows generally uniform dark gray tone in floodplains. (ii) Old Ghaghra Plain- Slightly brighter tone with medium texture (iii) Old Ghaghra Bar- This unit occurs in west central part of the Ghaghra Plain and shows medium gray tone with linear bar type features.

2.4.7.a Ghaghra Floodplain

The river Ghaghra is of braided nature for most part of the study area due to enormous amount of load. The river generally flows in SE direction. The width of the Ghaghra plain is very wide ranging 20 to 40 km, which is very wide in north and central regions and then tapers down to 10 km in south. The river seems to have migrated in SW direction in the recent past as many meander scars and oxbows are seen in eastern part of active river bed. The confluence of river Sarda with Ghaghra has also migrated in northern part, as it can be traced by paleochannels in the floodplain.

PEDON # PB10

Classification	: Coarse loamy Fluventic Ustorthent
Location	: Behra, Bahraich, Uttar Pradesh, (Lat. 27°50', Long.81°47')
Slope	: Nil
Landuse/Vegetation	: Cultivation presently as brick klin
Parent Material	: Alluvium
Moisture condition	: Moist throughout pedon
Depth of Ground water	: 4 m
Drainage class	: well drained
Erosion	: Nil
Physiography	: Ghaghra Floodplain

Ap 0-36 cm, light olive brown to olive brown (2.5Y 4.5/4), silty loam, structureless, friable (moist), slightly plastic and slightly sticky (wet), common fine medium fibrous roots, common fine medium pores, strongly calcareous, gradual smooth boundary

C1 36-72 cm, light olive brown to olive brown (2.5Y4.5/4), very few medium distinct mottles of dark yellowish brown (10YR4/6), silty loam, structureless, friable (moist) slightly plastic and slightly sticky (wet), few fine roots, common fine medium pores, strongly calcareous, gradual smooth boundary

C2 72-118 cm, light yellow (2.5 Y 6/4), very few medium distinct mottles of dark yellowish brown (10YR 4/6), silty, structureless, firm (moist) slightly plastic and slightly sticky (wet), no roots, common fine medium pores, strongly calcareous (kankars), gradual smooth boundary.

In Ghaghra Floodplain the soils show AC type horizonation and are marked by apedal and massive structure (Fig. 2.5b, c). The texture is silty loam. Colour varies from light olive brown (2.5 Y 5/4) in A horizon to light yellowish brown (2.5 Y 6/4) in C horizon. The soils are weakly to strongly calcareous with concretions in the lower horizons.

2.4.7.b Old Ghaghra Plain

PEDON # PA14

Classification	: Coarse Loamy Typic Ustochrept
Location	: Nighasan, Palia, Lakhimpur, U.P., (Lat.28°51', Long. 80°51')
Slope	: 1-2% towards south
Landuse/Vegetation	: Cultivation of Sugar cane
Parent Material	: Alluvium
Moisture condition	: Moist throughout pedon
Depth of Ground water	: 6 m
Drainage class	: well drained
Erosion	: el
Physiography	: Old Ghaghra Plain

Ap 0-25 cm, dark grayish brown (2.5Y 4/2), silty loam, structureless, friable (moist) slightly sticky slightly plastic (wet), common fine fibrous roots, common fine medium pores, moderately calcareous (no kankars), clear smooth boundary

C1 25-60 cm, very dark grayish brown (2.5Y 3/2), loam, structureless, friable (moist) slightly sticky and slightly plastic (wet), few fine fibrous roots, common fine medium pores, strongly calcareous (no kankars), clear smooth boundary

C2 60-77 cm, light yellowish brown (2.5Y 6/4), sandy loam, structureless, loose (moist), no roots, common fine medium pores, strongly calcareous (no kankars), clear smooth boundary,

B2 77-103 cm, dark grayish brown (2.5Y 4/2), weakly developed sub angular blocky structure, friable(moist) slightly sticky slightly plastic (wet), few fine roots, common fine medium pores, highly calcareous (kankars irregular shaped 1-2 cm. dia about 5% with Gastropod shells 2-3 mm size about 1%), gradual smooth boundary,

B3 103-126 cm, grayish brown (2.5Y 5/2), silty loam, very weakly developed subangular blocky structure, friable (moist) slightly sticky slightly plastic (wet), very few roots, common fine medium pores, calcareous (no kankars), gradual smooth boundary,

C 126-170 cm, grayish brown (2.5Y 5/2), silty loam, very weak subangular blocky structure, friable (moist) slightly sticky and slightly plastic (wet), no roots, common fine medium pores, moderately calcareous.

PEDON # PC10

Classification	: Coarse Loamy Typic Ustochrept
Location	: Masodha, Faizabad, U.P., (Lat. 26°42', Long. 82°7')
Slope	: Nil
Landuse/Vegetation	: Cultivation,
Parent Material	: Alluvium
Moisture condition	: Moist throughout pedon
Depth of Ground water	: 4-6m
Drainage class	: well drained
Erosion	: Nil
Physiography	: Old Ghaghra Plain

Ap 0-11 cm, pale yellow to light yellowish brown (2.5Y 6.5/4), silt loam, structureless, friable (moist) non plastic and non sticky (wet), many fine medium fibrous roots, common fine medium pores, weakly calcareous, clear smooth boundary

B1 11-21 cm, light brownish gray to light yellowish brown (2.5Y 6/3), common medium diffused mottles of dark yellowish brown (10YR 4/5) silty loam, weakly developed subangular blocky structure, friable (moist) slightly plastic and slightly sticky (wet), few fine medium fibrous roots, common fine medium pores, strongly calcareous (kankars up to 5 cm about 5%), clear smooth boundary

B2 21-47 cm, light yellowish brown to light olive brown (2.5Y 5.5/4), common medium diffused mottles of dark yellowish brown (10YR4/5) and very dark grayish brown (10YR 3/2) with Fe Mn concretions, silt loam, moderately developed subangular blocky structure, friable (moist) slightly plastic and slightly sticky (wet), few clay cutans, few fine roots, common fine medium pores, strongly calcareous (kankars up to 5 cm about 5%), clear smooth boundary

B3 47-88 cm, light yellowish brown to light olive brown (2.5Y 5.5/4), common medium diffused mottles of dark yellowish brown (10YR 4/5) and very dark grayish brown (10YR 3/2) with Fe Mn concretions, silty loam, weakly developed subangular blocky structure, friable (moist) slightly plastic and slightly sticky (wet), few fine roots, common fine medium pores, strongly calcareous (kankars up to 5 cm about 5%), gradual indistinct boundary.

C 88-157 cm, light yellowish brown to light olive brown(2.5Y 5.5/4), common medium diffused mottles of dark yellowish brown (10YR 4/5) and very dark grayish brown (10YR 3/2) with Fe Mn concretions, silty loam, structureless, friable (moist) slightly plastic and slightly sticky (wet), no roots, common fine medium pores, strongly calcareous (kankars up to 5 cm about 5%).

In the northern part (Pedon PA14) (Fig. 2.6a, b) ploughed layer (Ap horizon) thickness is 25 cm. It is dark grayish brown silty loam, and friable when moist and slightly plastic and sticky when wet. This Ap horizon grades to A1 horizon, showing light yellowish brown colour and single grain sandy loam texture. This A1 horizon soil abruptly change to slightly developed B horizon, which shows dark grayish brown colour (2.5 Y 4/2) and weakly developed medium to coarse subangular blocky structure in silty loam. It is highly calcareous with concretions of 1-2 cm size constituting about 5% soil matter by volume. Soils of this horizon are firm when moist and slightly plastic and sticky when wet. The B horizon with weakly developed structure soils grades down to light textured and light coloured soil without any structure in C horizon.

In eastern central part weakly developed soils occur. Solum thickness varies from 88 to 103 cm. of which B2 horizon is 21 to 26 cm thick. The colour of B2 horizon varies from dark grayish brown to olive brown in 2.5 Y hue with moist value 4 to 5 and 2 to 4 chroma. Strong brown mottles and FeMn concretions are observed and they increase with depth. The soils are weakly to strongly calcareous with irregular shaped (4-5 cm) dia concretions These B2 horizon soils merge into light coloured friable soils of C' horizons.

2.4.7.c Old Ghaghra Bar

PEDON # PB9

Classification : Fine Loamy Udic Haplustalf
Location : Nabinagar, Bahraich, U.P., Lat.27°44', Long. 80°54')

PEDON # PA14

Fig. 2.6 (a) Field View And (b) Typical Soil-Profile Of The Old Ghaghra Plain.

Slope	: Nil
Landuse/Vegetation	: Cultivation presently quarried as brick klin
Parent Material	: Alluvium
Moisture condition	: Moist below 50 cm
Depth of Ground water	: 6-8 m
Drainage class	: well drained
Erosion	: Nil
Physiography	: Old Ghaghra Bar

Ap 0-35 cm, brownish yellow (10YR 6/4), few medium coarse faint mottles, silty loam, structureless, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), common fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

B1 35-60 cm, dark yellowish brown (10YR 4/4), few medium coarse faint mottles, silty loam, weakly developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), common fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

B21t 60-118 cm, dark yellowish brown (10YR 3.5/4), few medium coarse faint mottles, silty loam, moderately developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few clay cutans, few fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

B22 118-145 cm, dark grayish brown (10YR 4/2), few medium coarse faint mottles, silty loam, moderately developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), clay clay cutans along pores, few fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

C 145-175 cm, yellowish brown (10YR 5.5/4), few medium coarse faint mottles, silty loam, structureless, hard (dry) friable (moist) slightly plastic and slightly sticky (wet), no roots, common fine medium pores, non calcareous.

Soils in this unit are moderately developed (Fig 2.7a). Solum thickness is about 145 cm. B2 horizon thickness is 80 - 85 cm, soils in this horizon are of dark yellowish brown in colour, with few medium coarse faint mottles. These soils show moderately developed subangular blocky soils structure. The soils are heavy silty loams. A few clay cutans in pores are observed. These B2 horizon soils change to light coloured yellowish brown (10 YR 5.5/4) silty loams of C horizon with clear smooth boundary.

2.4.8 Upper Deoha/Ganga-Ghaghra Interfluve

This unit comprises the northern part of Deoha/Ganga-Ghaghra Interfluve, and is salt-free as compared to the lower part with

extensive surfacial salt accumulation. In west this unit is bounded by Kosi-Gola Plain and in east by the Ghaghra Floodplain.

In Landsat black and white images this unit shows uniformly gray tone with medium texture. Very few and bright patches occur in the lower part. In Landsat TM and IRS FCC's it shows light brownish red colour with sparse mottles of bright in lower part.

Land surface in this soil geomorphic unit is generally level with regional slope in NS or in SSE direction. River Gomti along with its tributaries flowing in central part of this unit is the alluvial stream draining this unit. The Gomti shows deep cutting along its banks on either side, indicate that down cutting is prominent due to upland of this interfluve.

PEDON # PB4

Classification	: Coarse Loamy Typic Haplustalf
Location	: Vill. Jalalpur, 32 km SE Of Shahjhanpur, Sitapur-Shahjhanpur Road, Shahjhanpur, U.P., (Lat. 27°48', Long. 89°9')
Date of examination	: 9-12-89
Parent material	: Alluvium
Erosion	: Nil
Slope	: Nil
Land use	: Sugar cane cultivation
Depth of ground water	: 12m
Physiography	: Upper Deoha/Ganga-Ghaghra Interfluve

A 0-20 cm, grayish brown to light olive brown (2.5Y 5/3), common medium distinct mottles of red (2.5YR 4/6) color, silty loam, structureless, common fine medium pores; abundant fine medium roots; very weakly calcareous; clear smooth boundary.

B21t 20-60 cm, grayish brown to olive brown (2.5Y 4/3); common distinct coarse mottles of red (color); silty loam, moderately developed sub angular structure; few clay coatings on peds ; firm (moist) slightly plastic (wet) slightly sticky; common fine medium soil pores; common fine medium fibrous roots; very weakly calcareous; gradual smooth boundary.

(a)

PEDON # PB4

(b)

PEDON # PB 9

(c)

Fig. 2.7 (a) Field View And (b, c)) Typical Soil-Profile Of The Upper Deoha/Ganga-Ghaghra Interfluve (PEDON # PB4) and Old Ghaghra Bar (PEDON # PB9).

B22t 60-95 cm, dark grayish brown to olive brown (2.5Y 4/2); few medium coarse mottles of red (2.5YR 4/6) color; silty loam, moderately developed subangular blocky structure; few clay coatings, firm (moist)very plastic (wet); few fine fibrous roots; weakly calcareous; clear smooth boundary.

C1 95-135 cm, grayish brown (2.5Y 5/2); few medium coarse distinct mottles of red (2.5YR 4/6) color also few gray mottles due to carbonate concretions; silty loam, structureless; firm (moist) plastic(wet); no roots ; very strongly calcareous with carbonate concretions up to 25% of 1-2cm dia.

C2k 135+, grayish brown (2.5Y5/2); few medium coarse distinct mottles of red (2.5YR4/6) color; structureless; firm (moist) plastic (wet); no roots, very strongly calcareous with carbonate concretions up to 20-30% of 3-4cm dia.

PEDON # PB5

Classification	: Coarse Loamy Typic Haplustalf
Location	: Barwar, Sitapur, U.P., (Lat.27°50', Long. 80°16')
Date of examination	: 9-12-89
Parent material	: Alluvium
Slope	: <1%
Erosion	: Nil
Depth of ground water	: 12m
Land use	: sugar cane cultivation
Physiography	: Upper Deoha/Ganga-Ghaghra Interfluve

Ap 0-15 cm, Yellowish Brown (10YR 5/6), sandy loam, structureless, common fine medium soil pores; slightly hard (dry) and friable (moist) slightly sticky and slightly plastic (wet), common fine medium roots; non calcareous; clear smooth boundary.

B1 15-40 cm, dark yellowish brown (10YR 4/5), loam, weakly developed subangular blocky soil structure; common fine medium soil pores; slightly hard (dry) and friable (moist) slightly sticky and slightly plastic (wet), common fine medium roots; non calcareous; gradual smooth boundary.

B21 40-70 cm, dark yellowish brown (10YR 4/5), few medium faint mottles, loam, moderately developed subangular blocky structure, common fine medium soil pores; slightly hard (dry) and firm (moist) slightly sticky and slightly plastic (wet), few fine medium roots; non calcareous; gradual smooth boundary.

B22 70-94 cm, dark yellowish brown (10YR 4/5), common distinct mottles of dark brown (7.5YR 3/2) color,moderately developed subangular blocky structure, few clay cutans,common fine medium soil pores; slightly hard (dry) and firm (moist) slightly sticky and slightly plastic (wet), few fine medium roots; non calcareous; gradual smooth boundary.

B3 94-120 cm, dark yellowish brown (10YR 4/5), silty loam, common distinct mottles of dark brown (7.5YR 3/2) color with FeMn concretions, weakly developed subangular blocky structure, common fine medium soil pores; slightly hard (dry) and firm (moist) slightly sticky and slightly plastic (wet), few fine medium roots; non calcareous; gradual smooth boundary.

C1 120-150 cm, yellowish brown (10YR 5/6), silty loam, few distinct mottles of dark brown (7.5YR3/2) color, very weakly developed subangular blocky structure, common fine medium soil pores; slightly hard (dry) and firm (moist) slightly sticky and slightly plastic (wet), no roots; non calcareous; gradual smooth boundary.

C2 150-200 cm, brownish yellow (10YR 6/6), few distinct mottles of dark brown (7.5YR 3/2) color, structureless, common

fine medium soil pores, slightly hard (dry) and firm (moist) slightly sticky and slightly plastic (wet), no roots, non calcareous.

Soils of this geomorphic unit are moderately developed (Fig. 2.7b, c). Thickness of solum varies from 95 - 120 cm. In A horizon 15-20 cm, the soils show sandy loam to silty loam texture, The colour varies from grayish brown to yellowish brown. They are friable when moist and slightly hard when dry.

Thickness of the B horizon varies from 75 to 105 cm, with B2 horizon ~~thickness~~ ranging between 54 to 75 cm. Soils in this horizon show dark grayish brown to dark yellowish brown colour and silty loam texture. Usually the soils from horizon are non calcareous. Occasionally weak carbonate efflorescence have been noticed in B3 or C horizon. Soils from this horizon show clear smooth boundaries with underlying B3 or C horizons.

2.4.9 Middle Deoha/Ganga-Ghaghra Interfluve

This is, the largest soil geomorphic unit of the study area. It is bounded by the Ghaghra Floodplain and by the Ganga Fault in the east and west respectively. In Landsat black and white images it shows light gray tone with medium texture and strongly mottled with distinct white and dark patches elongated parallel to the general SE slope. These mottles are due to high salt efflorescence. In landsat TM FCC's and IRS FCC's it shows dull red to brownish red colour with strong bright mottles representing patches of salt efflorecsence. The Gomti and Sai are the two major rivers draining this unit. These rivers flow in SE to easterly direction in this unit. Both of these rivers are of incised nature and show dissected banks. The land surface

is gently slope with general slope in SE to easterly direction.

PEDON # PB6

Classification	: Fine loamy Typic Haplustalf
Location	: Vill. Gurdhapar, Hargaon Sitapur, U.P., (Lat. 27°47', Long.80°43')
Slope	: <1%
Landuse/Vegetation	: Cultivation of rice
Parent Material	: Alluvium
Moisture condition	: Moist below 50 cm
Depth of Ground water	: 6 m
Drainage class	: well drained
Erosion	: Nil
physiography	: Lower Deoha/Ganga-Ghaghra Interfluve

Ap 0-12 cm, light yellowish brown (2.5Y 6/4), few medium coarse faint motteles of yellowish red (5YR 6/4) color, silty loam, structureless, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), common fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

B21 12-30 cm, dark grayish brown to olive brown (2.5Y 4/3), few medium coarse faint motteles of yellowish red (5YR 6/4) color, silty loam, moderately developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few fine medium fibrous roots, common fine medium pores, non calcareous, gradual smooth boundary

B22 30-55 cm, dark grayish brown to olive brown (2.5Y 4/3), few medium coarse faint motteles of yellowish red (5YR 6/4) color, silty loam, moderately developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few clay cutans, few fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

B23 55-85 cm, yellowish brown (10YR 5/8), common medium coarse faint of yellowish red (5YR 6/4) and black (5YR 2.5/1) color, silty loam, moderately developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few clay cutans, few fine medium fibrous roots, common fine medium pores, non calcareous, gradual smooth boundary

B24 85-120 cm, yellowish brown (10YR 5/8), common medium coarse faint of yellowish red (5YR 6/4) and black (5YR 2.5/1) color, , silt loam , wea-kly developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few fine fibrous roots, common fine medium pores, non calcareous, gradual smooth boundary

C 120-150 cm, yellowish brown (10YR 5/8), medium coarse mottles of yellowish red (5YR 6/4) and black (5YR 2.5/1) color, silty loam, structureless, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), no roots, common fine medium pores, non calcareous

PEDON # PB7

Classification	: Fine Loamy Typic Haplustalf
Location	: Khairabad, Sitapur, U.P, (Lat.27°32', Long. 80°48')

Date of examination	: 15-2-91
Slope	: Nil
Landuse/Vegetation	: Cultivation, presently quarried as brick klin
Parent Material	: Alluvium
Moisture condition	: Moist throughout pedon
Depth of Ground water	: 12m
Drainage class	: well drained
Erosion	: Nil
Physiography	: Middle Deoha/Ganga-Ghaghra Interfluve

Ap 0-18 cm, light yellowish brown (10YR 6/4), very few faint mottles, silty loam, structureless, firm (moist) slightly plastic and slightly sticky (wet), common fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

B1 18-38 cm, light yellowish brown to yellowish brown (10YR 5.5/4), common medium distinct mottles of very dark grayish brown (10YR 3/2) color with Fe Mn concretions, silty loam, moderately to strongly developed subangular blocky structure, firm (moist) slightly plastic and slightly sticky (wet), common fine medium fibrous roots, common fine medium pores, non calcareous, gradual smooth boundary

B21t 38-84 cm, yellowish brown (10YR 5/4), common medium distinct mottles of very dark grayish brown (10YR3/2) color with Fe Mn concretions, silty loam, moderately to strongly developed subangular blocky soil structure, firm (moist) slightly plastic and slightly sticky (wet), clay cutans along pores, common fine medium fibrous roots, few fine medium pores, non calcareous, gradual smooth boundary

B22t 84-133cm, yellowish brown to dark yellowish brown (10YR 4.5/4), common medium distinct mottles of very dark grayish brown (10YR 3/2) color with Fe Mn concretions, silty loam, strongly developed subangular blocky soil structure, firm (moist) slightly plastic and slightly sticky (wet), clay cutans along pores, few fine medium fibrous roots, common fine medium pores, non calcareous, gradual smooth boundary

B23t 133-175 cm, yellowish brown to dark yellowish brown (10YR 4.5/4), common medium distinct mottles of very dark grayish brown (10YR 3/2) color with Fe Mn concretions,silty loam, strongly developed subangualar blocky soil structure, firm (moist) slightly plastic and slightly sticky (wet), few fine fibrous roots, common fine medium pores, non calcareous.

B3 175-200 cm +, yellowish brown (10YR 5/4), common medium distinct mottles of very dark grayish brown (10YR 3/2) color with Fe Mn concretions, silty loam, weakly developed subangular blocky soil structure, firm (moist) slightly plastic and slightly sticky (wet), very few fine medium fibrous roots, common fine medium pores, non calcareous.

PEDON # PC7

Classification	:Fine Loamy Typic Haplustalf
Location	:Bikapur, Sultanpur, U.P., (Lat. 26°36',Long.82°9')
Date of examination	:18-2-91
Slope	:Nil
Landuse/vegetation	:Cultivation, presently quar-ried as brick kiln
Parent material	:Alluvium
Moisture condition	:Moist
Depth of ground water	:12 m

Drainage class :well drained
Erosion :Nil
Physiography :Middle Deoha/Ganga-Ghaghra Int fluve

Ap 0-18 cm, Light olive brown (2.5Y 5/4), very few fine medium distinct mottles of very dark grayish brown (10YR 3/2) color with Fe Mn concretions, silty loam, no developed structure, friable (moist) slightly plastic and slightly sticky, common fine medium fibrous roots, common medium coarse pores, non calcareous, clear smooth boundary

B1 18-38 cm, Light olive brown to olive brown (2.5Y 4.5/4), few fine medium distinct mottles of very dark grayish brown (10YR 3/2), silty loam, weakly developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few fine fibrous roots, common fine medium pores, non calcareous, clear smooth boundary,

B21 38-56 cm, Olive brown (2.5Y 4/4), few fine medium distinct mottles of very dark grayish brown (10YR 3/2), heavy silt loam, moderately developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), common clay cutans along pores, very few fine fibrous roots, common fine medium pores, non calcareous, clear smooth boundary,

B22 56-83 cm, Olive brown (2.5Y 4/4), few fine medium distinct mottles of very dark grayish brown (10YR 3/2), silty loam, moderately developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), clay cutans along pores, very few fine fibrous roots, common fine medium pores, strongly calcareous with irregular hard kankars upto 10%, clear smooth boundary,

B23tk 83-150 cm, light Olive brown (2.5Y 5/4), common medium coarse distinct mottles of very dark grayish brown (10YR3/2) and strong brown (7.5YR4/6) with FeMn concretions, silty loam, moderately developed subangular blocky soil structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), very few fine fibrous roots, common fine medium pores, strongly calcareous (kankars about 5%), clear smooth boundary.

Ck 150-200 cm, pale Olive (2.5Y 6/4), many medium coarse distinct mottles of very dark grayish brown (10YR3/2) and strong brown (7.5YR4/6) with FeMn concretions, silty loam, massive soil structure, friable (dry) firm (moist) slightly plastic and slightly sticky (wet), no roots , common fine medium pores, strongly calcareous (kankars about 5 to 10%).

PEDON # PC4

Classification : Fine Loamy Typic Hpustalf
Location : Hathkila, Amethi,Sultanpur, U.P,
(Lat.26°9' Long. 81°51')
Date of Examination : 31-1-90
Parent material : Alluvium
Erosion : Nil
Slope : Nil
Depth of ground water : 15 m
Physiography : Middle Deoha/Ganga-Ghaghra Interfluve

Ap 0-22 cm, silty loam; grayish brown (2.5Y 5/2); few fine distinct mottles of grayish brown (10YR 3/2) color; structureless; firm (moist) slightly sticky slightly plastic (wet); many fine pores; many fine fibrous roots; non calcareous; gradual smooth boundary

B1 22-47 cm, silty loam; grayish brown to light olive brown (2.5Y 4.5/3); few fine distinct mottles of very dark grayish brown (10YR 3/2) color; weakly developed subangular blocky structure; hard (dry) firm (moist) slightly

sticky slightly plastic (wet); many fine soil pores; few fine fibrous roots; non calcareous; clear smooth boundary.

B22t 47-78 cm, silty loam; grayish brown to light olive brown (2.5Y 4.5/3); common fine medium mottles of very dark grayish brown (10YR 3/2) color, moderately developed subangular blocky structure; clay coatings along pores; many fine soil pores; few fine fibrous roots; non calcareous; clear smooth boundary;

B23t 78-116 cm, silty loam; light olive brown to olive brown (2.5Y4.5/4); many medium coarse distinct mottles of very dark grayish brown (10YR 3/2) with fe Mn concretions up to 5-10%; moderately developed subangular blocky structure; clay coatings along pores, hard (dry) firm (moist) plastic & sticky (wet); non calcareous; clear smooth boundary;

B23 116-140 cm, silty loam; light olive brown (2.5Y 5/4); few fine faint mottles of very dark grayish brown (10YR 3/2) color; weakly developed subangular blocky soil structure; hard (dry) firm (moist) slightly sticky slightly plastic (wet); non calcareous; clear smooth boundary;

C 140-200 cm, light silty loam; olive yellow (2.5Y 6/6); no mottles; structureless; friable (moist) & slightly plastic (wet); many fine medium soil pores; no roots; very strongly calcareous with kankars 20-25% of 3-4 cm dia.

PEDON # PC1

Classification	: Fine Loamy Typic Haplustalf
Location	: Sheogarh, Aallahabad, U.P.,
	: (Lat. 27°21', Long. 82°2')
Slope	: Nil
Landuse/Vegetation	: Cultivation, Presently quarried as brick kiln
Parent Material	: Alluvium
Moisture condition	: Moist throughout pedon
Depth of Ground water	: 4-6m
Drainage class	: well drained
Erosion	: Nil
Physiography	: Middle Deoha/Ganga-Ghaghra Interfluve

Ap 0-15 cm, light yellowish brown (2.5Y 6/4), silty loam, structureless, slightly hard (dry) friable (moist) non plastic and non sticky (wet), many fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

B21t 15-29 cm, light olive brown (2.5Y 5/5), few medium faint mottles of very dark grayish brown (10YR 3/2) with Fe Mn concretions, silty loam, weakly to moderately developed subangular blocky structure,slightly hard (dry) firm (moist) non plastic and non sticky (wet), few clay cutans, many fine medium fibrous roots, common fine medium pores, non calcareous, gradual smooth boundary

B22t 29-80 cm, light olive brown (2.5Y 5/4), very few medium faint mottles of very dark grayish brown (10YR 3/2), silty loam, moderately developed subangular blocky structure, slightly hard (dry) friable (moist) slightly plastic and slightly sticky (wet), few clay cutans, few fine medium fibrous roots, common fine medium pores, strongly calcareous (fine concretions about 2%), clear smooth boundary.

B23t 80-125 cm, light olive brown (2.5Y 5/5), very few medium faint mottles of very dark grayish brown (10YR 3/2), silty loam, moderately developed subangular blocky structure, slightly hard (dry) friable (moist) slightly plastic and slightly sticky (wet), few clay cutans, few fine medium fibrous roots, common fine medium pores, strongly calcareous (kankars about 10% up to 1 cm size)

Two type of soils are associated in this unit due to microtopographical variation (Fig. 2.8a, b, c, d). Soils in shallow depressions are strongly calcareous and concretions may be present throughout the profile or only in the lower horizons. These are also highly salt affected. In topographically slightly raised areas, soils are free of calcrete and surfacial salt accumulations.

In soils free of $CaCO_3$ the solum thickness varies from 150 to 200 cm soils are very strongly developed. In these soils A horizons thickness varies from 12 to 22 cm, Texture is silty loam. The colour is light and varies in 2-5 Y and 10YR hue, 5 to 6 moist values and 2 to 4 chroma. Soils from these horizons do not show pedality development. Thickness of B2 horizon varies from 108 to 137 cm. The colour of the soils from this horizon is dark. The soils show strongly to very strongly developed subangular and angular blocky soil structure. Clay cutans are observed. Strong brown and black mottles of ferro manganese are also observed and generally increase with depth. These B2 horizon soils gradually merge in to light coloured friable soils of C horizons with transional B3 horizons.

Soils bearing $CaCO_3$, in profile in shallow depressions show solum thickness varying from 125 to 150 cm. In these soils the B2 horizon thickness is upto 94 cm. The colour varies from light olive brown to olive brown in 2.5 hue and 4 to 5 moist values and 4 to 5 chroma. Subangular blocky soil structure is strongly developed in these soils. The soils are highly calcareous with thin cylindrical to irregular shaped concretions of CaC03 of few

mm to 1 cm size. Clay cutans are often noticed along pores of these soils. Strong brown and dark grayish brown mottles increase with depth with formation of hard globular Fe-Mn concretions in B3 and C horizons. These soils show gradual and clear boundaries with underlying horizons.

In C horizons the soils show light olive brown colour, and massive and apedal structure. $CaCO_3$ kankars vary from 5 to 20% by volume and range 2 to 3 cm in size.

2.4.10 Upper Rapti-Ghaghra Interfluve

This soil geomorphic unit comprises the northern part of the Rapti-Ghaghra Interfluve. In east it is bounded by the Rapti Floodplain and in west by the Ghaghra Floodplain.

In Landsat black and white images it shows uniformly light gray tone with medium texture and in landsat TM and IRS FCC's it shows uniform light red colour with medium texture.

This upland surface rises from the adjacent floodplains of Rapti and Ghaghra. Land surface is generally level with regional slope in S and SE direction. Number of streams drains this unit. A few ravine land are notable feature of this geomorphic unit. Soils of the unit are moderately to strongly developed and are medium textured.

PEDON # PB11

Classification : Fine Loamy Typic Haplustalf
Location : Nanpara, Bahraich, U.P. (Lat.27°53', Long. 81°2')
Date of examination : 19-1-90

(a)

PEDON # PC 1

(b)

PEDON # PC2

(c)

Fig. 2.8 (a) Field View Of The Salt Affected Land And (b, c) Typical Soil-Profiles Of The Middle Deoha/Ganga-Ghaghra Interfluve.

PEDON # PB7

HORIZON COLOUR DEPTH

AP 10 YR 6/4
---------- 18 cm

B1 10 YR 5.5/4
---------- 38 cm

B21 10 YR 5/4
---------- 84 cm

B23 10 YR 4.5/4
---------- 133 cm

B23 10 YR 4.5/4
---------- 175 cm

B3 10 YR 5/4
---------- 200 cm

Fig. 2.8 (d) Typical Soil-Profile Of The Middle Deoha/Ganga-Ghaghra Interfluve.

Slope	: Nil
Landuse/Vegetation	: Cultivation
Parent Material	: Alluvium
Moisture condition	: Moist throughout pedon
Depth of Ground water	: 6 m
Drainage class	: impefect
Erosion	: Nil
Physiography	: Upper Rapti-Ghaghra Interfluve

Ap 0-12 cm, light yellowish brown (2.5Y 6/4), silty loam, structureless, friable (moist) non plastic and non sticky (wet), common fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

B1 12-30 cm, light olive brown (2.5Y 5/4) color, silty loam, weakly developed subangular blocky structure, firm (moist) non plastic and non sticky (wet), few fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

B21t 30-62 cm, olive brown (2.5Y 4.5/4) color, silty loam, moderately developed subangular blocky structure, firm (moist) non plastic and non sticky (wet), few fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

B21t 62-100 cm, olive brown (2.5Y 4.5/4), many medium distinct mottles of yellowish red (5YR 5/8) color with Fe Mn concretions sandy loam, moderately developed subangular blocky structure, firm (moist) non plastic and non sticky (wet), very few fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

B3 100-140 cm, light olive brown (2.5Y 5/4), common medium distinct mottles of yellowish red (5YR 5/8) color with Fe Mn concretions, silty. loam, moderately developed subangular blocky structure, firm (moist) non plastic and non sticky (wet), many fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

C1 140-172 cm, light olive brown (2.5Y 5/4), few medium distinct mottles of yellowish red (5YR5/8) color with Fe Mn concretions, silty loam, structureless, firm (moist) non plastic and non sticky (wet), very few fine fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

C2 172-210 cm, light olive brown (2.5Y 5/4), few medium distinct mottles of yellowish red (5YR5/8) color with Fe Mn concretions loam, structureless, friable (moist) non plastic and non sticky (wet), many fine medium fibrous roots, common fine medium pores, non calcareous.

PEDON # PB12

Classification	: Fine Loamy Typic Haplustalf
Location	: Nawabganj, Bahraich, U.P., (Lat.27°53', Long. 81°39')
Date of examination	: 19-1-90
Slope	: (1%
Landuse/Vegetation	: Cultivation
Parent Material	: Alluvium
Moisture condition in pedon	: Moist throughout pedon
Depth of Ground water	: 6 m
Drainage class	: Impefect
Erosion	: Nil
Physiography	: Upper Rapti-Ghaghra Interfluve

Ap 0-18 cm, grayish brown (2.5Y 5/2), loam, structureless, friable (moist) non plastic and non sticky (wet), common fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

B21t 18-43 cm, light olive brown (2.5Y 5/4), loam, weakly developed subangular structure, friable (moist) slightly plastic and slightly sticky (wet), very few clay cutans, few fine medium fibrous roots, common fine medium pores, non calcareous, gradual smooth boundary

B22t 43-82 cm, light olive brown (2.5Y 5/4), sandy loam, weakly developed subangular structure, friable (moist) slightly plastic and slightly sticky (wet), few clay cutans, few fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

C 82-130 cm, grayish brown (2.5Y 5/2), sandy loam, structureless, friable (moist) slightly plastic and slightly sticky (wet), few fine no roots, common fine medium pores, non calcareous, clear smooth boundary

These soils are free of calcium carbonate concretions. Thickness of solum varies from 82 to 140 cm. Thickness of Ap ploughed layer varies 18-30 cm and shows apedal to very weakly developed subangular peds. Colour of soils in A horizon is light olive brown to olive yellow with 2.5 Y hue and chroma of 5 and values 2 to 4.

B horizon thickness is 64 to 110 cm, of which B2 is about 70 cm thick. Soils in this horizon are moderately to strongly developed, showing medium to coarse subangular blocky in structure. Texturally these are heavy sandy loam to silty loam in nature. These are hard when dry and slightly plastic and sticky when wet. Colour of B2 horizon is olive brown (2.5 Y 5/4). The soils of B2 horizon grade to light coloured and brittle friable soils of C horizon. Sometimes a transitional horizon B occur in between B2 and C horizon which shows weak development of soil and slightly heavier texture and darker colour than underlying C horizon.

2.4.11 Lower Rapti-Ghaghra Interfluve

This comprises the lower part of the Rapti-Ghaghra

Interfluve. In Landsat B & W, it shows medium dark gray tone with coarse texture, often mottled with bright patches marking salt affected areas. In Landsat TM and IRS FCC's it shows dull red colour and it is coarsely mottled with bright pink and uniform dark red patches of salt affected area.

This unit has very gently sloping land surface, with regional slope in eastern direction. Few alluvial rivers like Bisuhi, Kunwana and river, drain the central part of this unit and a lot of ravine land is associated with them.

PEDON # PC12

Classification	: Fine Loamy Typic Haplustalf
Location	: Jankinagar, Mahadeva, Gonda, U.P.,
	: (Lat. 27°21', Long. 82°2')
Slope	: Nil
Landuse/Vegetation	: Cultivation, Presently as brick kiln
Parent Material	: Alluvium
Moisture condition	: Moist throughout pedon
Depth of Ground water	: 6m
Drainage class	: well drained
Erosion	: Nil
Physiography	: Lower Rapti-Ghaghra Interfluve

Ap 0-18 cm, light olive brown (2.5Y 5/4), loam, structureless, friable (moist) non plastic and non sticky (wet), no clay cutans on ped faces, many fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary

B21 18-40 cm, yellowish brown to dark yellowish brown (10YR 4.5/4), loam, moderately developed subangular blocky structure, friable (moist) slightly plastic and slightly plastic, common fine fibrous roots, clay cutans along pores common fine medium pores, non calcareous, clear smooth boundary

B22 40-78 cm, yellowish brown to dark yellowish brown (10YR 4.5/4) few medium faint mottles, loam, moderately developed subangular blocky structure, friable (moist) slightly plastic and slightly plastic, few fine fibrous roots, clay cutans along pores, common fine medium pores, non calcareous, gradual smooth boundary

B23 78-123 cm, light olive brown (2.5Y 5/4), common medium distinct mottles of very dark gray (10YR 3/1) color, silty loam, moderately developed subangular blocky structure, friable (moist) slightly plastic and slightly plastic, few fine roots, few clay cutans along pores, common fine medium pores, non calcareous, gradual smooth boundary

B3 123-149 cm, light olive brown (2.5Y 5/6), common medium distinct mottles of very dark gray (10YR 3/1) color, silty loam, weakly developed subangular blocky structure, firm (moist) slightly plastic, very few fine roots, few clay cutans along pores, common fine medium pores, non calcareous, gradual smooth boundary

C 149-200 cm, light olive brown (2.5Y 5/6), common medium distinct mottles of very dark gray (10YR 3/1) color, silty loam, Massive, friable (moist) non plastic and non plastic, no roots, common fine medium pores, non calcareous.

PEDON # PC13

Classification	:Fine Loamy Typic Haplustalf
Location	:Ranipur, Uturolla, U.P., (Lat. 27°16', Long. 82°22')
Date of examination	:19-2-91
Slope	:Nil
Landuse/vegetation	:cultivation, presently a canal section
Parent material	:Alluvium
Moisture condition in pedon	:moist
Depth of ground water	:12 m
Drainage class	:well drained
Erosion	:Nil
Physiography	:Lower Rapti-ghaghra Interfluve

Ap 0-22 cm, Light yellowish brown (10YR 6/4), many medium distinct mottles of strong brown (7.5YR 4/6) color with Fe Mn concretions, silty loam, structureless, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), common fine fibrous roots, many fine medium pores, non calcareous, gradual smooth boundary.

B1 22-50 cm, Yellowish brown (10YR 5/4), many medium distinct mottles of strong brown (7.5YR 4/6) color with Fe Mn concretions, loam, weakly developed subangular blocky structure, very hard (dry) firm (moist) plastic and sticky (wet), common fine fibrous roots, common fine medium pores, non calcareous, clear smooth boundary,

B21t 50-66 cm, Brown (10YR 5/3), many medium distinct mottles of strong brown (7.5YR 4/6) color with Fe Mn concretions, loam, strongly developed subangular blocky structure and prismatic structure is also seen, very hard (dry) firm (moist) plastic and sticky (wet), few clay cutans along pores, common fine fibrous roots, common fine medium pores, non calcareous, clear smooth boundary,

B22t 66-100 cm, Dark yellowish brown to yellowish brown (10YR 4.5/4), many medium distinct mottles of strong brown (7.5YR 4/6) color with Fe Mn concretions, silty loam, strongly developed subangular blocky structure, very hard (dry) firm (moist) plastic and sticky (wet), common clay cutans along pores, few fine roots, common fine medium pores, non calcareous, clear smooth boundary,

B23t 100-137 cm, Dark yellowish brown to yellowish brown (10YR 4.5/4), many medium distinct mottles of strong brown (7.5YR 4/6) color with Fe Mn concretions, loam, moderately developed subangular blocky structure, very hard (dry) firm (moist) plastic and sticky (wet), common clay cutans along pores, few fine roots, common fine medium pores, non calcareous, clear smooth boundary,

B3 137-180 cm, Yellowish brown (10YR 5/4), many medium distinct mottles of strong brown (7.5YR 4/6) color with Fe Mn concretions, loam, weakly developed subangular blocky structure, very hard (dry) firm (moist) plastic and sticky (wet), no roots, common fine medium pores, strongly calcareous (kankars about30%), clear smooth boundary,

C1 180-222 cm, Yellowish brown (10YR 5/4), many medium distinct mottles of strong brown (7.5YR 4/6) color with Fe Mn concretions, silty loam, Very weakly developed subangular blocky structure, very hard (dry) firm (moist) plastic and sticky (wet), no roots, common fine medium pores, strongly calcareous (kankars about 30%), clear smooth boundary,

C2 222-252 cm, Yellowish brown (10YR 5/4), many medium distinct mottles of strong brown (7.5YR 4/6) color with Fe

Mn concretions, silty loam, massive, hard (dry) firm (moist) plastic and sticky (wet), no roots, common fine medium pores, strongly calcareous (kankars about30%-40%)

PEDON # PC14

Classification	:Fine Loamy Typic Haplustalf
Date of examination	:20-2-91
Location	:Dudhara, Basti, U.P., (Lat.26°53' Long.82°58')
Slope	:Nil
Landuse/vegetation	:Cultivation, presently quarried as brick kiln
Parent material	:Alluvium
Moisture condition	:moist below 30 Cm from surface
Depth of ground water	:12 m
Drainage class	:well drained
Erosion	:Nil
Physiography	:Lower Rapti-Ghaghra Interfluve

A 0-16 cm, Light yellowish brown (2.5Y 6/4), silty loam, structureless, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), many fine medium fibrous roots, many fine medium pores, strongly calcareous (kankars), clear smooth boundary

B21t 16-30 cm, Light olive brown (2.5Y 5/4), silty loam, moderately developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few clay cutans along pores, few fine medium fibrous roots, common fine medium pores, strongly calcareous (kankars about 10% of 1-2 cm dia), clear smooth boundary

B22t 30-75 cm, Light olive brown (2.5Y 5/4), few medium distinct mottles of very dark grayish brown(10YR 3/2), silty loam, moderately developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few clay cutans along pores, few fine medium fibrous roots, common fine medium pores, strongly calcareous (kankars about 10% up to 1Cm dia), gradual smooth boundary

B23t 75-95 cm, light olive brown (2.5Y 5/4), few medium distinct mottles of very dark grayish brown (10YR 3/2), silty loam, moderately developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few clay cutans along pores, few fine medium fibrous roots, common fine medium pores, strongly calcareous (kankars), clear smooth boundary.

B23 95-127 cm, grayish brown (2.5Y 5/2), many medium distinct mottles of dark brown (7.5YR 5/6), silty loam, moderately developed subangular blocky structure, hard (dry) fragile (moist) slightly plastic and slightly sticky (wet), few clay cutans along pores, few fine medium fibrous roots, common fine medium pores, strongly calcareous (soft kankar), clear smooth boundary,

C 127-155 cm, light olive brown to olive brown (2.5Y 4.5/4), many medium distinct mottles of dark brown (7.5YR 5/6) with Fe Mn concretions up to 5%, silty loam, stuctureless, friable (moist) slightly plastic slightly sticky (wet), no roots, common fine medium pores, strongly calcareous (soft kankars).

The soils in this unit are strongly developed and are medium to fine textured. The soils in this unit are moderately salt affected in slightly topographically lower areas.

In this soil-geomorphic unit, three kinds of soils occur, firstly those almost free of any calcium carbonate accumulation; secondly those in which $CaCO_3$ concretions are associated with lower parts of B horizon and thirdly those in which $CaCO_3$ content occur throughout the profile in some other form, particularly these are usually occurring in salt affected area.

The solum (A and B horizon) is quite thick and varies between 127 to 180 cm (Fig. 2.9). Particularly in area not affected by salt the solum thickness is more. Thickness of ploughed layer (Ap horizon) varies from 16 to 22 cm, and shows light colour with 2.5Y hue and chroma 4, 2, and value 5 to 6. Low chroma in soils are due to CaC03 in soils in salt affected area. Texture of these soil horizons is silty loam and they do not show any of pedality development.

Thickness of B2 horizon ranges from 97 to 114 cm. Soils from these horizon are heavy textured. The colour in these varies from yellowish brown (10YR5/4) to light olive brown (2.5Y5/4). Fine to coarse subangular blocky to blocky structure is strongly developed and occas-ionaly moderately develop-ed prismatic structure is also noted. Thin clay cutans occur quite commonly along pores. These heavy textured dark coloured soils of B2 horizon gradually changes to light coloured and light textured C horizon with a transitional B3 horizon inbetween.

Calcium carbonate concretions occur throughout the profile in salt affected soils in shallow depression. These are imperfectly drained soil as very dark grayish brown oxidation

PEDON # PC 13

HORIZON COLOUR DEPTH

AP 10 YR 6/4
---------- 38 cm

B 10 YR 5/4
---------- 50 cm

B21 10 YR 5/3
---------- 66 cm

B22 10 YR 4.5/4
---------- 100 cm

B23 10 YR 4.5/4
---------- 137 cm

B3 10 YR 5/4
---------- 180 cm

Fig. 2.9 Typical Soil-Profile (PEDON # PC13) Of The Lower Rapti-Ghaghra Interfluve.

mottles occur in these soils and show an increase with depth. Fe Mn concretions occur (by about 5% in volume) in the lower horizons. Carbonate concretions are irregular shaped, generally hard in horizons 2.3 cm dia, and gradually change to soft medium sized concretions in C horizon. These concretions range in percentage from 10 to 15% of soil by volume.

2.5 RESUME

Using remote sensing techniques and field studies fourteen soil-geomorphic units have been recognised. These units are Kosi-Gola Piedmont, Upper Kosi-Gola Plain, Lower Kosi-Gola Plain, Upper Deoha/Ganga-Ghaghra Interfluve, Middle Deoha/Ganga-Ghaghra Interfluve, Young and Old Sihali-Mohan-Kandra Piedmonts, Ghaghra Floodplain, Upper Rapti-Ghaghra Interfluve, Lower Rapti-Ghaghra Interfluve, Rapti Floodplain and Gholia-Dhobania-Bhambhar Piedmont.

Various soil profiles in each soil geomorphic unit have been studied in detail in field and representative soil profiles are shown in (Fig. 2.10). A brief account of field observations of these soils in each unit is given in (Table. 2.2).

Soils of the study area are classified on the basis of Soil Taxonomy (1975) and various soil classes are: Kosi-Gola Piedmont- Coarse Loamy Typic Ustorthent; Upper Kosi-Gola Plain- Coarse Loamy to Fine Loamy Typic Ustochrept; Lower Kosi-Gola Plain- Coarse Loamy to Fine Loamy Typic Haplustalf; Upper Deoha/Ganga-Ghaghra Interfluve, Middle Deoha/Ganga-Ghaghra Interfluve- Fine Loamy Typic Haplustalf; Sihali-Mohan-Kandra Piedmont- Coarse Loamy Typic Ustorthent; Ghaghra Floodplain- Coarse Loamy

Fluventic Ustorthent; Upper Rapti-Ghaghra Interfluve- Fine Loamy Typic Haplustalf; Lower Rapti-Ghaghra Interfluve- Fine Loamy Typic Haplustalf; Rapti Floodplain- Coarse Loamy Fluventic Ustorthent; and Gholia-Dhobania-Bhambhar Piedmont- Coarse Loamy Typic Ustorthent.

Representative soil profiles from each horizon are plotted in (Fig. 2.10), which shows variation of A, B and C horizons in different soil geomorphic units. It is evident from field checks, Table. 2.2 and Fig. 2.10 that solum has maximum thickness (upto 200 cm, and B2 horizon upto 137 cm) in the Middle Deoha/Ganga-Ghaghra Interfluve and Lower Rapti-Ghaghra Interfluve. Soils of B horizons in pedons of these two soil-geomorphic unit show strongly to very strongly developed angular blocky to subangular blocky structure. Colour of these varies in 2.5 Y and 10 YR hue, 4-5 chroma and 3-6 (moist) value. Oxidation mottles and sesquioxide concretions are common and generally show increase with depth in to B3 and C horizon.

Field studies show that the soils developed in the Lower Kosi-Gola Plain, Upper Deoha/Ganga-Ghaghra Interfluve, Upper Rapti-Ghaghra Interfluve and Old Ghaghra Bar are comparable, and have B2 horizon thickness 52 to 85 cm. Soil structure in B2 horizons is moderately developed. Colour varies in 2.5 Y and 10 YR hue. Redder colour due to leaching of sesquioxides is seen in some soils from lower Kosi-Gola Plain and Upper Rapti-Ghaghra Interfluve. Generally these soils are free of calcium carbonate accumulations, but in the Lower Kosi-Gola plain (Pedon PA7) shows hard irregular shaped kankars (5%) distributed in B3 and C

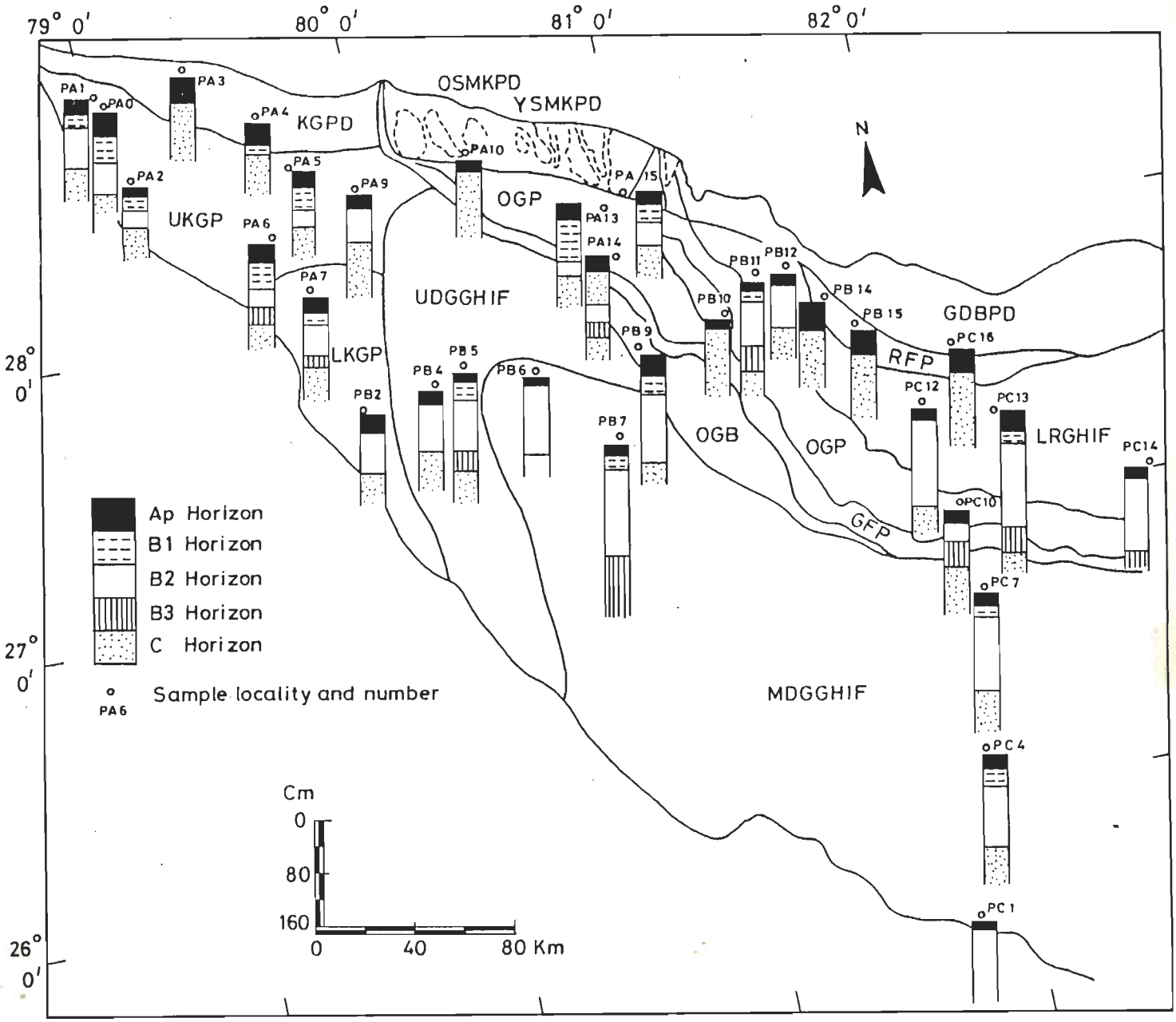

Fig. 2.10 Variation in thickness of various soil horizons in different soil-geomorphic units in the study area.

horizon, and in Pedon PB4 in Upper Deoha/Ganga-Ghaghra Interfluve kankars of 1-2 cm dia., upto 20% of soil matter have been observed. Mottles and FeMn concretions are generally present and show a relative increase in abundance with depth. Texture of these soils vary from loam to silty loam. These soils are hard when dry and show adherence in form of stickness and plasticity when wet and are firm when moist.

Soils in the Upper Kosi-Gola Plain, Old Ghaghra Plain and in Old Sihali-Mohan-Kandra Piedmont show, weak to moderate development. B2 horizon thickness varies from 21 to 57 cm. Structure in soils is weakly to moderately developed. Calcium carbonate concretions are found in B and C horizons and Old Ghaghra Plain at few places these are associated with fresh water Gastropod shells.

Soil in the Kosi-Gola Piedmont, Gholia-Dhobania-Bhambhar Piedmont, Rapti Floodplain, Ghaghra Floodplain and in Sihali-Mohan-Kandra Piedmont are ~~least~~ weakly developed, and show A/C type boundaries. Texture of these soils varies from sandy loam to silty loam. Calcium carbonate are associated with lower parts of C horizons. In case of Ghaghra Floodplain, concretions are hard and coarse grained as compare to those of in Upper Kosi-Gola-Plain and Old Ghaghra Plain.

C H A P T E R - 3

PHYSICAL, CHEMICAL AND MINERALOGICAL CHARACTERISTICS OF SOIL - GEOMORPHIC UNITS

3.1 INTRODUCTION

The history of depositional and erosional events of soil-forming processes in various environments that together produced the soil mantle of an area can be reconstructed by detailed field studies with supporting petrographic, chemical and other analyses of representative profiles and parent material (Catt, 1986). Keeping this in view, grain size analysis, chemical analysis and clay mineralogical studies have been carried out for the typical soil samples from the representative soil profiles of different soil-geomorphic units in study area.

In the laboratory 166 samples were analyzed for grain size distribution. Analysis of 116 samples was carried out for nine major elements. For clay mineral studies 53 samples from various soil profiles of different soil-geomorphic units were analyzed. Apart from these studies, 11 calcrete samples were analyzed for stable isotopes of $\delta^{13}C$ and $\delta^{18}O$ and 18 samples from coarse C/R horizons were analyzed for quartz/feldspar ratios in parent material. In the following description and discussion grain size, clay mineral and chemical data for Lower Deoha/Ganga-Ghaghra given by Mohindra (1989) have been used.

3.2 GRAIN SIZE

Grain size analysis is used to determine particle size

distribution within the soil profiles, to determine the textural class of soils and amount of pedogenic clay. Variation in pedogenic clays can be used to decipher the pedogenic and geomorphic history of the soils (Catt, 1984). Amount of pedogenic clay or development of Bt horizon can be used as indicative of long or short term landscape stability and thereby estimating the ages of surfacial deposits and constructing a soil chronosequence (Birkeland, 1990).

3.2.1 Methodology

For grain size analysis grab samples collected during field work were air-dried and then all the clumps and clods were broken by mashing them with fingers or gently crushing them by a wooden pestle in a mortar. These samples were then mixed up thoroughly and split.

Since soil particles adhere to each other due to the presence of organic matter, calcium carbonate, iron oxide and soluble salts, samples were treated for the removal of these binding constituents by the methods described by Galehouse (1971). The carbonates were removed by adding 10% HCl slowly into soil samples, until the effervescences were stopped. Organic matter was removed from the soil samples by adding 6% H_2O_2 slowly with constant stirring and then boiling it. Iron oxide from soil samples was removed by placing an alumin-um foil and 15 grams of oxalic acid powder into the soil solution and then boiling it. Repeated washing of the soil samples was used to remove all the soluble salts. For complete dispersion Sodium Hexametaphosphate $[Na(PO_3)_6]$ was used as a dispersing agent.

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From the dispersed samples sand fraction was separated by wet sieving on a 230 mesh sieve. Silt and clay fractions were collected in 1 litre graduated cylinder and were then analysed by pipette method (Galehouse, 1971). Sand, silt and clay percentages were calculated according to size classification of the U.S. Bureau of Soils (1975) (i.e. sand = 2 mm to 0.05 mm, silt = 0.05 mm to 0.002 mm and clay < 0.002 mm).

3.2.2 Textural Variation and Amount of Pedogenic Clays in Soils of Various Soil-Geomorphic Units

From the grain size data obtained above, textural classes were determined according to USDA Soil Survey Manual (1966) by plotting the sand, silt and clay percentages in a triangular diagram. The results of the grain size analysis are given in Appendix I.

Particle size analysis carried out for soils of the various soil-geomorphic units shows that the texture of the soils varies in a wide range from sandy loam to silty clay loam. Soils from the piedmonts and floodplains are coarse textured, whereas soils from the older geomorphic surfaces such as interfluves and Kosi-Gola Plains are medium to fine textured.

Variation of sand, silt and clay content with depth in various soil-geomorphic units has provided soil development indices as well as fluvial sedimentation charactersitics. From the data of the particle size analysis (Appendix 1), it is evident that the finer particles, particularly the clay content, shows a relative increase from the A horizon to the most developed B2 horizon. This increase is attributed predominantly to the

translocation of clays from the upper to the lower horizons. In situ weathering of the primary particles may have also contributed to some extent.

Variation in sand content with depth in most of the soil profiles does not give any trend and shows irregular pattern, suggesting primary sedimentary layering due to fluvial deposition. But in some of the well developed soil profiles (PB2, PC7 and PC14) a relative decrease of sand content upto B2 horizon is observed. This may be due to relative increase in silt and clay content. An increase in silt content with depth upto B2 horizon has been observed in some of the very well developed soil profiles (PB2, PB11, PC7, and PC14). This increase of silt could be due to residual silt production by the weathering of sand fraction and also to some extent due to translocation of the finer silt to lower horizons. This is confirmed by later micromorphological studies.

Increase in clay content in B horizon is a useful indicator of relative age of soils (Birkeland, 1984). Plots of total clay content and pedogenic clay content with depth for various pedons from different geomorphic units are given in Fig. 3.1. Increase of clay content in B horizon over A or C horizon is the amount of pedogenic clay. In the study area maximum amount of pedogenic clays is observed in the Middle Deoha/Ganga-Ghaghra Interfluve and Lower Rapti-Ghaghra Interfluve, followed by other geomorphic surfaces i.e. Upper Deoha/Ganga-Ghaghra Interfluve, Upper Rapti-Ghaghra Interfluve, Lower Kosi-Gola Plain and Upper Kosi-Gola Plain. Amount of pedogenic clay is nil to very small in

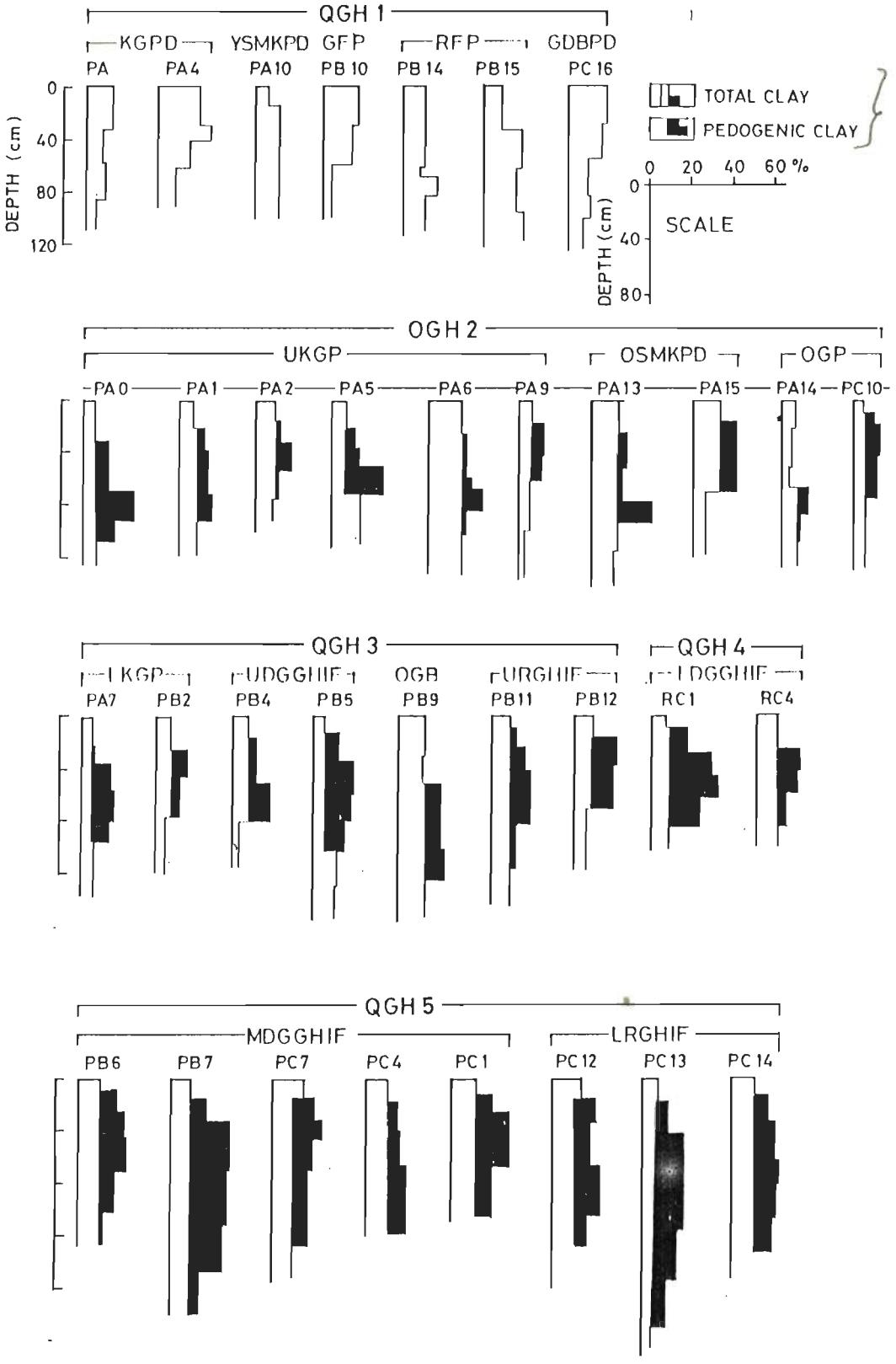

Fig. 3.1 Variation of total clay and pedogenic clay in five members of soil-chronoassociation in study area.

piedmonts and floodplains. But soils in the Old Ghaghara Bar and erosional remnants of the Old Sihali-Mohan-Kandra Piedmont show some amount of pedogenic clays.

Clays accumulation index, as suggested by Levine and Ciolkosz (1983), has been calculated to assess the relative age of geomorphic surfaces. Based on this index the soil-geomorphic surfaces of the study area can be ranked into five groups (Table 3.1).

TABLE 3.1 Ranking Of Soils Of Different Geomorphic Units Based On Clay Accumulation Index

Soil Geomorphic Units	Clay accumulation Index
i) Kosi-Gola Piedmont, Sihali-Mohan-Kandra Piedmont, Gholia-Dhobania-Bhambhar Piedmont, Ghaghra Floodplain, and Rapti Floodplain	Nil
ii) Upper Kosi-Gola Plain, Old Ghaghra Plain, and Old Sihali-Mohan-Kandra Piedmont.	131.67 - 353.43
iii) Lower Kosi-Gola Plain, Upper Deoha/ Ganga-Ghaghra Interfluve, Upper Rapti-Ghaghra Interfluve and Old Ghaghra Bar	501.00 - 845.25
iv) Middle Deoha/Ganga-Ghaghra Interfluve,	560.90 - 1050.0
v) Lower Rapti-Ghaghra Interfluve, Middle Deoha/Ganga-Ghaghra Interfluve	1010.34 - 2361.45

3.3 CHEMICAL ANALYSIS

3.3.1 Introduction

Total chemical analysis is the most widely used way of

determining the amount of chemical weathering that has taken place in a rock (Birkeland, 1984). All the chemical data are presented as oxides, because the main balancing anion usually is oxygen. These oxide values given as percentages, therefore, show relative increase or decrease.

Values for individual oxides vary as a function of many soil forming processes. SiO_2 is almost always present in parent material in amounts greater than needed to form clay minerals. So it commonly decreases in a leaching environment. And Al_2O_3, which has a very low solubility over the usual pH range, is an essential element of most clay minerals. So it commonly shows a relative increase. Iron in most rock forming minerals is present in the Fe^{+2} form and on weathering in a leaching environment, converts to Fe^{+3} bearing various substances and increases on weathering. Of the major remaining elements (MnO_2, CaO, MgO and K_2O), Mg and K are associated as interlayer cations for clay minerals. Mn can form bluish black mottles. Ca, K and Na are the major exchangeable cations and are depleted in wet environments, but in dry environments Ca can increase at depth where $CaCO_3$ has accumulated.

Keeping in view, total chemical analysis for major elements has been carried out for 116 soil samples from different pedons of various soil-geomorphic units.

3.3.2 Methodology

All the soil samples were air-dried and grinding was done till the soil passed through 100 mesh size sieve. The total major elemental analysis was carried out by two solution method

as suggested by Shapiro (1975). Solution 'A' is used to determine SiO_2, Al_2O_3 and TiO_2 and solution `B' is used for determination of Fe_2O_3, MgO, Na_2O, K_2O, MnO, and CaO.

Solution `A'

50 mg soil sample was decomposed by fusion with NaOH in a nickel crucible at a temperature of 500 - 600°C on a gas burner. After a complete fusion for 20 minutes, the melt was cooled and leached with water. The solution was then acidified with 50 percent HCl and diluted to 250 ml.

Solution`B'

200 mg of soil samples placed in a teflon beaker was heated with 10 ml of 50% HCl at a temperature of 70°C on a hot plate for 20 minutes. Then 7 ml of 48 percent hydrofluoric acid was added and the solution was kept overnight for digestion at 70° C. The remaining acid after digestion was evaporated and 4 ml of perchloric acid and 5 ml of HNO_3 were added to the digested sample and the solution was heated. This solution was again heated for 20 minutes after adding 10 ml of 50 percent HCl. The solution was diluted to 200 ml. In this way, solution `B' was prepared.

After preparing the solutions SiO_2, Al_2O_3 and TiO_2 were analysed on Inductively Coupled Plasma Spectrometer and CaO, MgO Fe_2O_3 and MnO were analysed on Atomic Absorption Spectrometer. K_2O and Na_2O were analysed on a Flame Photometer. Results of the analysis are given in Appendix II.

3.3.3 Variation of Major Oxides and Molar ratios in Soils of Different Geomorphic Units.

Chemical analysis of the nine major elements (Si, Al, Fe, Ti, Ca, Mg, Mn, Na and K) may indicate the amount of weathering and soil formation in the study area. Values of individual oxides vary as a function of soil forming processes and, therefore, broad statements regarding soil development can be made. As molar ratios SiO_2/Al_2O_3, $SiO_2/Al_2O_3 + Fe_2O_3$ and $SiO_2/Al_2O_3 + Fe_2O_3 + TiO_2$ can give idea about the degree of weathering and soil profile development (Birkeland, 1984), these values are calculated from the chemical data and are listed in Appendix II.

Due to leaching of different oxides a decrease in SiO_2 from A horizon to the most developed B2 horizon and corresponding increase of Al_2O_3 and Fe_2O_3 is observed. Also, TiO_2 shows an increase upto B2 horizon. Values of the major oxides show the more systematic variation with depth (Fig. 3.21 to 3.23) in the Middle Deoha/Ganga - Ghaghra Interfluve and in Lower Rapti - Ghaghra Interfluve than other units. Variation of these four major oxides is less in the Lower Kosi - Gola Plain, Upper Rapti-Ghaghra Interfluve, Upper Deoha - Ganga Ghaghra Interfluve and in Old Ghaghra Bar, followed by Upper Kosi-Gola Plain, Old Sihali-Mohan-Kandra Piedmont and Old Ghaghra Plain and least variation has been recorded in case of the Ghaghra Floodplain, Rapti Floodplain and Piedmonts.

Values for individual oxides do provide information about degree of leaching. However, molar ratios SiO_2/R_2O_3 (R_2O_3 = $Al_2O_3 + Fe_2O_3 + TiO_2$) may enhance the information regarding

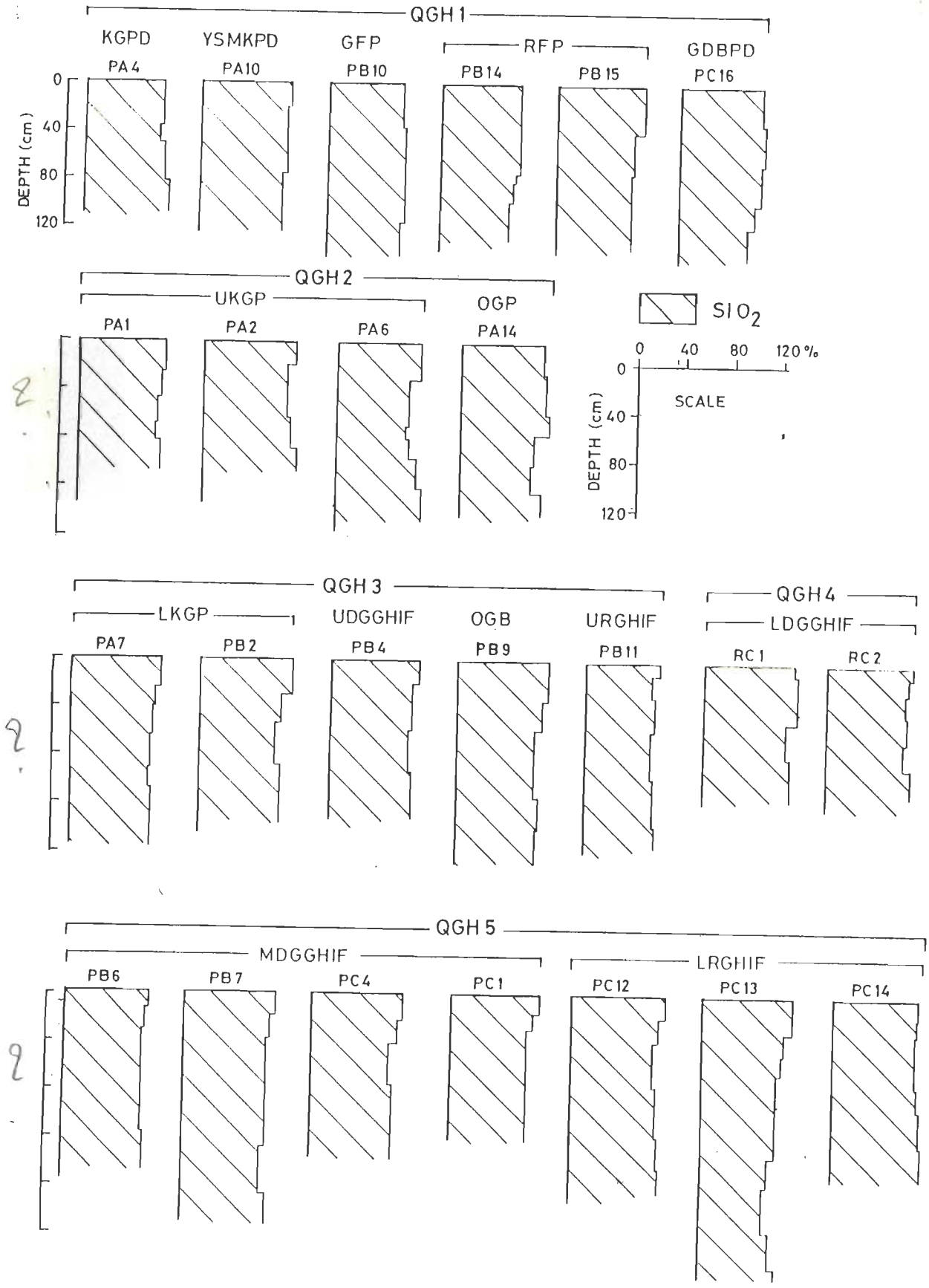

Fig. 3.2.1 Variation of silica with depth in soil profiles and in five members of soil-chronoassociation in the study area.

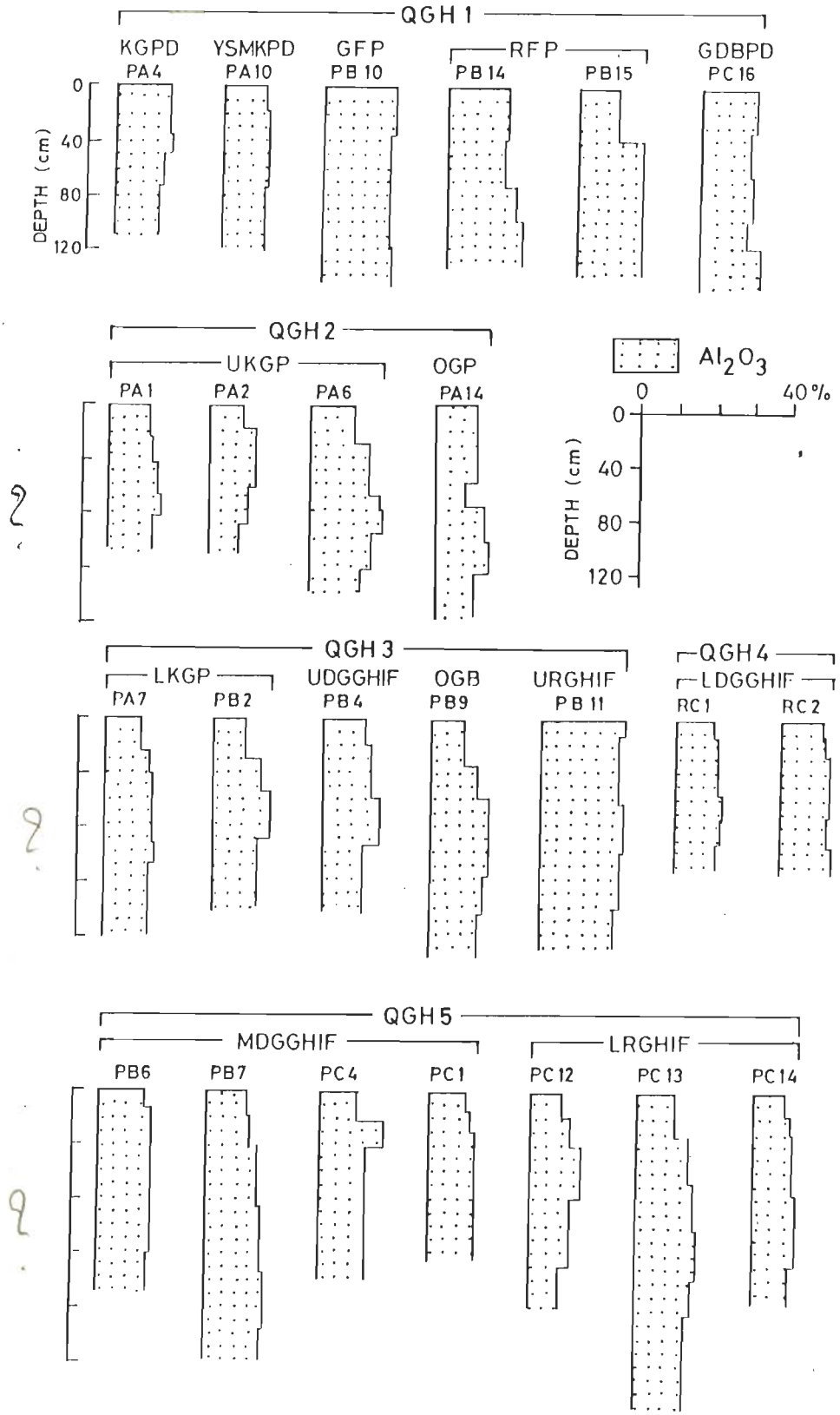

Fig. 3.2.2 Variation of Al_2O_3 with depth in soil profiles and in five members of the soil-chronoassociation

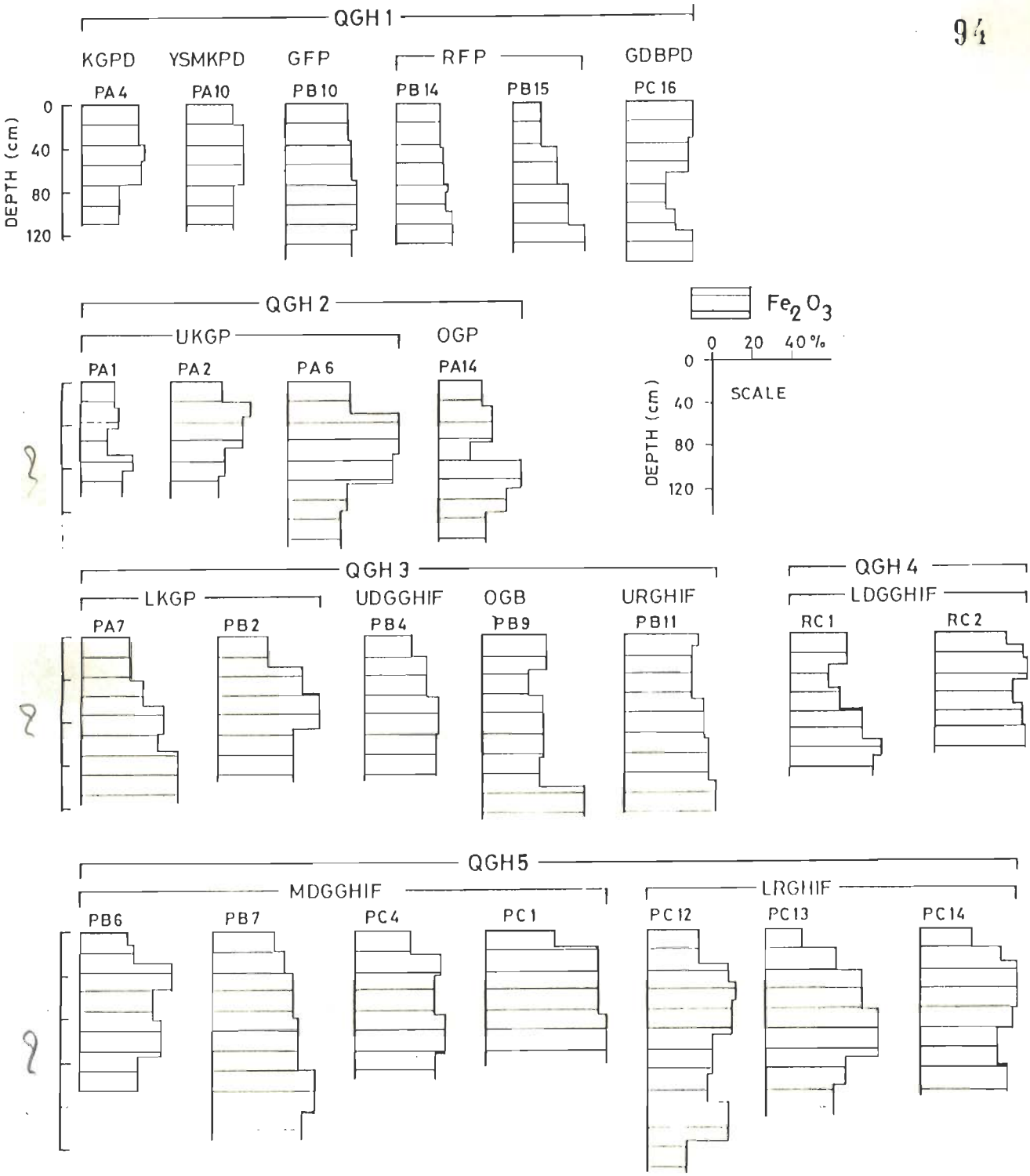

Fig. 3.2.3 Variation of Fe_2O_3 with depth in soil profiles and in five members of soil-chronoassociation in the study area.

weathering. Table 3.2 shows that the range of SiO_2/R_2O_3 decrease is maximum in the Middle Deoha/Ganga-Ghaghra Interfluve and Lower Rapti-Ghaghra Interfluve, followed by the Lower Kosi-Gola Plain, Upper Deoha/Ganga-Ghaghra Interfluve and Upper Rapti-Ghaghra Interfluve. Decrease of SiO_2/R_2O_3 to a lesser extent has been observed in the Upper Kosi-Gola Plain and Old Ghaghra Bar. Virtually no significant decrease of SiO_2/R_2O_3 ratio could be recorded in case of Kosi-Gola Piedmont, Gholia-Dhobania-Bhambhar Piedmont and in Floodplains of Rapti and Ghaghra. The molar ratio follows closely the silica depletion trend (Fig. 3.24).

The values of relative decrease in R_2O_3 ratio from A to B horizon for soils from group III to V (recognised above from textural studies) fall in the same range. As discussed later the soils of groups IV and V were formed in an accumulating environment and thus these ratios do not reflect the degree of soil profile development and these values are same as that of soils of group III of much lower degree of soil profile development (which were formed under leaching environment).

Values of individual oxides given in Appendix 2 indicates that the soils of the study area are high in silica and low in Al_2O_3 and Fe_2O_3, suggesting that these have been derived from acidic source rock area. It confirms the provenance of these sediments to be the Himalayas.

Table 3.2 Range of SiO_2/R_2O_3 decrease from A horizon to B2 horizon in soils from group I to V

Group	Units	Decrease of SiO_2/R_2O_3 in B2 horizon over A horizon
I	Kosi-Gola Piedmont, Sihali-Mohan-Kandra Piedmont, Gholia Dhobania Bhambhar Piedmont, Ghaghra Floodplain, Rapti Floodplain,	nil
II	Upper Kosi-Gola Plain, Old Ghaghra Plain, Old Sihali-Mohan-Kandra Piedmont	19.29-21.87 and rarely 44.6
III	Lower Kosi- Gola Plain, Upper Deoha/Ganga-Ghaghra Interfluve Upper Rapti - Ghaghra Interfluve, and Old Ghaghra Bar	32.60 -46.01
IV	Middle Deoha/Ganga - Ghaghra Interfluve	29.48 - 46.69
V	Middle Deoha/Ganga-Ghaghra Interfluve and Lower Rapti-Ghaghra Interfluve	28.49 - 53.07

Among oxides, other than SiO_2, Al_2O_3 Fe_2O_3 and TiO_2, only CaO has shown an increase in some of the calcareous soil profiles of the study area, as in Pedons PA6, PB4, PC13 and PC14 of Upper Kosi-Gola Plain, Upper Deoha/Ganga-Ghaghra Interfluve and Lower Rapti-Ghaghra Interfluve respectively. In other Pedons containing $CaCO_3$ concretions, CaO does not increase significantly as the $CaCO_3$ concretions larger than 2 mm have been removed before carrying out chemical analysis.

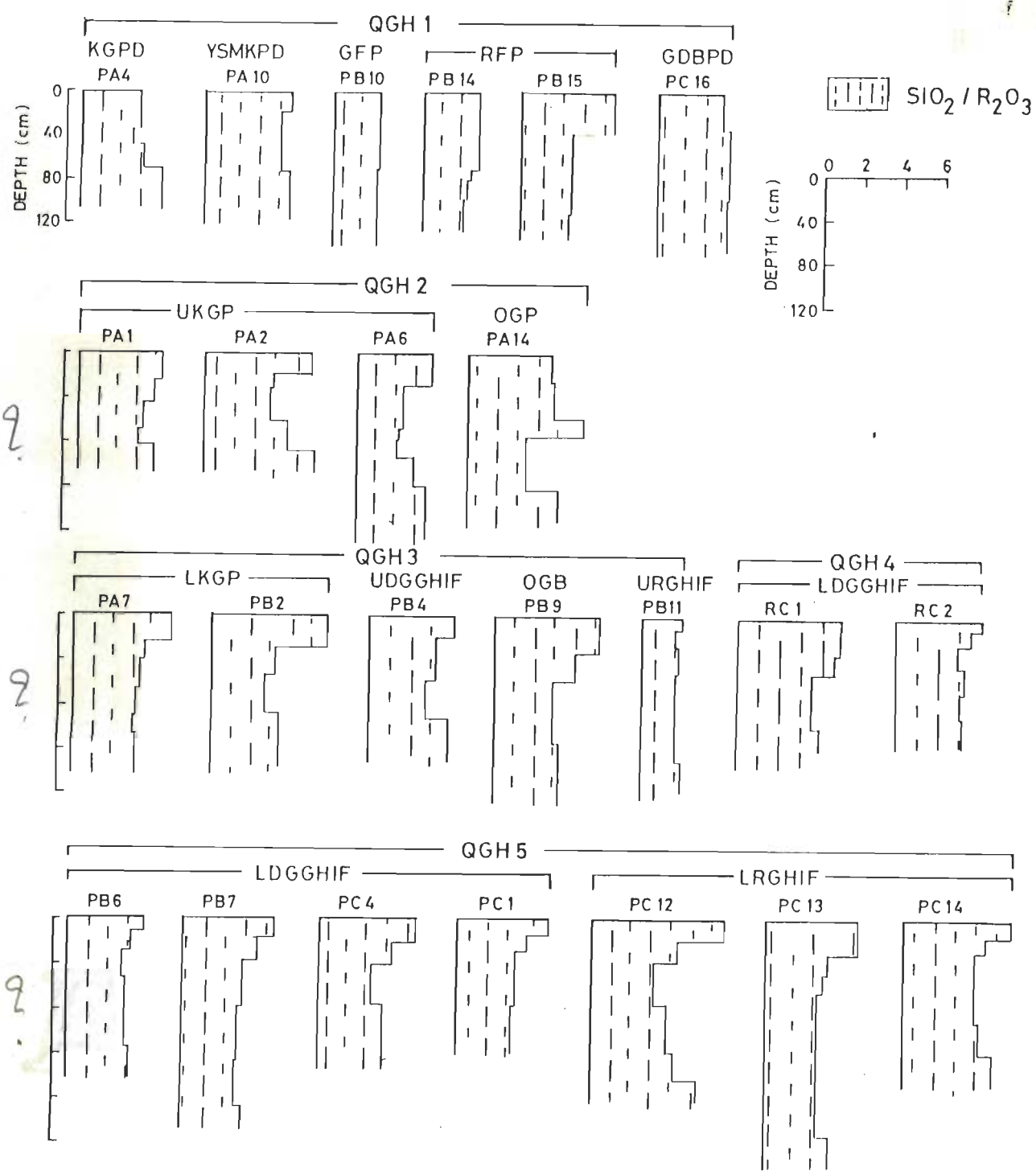

Fig. 3.2.4 Variation molar ratio SiO_2/R_2O_3 with depth in soil profiles and in five member of soil-chronoassociation in the study area.

3.4 CLAY MINERALOGY

3.4.1 Introduction

A variety of clay minerals result during weathering and soil development. Their distribution with depth can be uniform or highly variable. Formation of clay minerals and their transformation in soils are slow processes and depend upon environment, which is mainly dependent upon climate and drainage. The type of clay minerals that forms in a soil mostly depends on the content of silica, kind of cations present, the soil pH and amount of leaching. Thus clay mineral analysis can be very useful in understanding the pedogenic processes.

The present study of clay minerals includes identification of major clay minerals, their semiquantitative estimation and vertical and lateral variation in various soil-geomorphic units.

3.4.2 Sample Preparation

The preparation of sample for clay mineralogical studies depends on the method used to identify the minerals. In the present study X-ray diffraction method has been used. To identify clay minerals it is essential to record their diagnostic basal reflections from oriented clay mineral slides. The method of preparation of oriented clay slides is described below.

About 20 gm of soil sample was air-dried and passed through 230 mesh sieve. The finer fraction was mixed with distilled water and volume was made to about 500cc in a graduated 1 litre cylinder. The mixture was thoroughly stirred and kept for 24 hours. This allowed the soil to settle and clear water containing the excess salts was removed by decantation. This process was

repeated several times till the completely dispersed sample was obtained. This final dispersed sample was kept undisturbed after a thorough stirring till the particles larger than 2 μm were settled down according to Stoke's Law. Then the uppermost 5 cm of the dispersed sample from each cylinder was siphoned off. This process was repeated till we got sufficient amount of clay. This clay sample was centrifuged to obtain a slurry. This clay slurry was divided into three parts. One part was kept untreated, and second and third parts of the clay fraction were made homoionic by saturation with Mg^{+2} and K^{+} with 1N solution of $MgCl_2$ and KCl respectively (Klages and Hopper, 1982).

After complete saturation, excess of solution was removed by three distilled water centrifuge washing to obtain a thin paste of clays. The thick slurry obtained after the third washing was used to prepare oriented samples by spreading it on microscope glass slides placed on a perfectly horizontal platform with the help of pipette to have a uniform thickness. The pipette method provides a fairly good and reproducible orientation (Wilson, 1987). The oriented clay slides have been prepared accordingly. Mg^{+2} saturated clay slides were treated with vapours of Ethylene Glycol in a desiccator for 24 hrs. Two K^{+} saturated slides were heated to 350°C (K-350°C slide) and 550°C (K-550°C slide) respectively. Heated slides were kept in an air tight desiccator with silica gel to prevent dehydration of minerals before exposing them to the x-rays. X-ray diffractograms were obtained using Philips PW 1140/90, X-ray machine at University Scientific Instrumentation Centre, University of

reas of vermiculite and chlorite by 5, illite by 1 and kaolinite y 2.5.

.4.4 Clay Mineralogical Variation in Different Geomorphic Units

The major clay minerals identified from the x-ray iffractograms (Fig. 3.31a, b) of soils of the study area are llite, kaolinite, vermiculite and chlorite (Appendix III). ariation of the clay minerals with depth in various soil-eomorphic units (Fig. 3.32) shows that the clay minerals ormation and transformation has been affected by pedogenesis cting in the study area. Though chlorite is the least abundant mong all the clay minerals present, it is significantly present n the least developed soils, such as those of piedmonts and in loodplains and shows a gradual decrease in abundance in better eveloped soils and then complete absence in most developed oils such as those of the Lower Kosi-Gola Plain, Deoha/Ganga-haghra Interfluve and Rapti-Ghaghra Interfluve.

X-Ray examination of clay fractions of soil samples from ifferent pedons in a North South traverse in Kosi-Gola Plain, edon PA6, PA76, PB2 show that the dominant clay minerals are llite followed by kaolinite, vermiculite and chlorite in escending order. Illite content in northern part close to Kosi-ola Alluvial fan is less as compared to lower parts. In parts lose to fan it varies from 44 to 62% and in the lower part it aries from 86 to 93%. This increase is probably due to the ecrease in grain size and transformation of other clay minerals nto illite in the lower part, where older soils occur. aolinite is the second dominant clay mineral in this traverse,

Roorkee. Diffractograms were obtained under the following conditions.

Target :	CuK α,	filter :	Ni
Current :	20 mA,	Goniometer speed	1° of 2θ angle/mt
Range :	2 KC/s	Scanned angle	3° to 30° of 2θ angle
Wavelength	1.5418 A°	Chart speed	1 cm/min.

3.4.3. Identification of Clay Minerals

Various clay mineral species have been identified according to a scheme given by Wilson (1987). Basal reflections of the oriented clay samples have been used for identification. During the present study of clay minerals care has been taken to keep the factors such as crystallinity, impurities, evenness and thickness of the mounted samples and irradiation effects of X-ray machines, uniform as far as possible .

Relative amount or semi-quantitative estimation of different clay minerals present in soil was done according to the scheme described by Klages and Hopper (1982). Relative x-ray areas for relevant peaks for all the clay minerals ranging between 7°A to 17°A were calculated from x-ray diffractograms of Mg^{+2} saturated ethyline glycolated slides (Mg-Eg) except for vermiculite and chlorite. 10 A° and 7.2A° peak area in Mg-Eg diffractograms were measured for illite and kaolinite. For vermiculite the area was calculated from the difference between 14A° peak area of Mg-Eg and K - 350° C slides, and chlorite from 14A° peak area of K - 350° C slides. In order to estimate the clay minerals factors from the model described by Klages and Hopper (1982) has been used. This involved dividing the peak

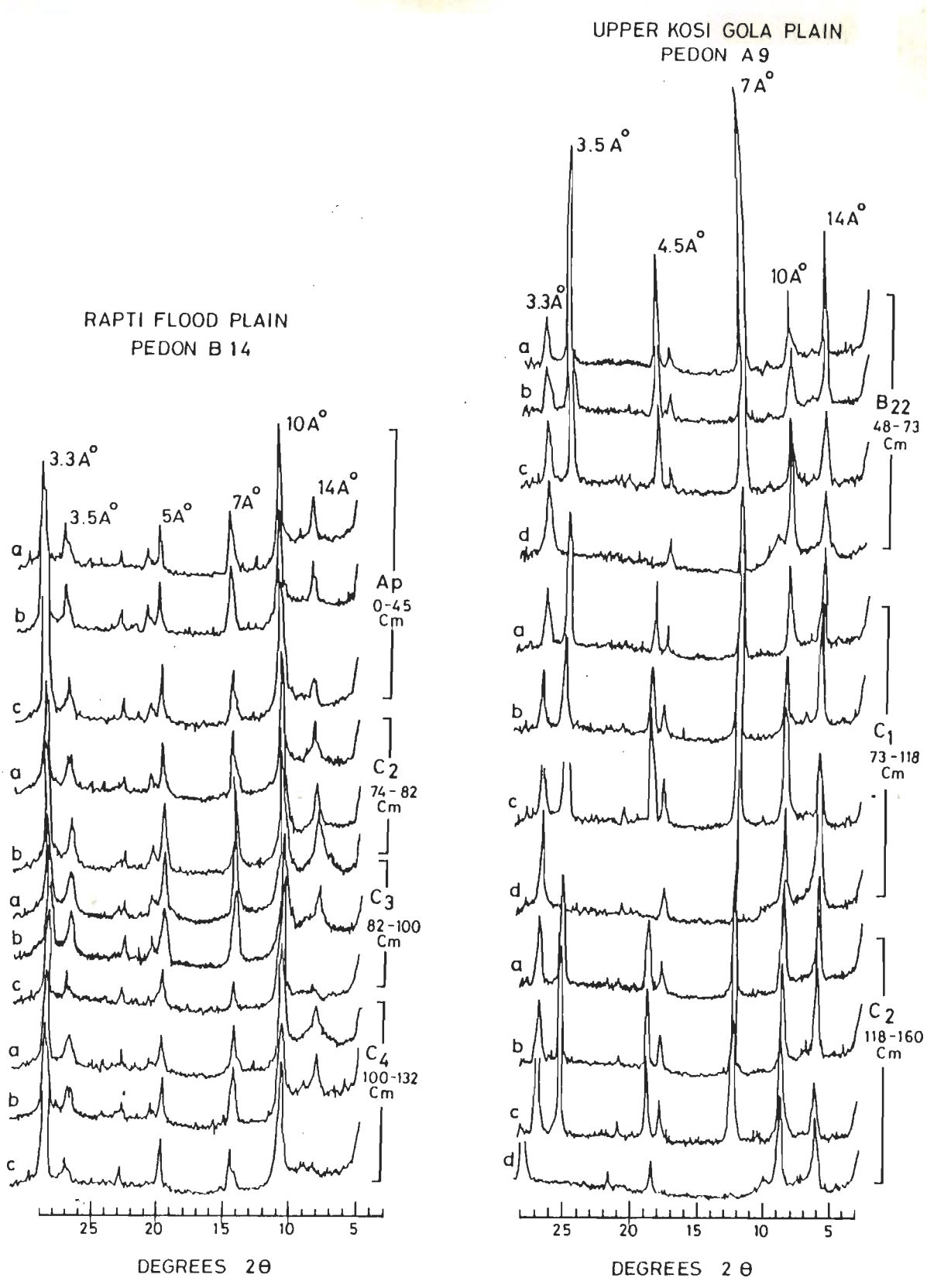

Fig. 3.3.1 a X-ray diffractograms of clay fraction from selected soil profiles from different soil-geomorphic units.

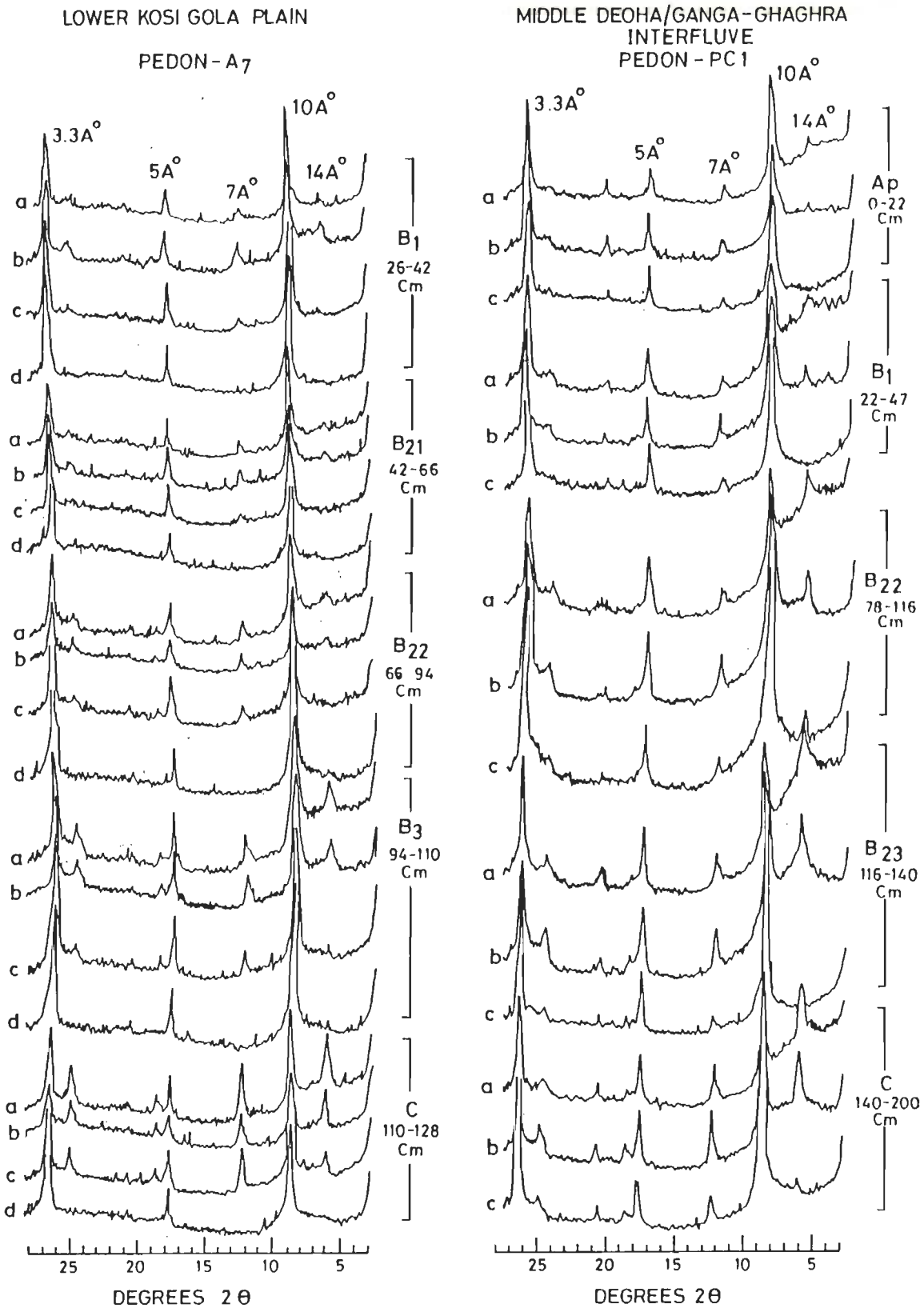

Fig. 3.3.1 b X-ray diffractograms of clay fraction from selected soil profiles from different soil-geomorphic units.

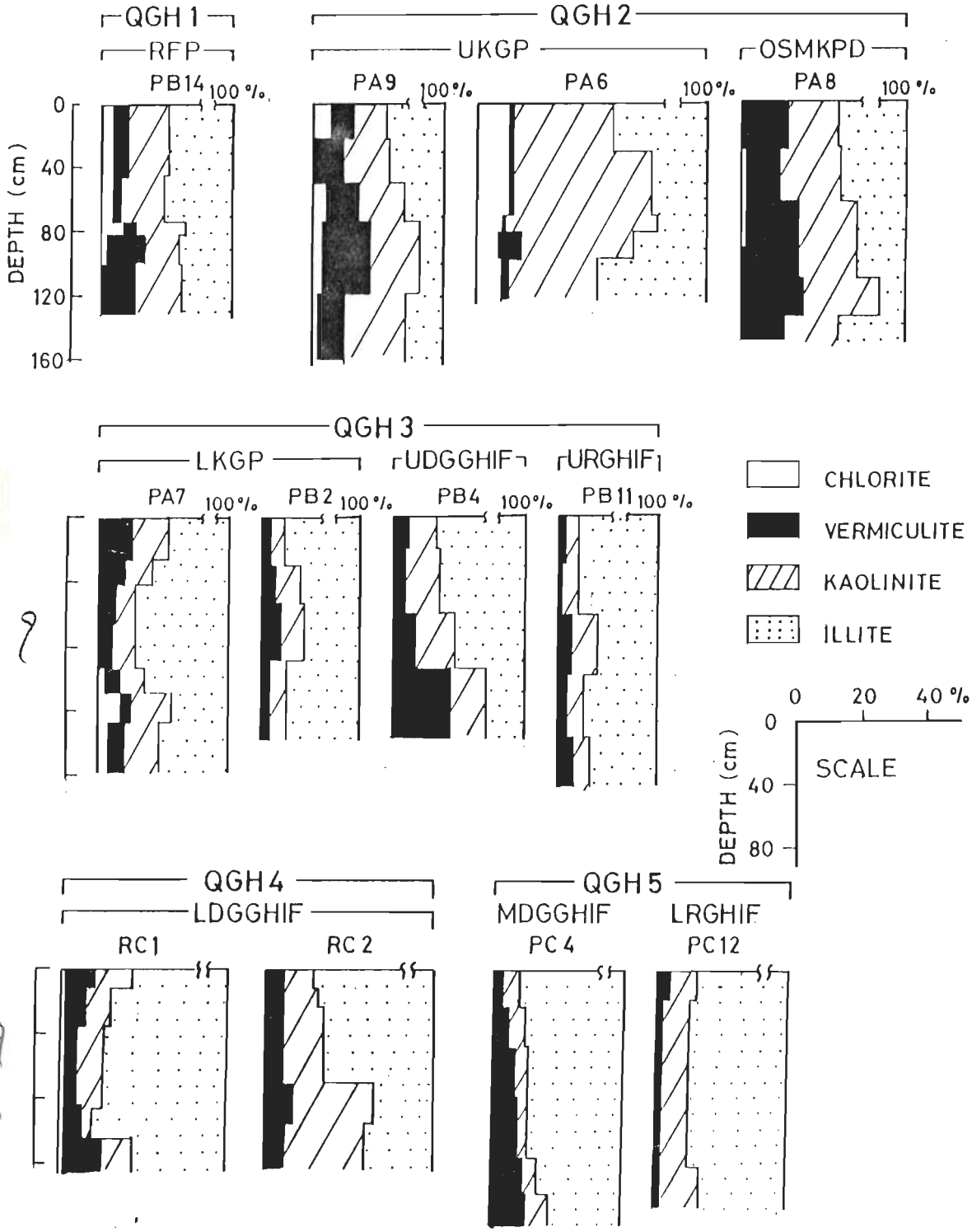

Fig. 3.3.2 Variation of clay minerals with depth in some typical soil-profiles of the five members of soil-chronoassociation.

but its distribution does not show any marked variation or trend, though its amount is slightly higher in the soils of northern part close to Kosi-Gola Fan as compared to the soils in lower parts. Vermiculite also shows a trend similar to kaolinite.

The Upland soils i.e. those in interfluve areas (pedons PB4, PC4, PB11, PC12) show that illite is the dominant clay mineral and its percentage varies from 72 to 87% in Upper Deoha/Ganga-Ghaghra Interfluve and shows relative increase in the middle part of Deoha/Ganga-Ghaghra Interfluve, where it varies from 81 to 91%. It is probably due to higher pedogenesis in the Lower Deoha/Ganga-Ghaghra Interfluve. Kaolinite and Vermiculite are other minerals present in these soils. They do not show any marked variation in soils and their percentage vary between 5 to 12%. Chlorite is completely absent in these soils.

3.5 X - RAY DIFFRACTION STUDIES OF QUARTZ AND FELDSPARS

3.5.1 Introduction:

Chemical weathering of primary minerals depends largely upon the climatic regime. According to Basu (1975, 1976), rock fragments, felspars, and accessory minerals are eliminated more rapidly in "humid" than in "arid" climates. Feldspar is a sensitive climate indicator (Folk, 1961; Fairbridge, 1976; Girty, 1991), when the feldspar is an allogenic mineral derived from adjacent plutonic rocks. Variation in its relative contents reflects weathering rates and hence the climate.

Paleoclimatic inferences regarding the Holocene Period from the Western Indian continental shelf have been drawn by Nair and Hashimi (1980), and Hashmi & Nair (1986). They have inferred

climatic aridity during the Early Holocene (9000-11000 yrs B.P.) and then rapid change to humid climate based on characteristic facies and feldspar distribution. Also, Singh et al. (1974) based on their studies on inland lake basins (Sambhar, Didwana and Lunkarasar of Rajasthan) have suggested a similar change in climate at about 10,000 yrs B.P. The possibility of records of this climatic change being preserved in the soils/sediments of the Indogangetic Plains is fairly high.

Keeping the above aspects in view, x-ray diffraction studies of sand and silt fraction from parent material or C horizon samples of different soil profiles in study area for determination of feldspar contents and quartz/feldspars has been undertaken to infer the climatic variation for the Holocene Period in the Gangetic Plain.

Though the sediments deposited in Indogangetic Plains are not the first cycle ones, it can be assumed that over the short period of the Holocene, composition of the source rocks (and hence that of sediments released by their erosion) has remained the same and felspar content of the sediments brought into the Indogangetic Plains by rivers from the Himalaya mainly reflects climatic conditions in the source area.

3.5.2 Methodology

In the present study, the grab samples from C horizon have been fractionated into sand and silt+clay fractions by wet sieving. Clay fraction was removed from silt and clay by a method described by Galehouse (1971). The combined sand and silt

fraction were air dried and were ground to 230 mesh size (62.5 µm) in an agate mortar, and the powdered samples were analysed on X-ray diffractometer, using a procedure described by Hashmi and Nair (1986). The diffractometer settings were as follows:

Target: CuKα Filter: Ni

Current: 20 m A Goniometer speed: 1/2° of 2 θ angle/mt

Range: 2 KC/S Scanned angle 26-30° 2θ angle

Wavelength 1.5418 A° Chart speed 1/2 cm/min.

3.5.3 X-Ray Diffraction Analysis of Quartz and Feldspar

The relative abundances of quartz and felspars were determined by absolute counts per second over the background for peaks 26.66° 2θ' (101) of quartz and the 27.4 - 27.8° 2θ' (002) and 27.9 - 28.1° 2θ' (002) for potash and sodic feldspars respectively. The results of absolute counts from the X-ray diffractograms (Fig.3.41) are given in Appendix V.

The counts for peak intensities of quartz and feldspar (Fig. 3.42) for parent material for older geomorphic surfaces such as the Middle Deoha/Ganga-Ghaghra and Lower Rapti-Ghaghra Interfluve range for quartz from 5833.3 to 8333.3 and for feldspars from 1209.2 to 2511.5 respectively. The counts particularly for total felspars in other geomorphic surfaces such as in floodplains and in piedmonts are low and range between 201.7 to 888.8

Ratio of absolute counts for total felspar and quartz have given better differentiation between different units. For upland areas such as the Upper and Middle Deoha/Ganga-Ghaghra Interfluve, Upper and Lower Rapti-Ghaghra Interfluve and Lower

Kosi-Gola Plain the ratio of Felspar and quartz range from 0.15 to 0.30. This ratio shows lower values for the Upper Kosi Gola Plain, and Old Ghaghra Bar and it ranges from 0.11 to 0.13. The lowest values for this ratio (0.04 to 0.1) have been recorded for floodplains of Ghaghra and Rapti and from piedmonts.

As Glenie (1970) has suggested that during tropical weathering conditions, sodic feldspars are less stable than potash feldspars (Fig. 3.43). Ratio is for sodic/potash felspars were also examined. For most of the samples this ratio is less than 1.0 as absolute counts for potash feldspars are higher than sodic feldspar (Fig. 3.43). Only from two pedons PC12 and PC10 from Middle Doha/Ganga-Ghaghra Interfluve and Ghaghra Floodplain this ratio is more than 1. Thus, this ratio does not seem to be very useful in inferring climatic conditions.

The higher values of feldspars for the older geomorphic surfaces (Middle Deoha/Ganga-Ghaghra Plains and Upper and Lower Ghaghra-Rapti Plains) from the study area are attributed to deposition in such areas during climatic aridity (as discussed later, their age is assigned as early Holocene), which helped to preserve the feldspars from weathering. The low values of feldspars from the less developed soils on the geomorphic surfaces (as group I and II soils in Table 3.) could be due to climatic change from arid to present day humid (Monsoon) climate.

3.6 Carbon and Oxygen Isotope Analysis of Calcretes

3.6.1 Introduction

Analysis of carbon and oxygen isotopes for the calcrete can

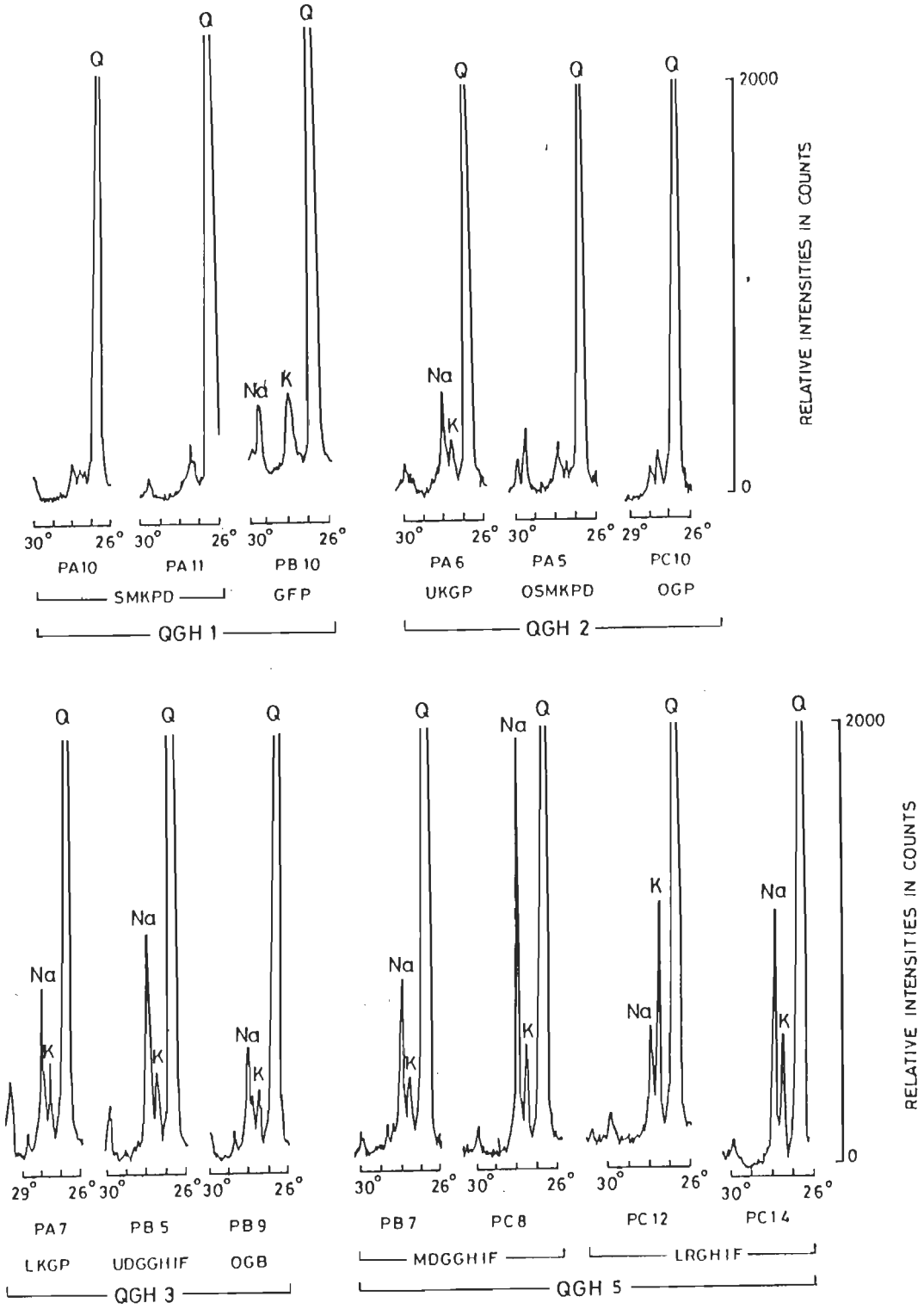

Fig. 3.4.1 X-ray diffractograms for some of selected sample for quartz and feldspar distribution in various soil-geomorphic units in members of soil-chronoassociation in the study area.

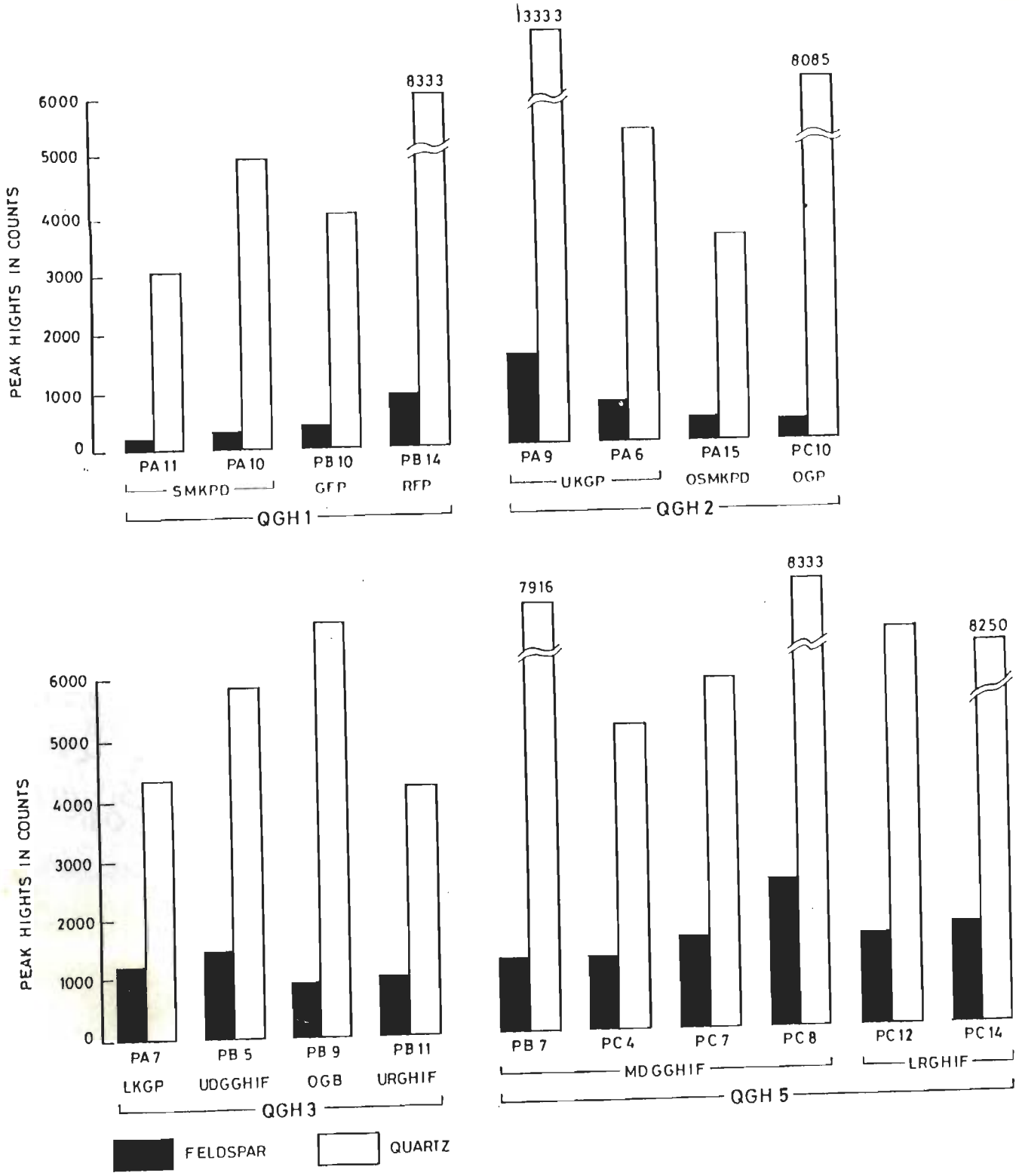

Fig. 3.4.2 Bar diagrams showing distribution of feldspars and quartz in some of selected soil samples from C horizons of various soil profiles from different soil-geomorphic units.

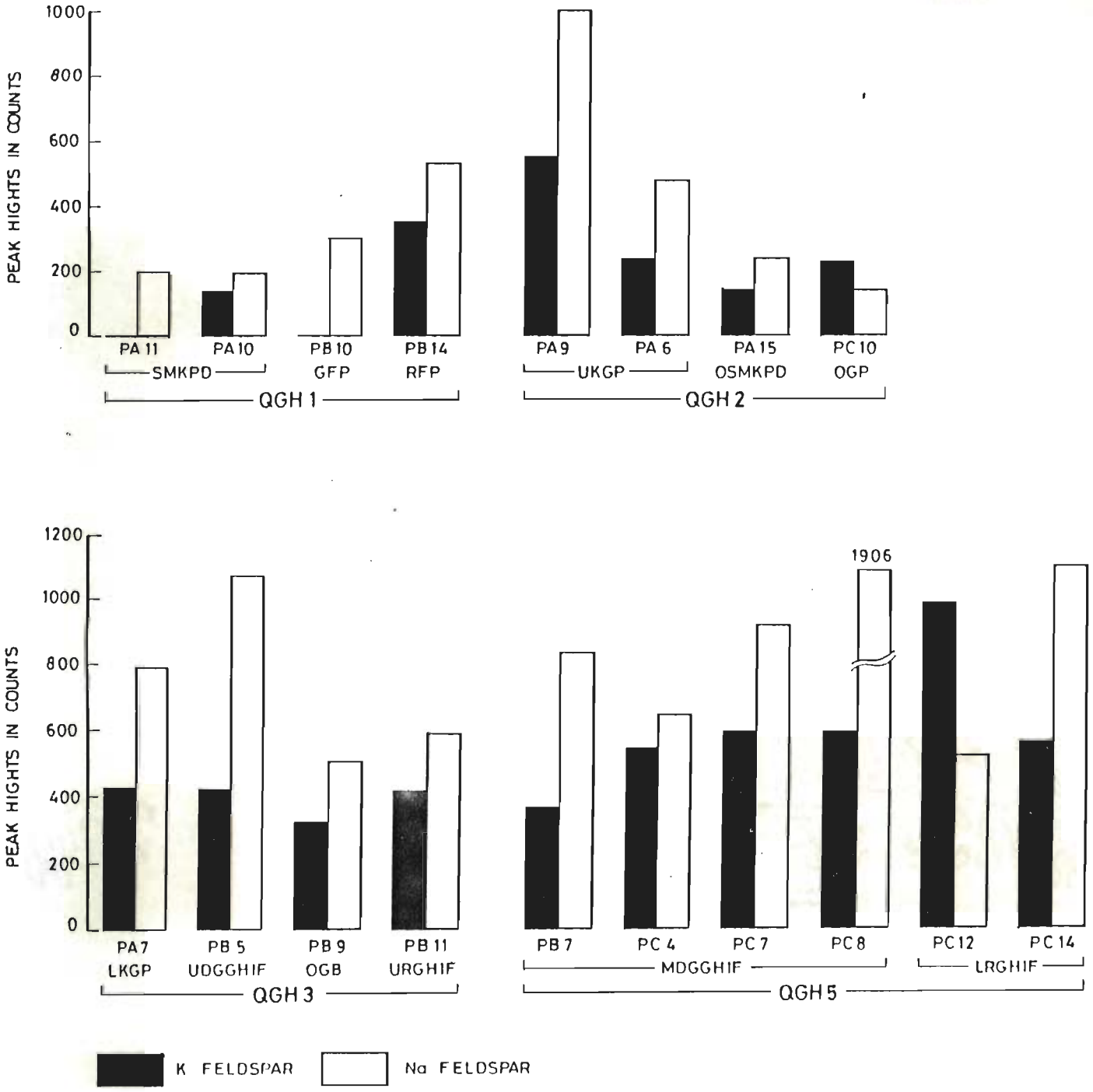

Fig. 3.4.3 Bar diagram showing variation of potash and sodium feldspars in some of soil samples from C horizon of the various soils profiles from different soil-geomorphic units.

be used to infer the processes involved in their formation (Salomons et al., 1978). Keeping this in view, 11 calcrete samples obtained from various horizons of different soil profiles from study area were selected for their carbon and oxygen isotope composition analysis. These calcrete samples were air dried and ground to 230 mesh (62.5 µm). These fine powdered calcretes were reacted with 100% Ortho Phosphoric acid at 90° C. The resultant CO_2 was analysed in a mass spectrometer at ONGC, KDMIPE, Dehradun, with a machine standard that was calibrated against the NBS-19 standard.

3.6.2 Carbon and Oxygen Isotope Composition

The result of the isotopic studies for carbon and oxygen isotopes from the calcretes of the study area are given in Appendix 5 and Fig. 3.51. The following generalisations can be made from the observed data:

i. $\delta^{18}O$ values lie within a small range of -8.00 to -10.47 permil with an average of -8.89 permil. Only one value of -16.10 permil lies outside this range.

ii. Two groups of samples can be recognised on the basis of distribution of $\delta^{13}C$ values.

(a) Samples mainly from B2 horizons of the older units (MDGGHIF & LRGHIF) are generally depleted in $\delta^{13}C$ and have a wide range of -2.39 to -6.90 permil and number of samples from this group is limited (PC6/3, PC13/5, PB7/2).

(b) Second group includes samples from C horizons from older

units and from surface to C horizons in the units (UKGP,GFP OSMKPD) where calcrete is presently known to be precipitated by evaporation from shallow ground water table. These samples are generally enriched in $\delta^{13}C$ and the range is narrow from 0.60 to 1.64 permil.

iii. Values of $\delta^{13}C$ and $\delta^{18}O$ from calcretes of the study area are, in general, similar to those for calcretes from other parts of the world. As summarised by Talma and Netterberg (1983), in modern and in submodern pedogenic carbonates, $\delta^{13}C$ varies between - 12.00 and +4.00 permil (mean of -4.00) and $\delta^{18}O$ varies between -9.00 and +3.00$^{o}/_{oo}$ (mean of -5.00$^{o}/_{oo}$). Present values of $\delta^{13}C$ are similar to those reported by Salomons et al., (1978) from India, mainly from aridic region of Rajasthan but $\delta^{18}O$ values (mean = -8.8$^{o}/_{oo}$) are less than those of Rajasthan (mean value = -4.95 $^{o}/_{oo}$).

Fairly constant values of $\delta^{18}O$ of calcretes from the study area suggest that prevailing temperatures during formation of calcrete were similar. Also group 1 calcrete may have been formed due to the loss of soil CO_2 and pedogenesis, whereas group 2 calcrete samples may have been formed by dissolution of calcrete from B horizons and its migration downward and reprecipitation and precipitation due to evaporation. This process would have resulted in enrichment of calcrete in $\delta^{13}C$ as suggested by Salomons et al., (1978). Depletion of $\delta^{18}O$ in the calcrete as compared to that of Rajasthan may be due to slightly higher temparature of formation of calcrete in the study area.

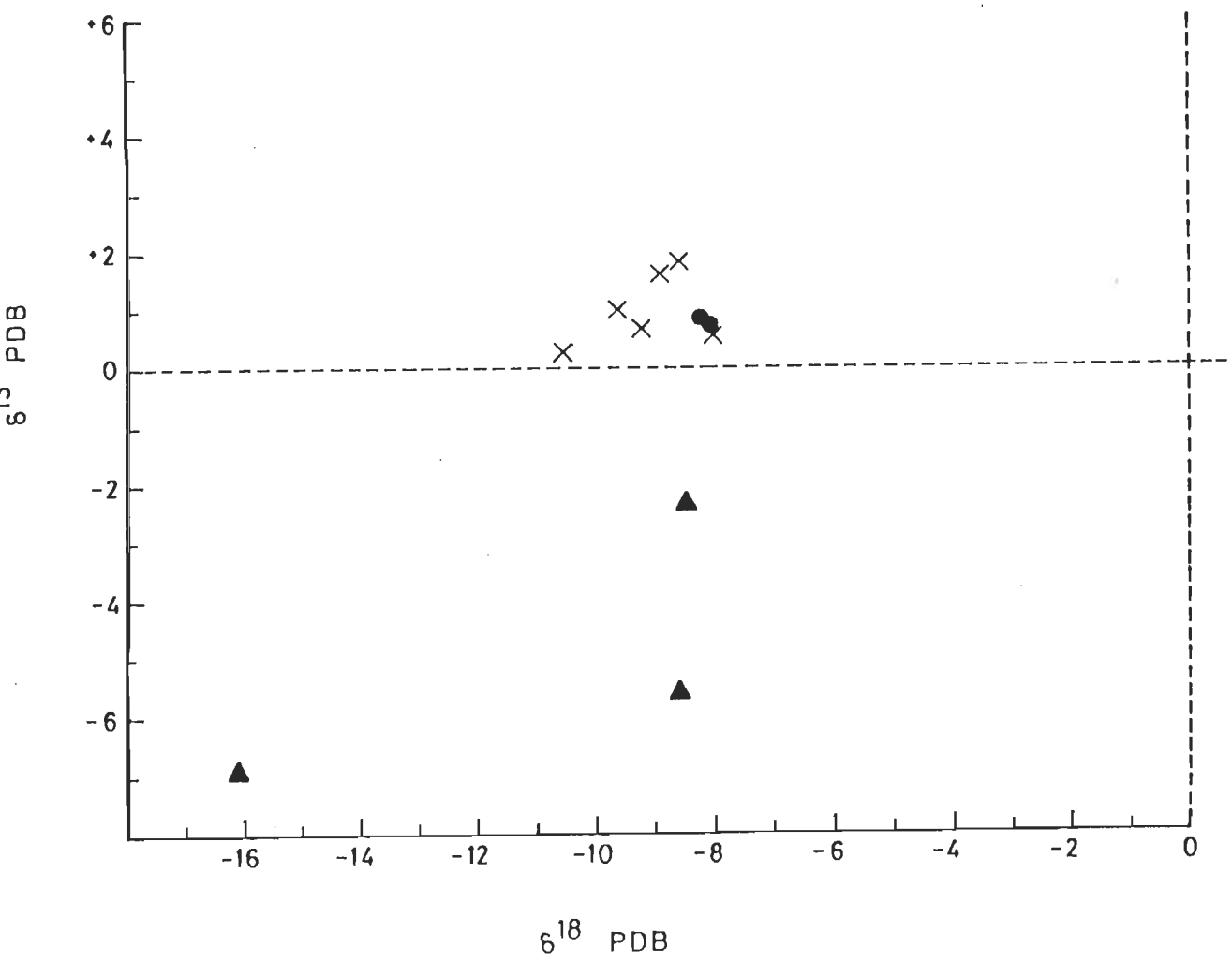

Fig. 3.5.1 Plot of oxygen and carbon stable isotopic compositions (°/₀₀) of main calcrete types. ▲ Type I, ● Type II, × Type III.

3.7 RESUME

The analytical studies of the soils of the study area have given evidences about the variations in the soil characteristics and degree of soil profile development. Grain size analysis suggests that the amount of the pedogenic clay accumulated in B2 horizon serves as a very good indicator of soil profile development. Amount of the pedogenic clay is found to be maximum in the older geomorphic surfaces, such as in Middle Deoha/Ganga-Ghaghra Interfluve and Lower Rapti-Ghaghra Interfluve, and it is very low or virtually nil in the youngest geomorphic surfaces such as in floodplains and piedmonts. The chemical analysis carried out for the major elements has supported the observations made by the grainsize analysis, but it is not useful for soils found in accumulating environment. The clay mineral studies indicate that the dominant clay mineral is illite, followed by kaolinite, vermiculite and chlorite. Illite content is found to increase from the younger soils to older soils, and chlorite content, which is present in younger soils, is decreasing gradually and then almost disappears in the older soils. The studies about the quartz and felspar distribution in the parent material has given idea about the climatic aridity in the Gangetic Plain during the Late Holocene Period. The carbon and oxygen isotopes studies have provided the clues about mode of formation of calcretes in the study area. Based on the physical and chemical characteristics determined, the soils of the study area can be grouped into five groups. A summary of the physical and chemical characters of these major soil groups is given in the Table 3.3

TABLE 3.3 : PHYSICAL AND CHEMICAL CHARACTERS OF THE SOILS

Member	Soil-Geomorphic Unit	Pedogenic Clay Accumulation Index	SiO_2/R_2O_3 Ratio	Clay Minerals	Q/F Ratio
I	Kosi-Gola Piedmont, Gholia-Dhobania-Bhambhar Piedmont, Young Sihali-Mohan-Kandra Piedmont, Rapti and Ghaghra Floodplain	Nil	(2.88-2.20) A Horizon (2.25-3.94) B Horizon	Illite (58.2 - 81.36%) Kaolinite (10.9 - 22.3%) Vermiculite (2.93-19.4%) Chlorite (1.73-6.81%)	0.04-0.10
II	Upper Kosi-Gola Plain, Old Sihali-Mohan-Kandra Piedmont, Old Ghaghra Plain	Weak Illuviation, (214.02 to 605.6)	(3.45 - 5.93) A Horizon (1.91 - 3.25) B Horizon (3.08 - 5.26) C Horizon	Illite (44.53 - 76.78) Kaolinite (13.13 -46.96) Vermiculite (2.2 - 15.04) Chlorite (1.2 - 10.21)	0.11 -0.13
III	Lower Kosi-Gola Plain, Upper Rapti-Ghaghra Interfluve, Upper Deoha/Ganga-Ghaghra Interfluve, Old Ghaghra Bar	Moderate Illuviation (693.3 to 845.25)	(3.95 - 5.52) A Horizon (2.48 - 2.99) B Horizon (3.06 - 3.66) C horizon	Illite (77.7 -93.75) Kaolinte (3.2 -12.15) Vermiculite (1.46 - 8.02) Chlorite (1.60 - 7.40)	0.23 - 0.25
IV	Lower Deoha/Ganga-Ghaghra Interfluve	Moderate to strong Illuviation (560.0 - 1050.0)	(4.85 - 6.21) A Horizon (2.91 -3.41) B Horizon (3.72 - 3.95) C Horizon	Illite (78.4 - 85.70) Kaolinite (8.4 -13.9) Vermiculite (2.4 - 5.7) Chlorite (1.8 - 4.8) Minor amount of mixed layer	
V	Lower Rapti- Ghaghra Interfluve, Middle Deoha/Ganga-Ghaghra Interfluve	Strong Illuviation (1010.34 -2566.50)	(3.56 - 6.23) A Horizon (2.39 - 3.31) B Horizon (3.02 - 4.88) C Horizon	Illite (81.86 - 91.89) Kaolinite (3.55 - 12.3) Vermiculite (1.51 -11.33) Chlorite (Nil)	0.15 - 0.30

CHAPTER - 4

MICROMORPHOLOGY

4.1 INTRODUCTION

Micromorphology is the science that studies microfabrics of undisturbed soil materials by microscopic methods, commonly using thin section techniques. Micromorphology is used as a powerful tool to refine and generalize macromorphological submicroscopic observations.

A detail description of typical thin sections from different soil geomorphic units has been done to infer the pedogenic processes and degree of soil profile development.

4.2 PROCEDURE

Undisturbed, insitu soil samples from characteristic horizons from typical pedons of different soil geomorphic units were collected in metal boxes of sizes 5 x 6 x 8 cm during the field investigations. 43 such samples from 11 soil geomorphic units were selected for detailed micromorphological studies.

The impregnation of the soil sample was carried out by the method suggested by Jongerious and Heintzberger (1963) and Miedema et al. (1974). For impregnation of soil samples, crystic resin with catalyst was used in a vacuum chamber. Then the samples were cured for 20 - 30 day at room temperature. These hard blocks of impregnated soil were used for preparation of thin-section.

Description of the soil thin sections (Appendix iv) under microscope was given according to the system described by Bullock et al. (1985). The description was done under the main headings i.e. microstructure, basic mineral components and pedofeatures. Micromorphological description is preceded by the macromorphological characters of the horizon/subhorizon. Additionaly the degree of b-fabric development is described by terms such as weakly, moderately, strongly and very strongly developed. The extent of development is measured by the percentage of area of the thinsection covered by b-fabric. The terms used for this are rare (<10%), common (10-20%) and very common (>20%).

Microstructures were studied in comparatively thick sections (about 50-60µm thick) for development of pedality, voids and their arrangement. Basic mineral components and pedofeatures were examined in 25-30 µm thick thin-sections. Three types of calcretes - I, II and III are recognised from field occurrence and micromorphological characters.

4.2.1 Micromorphological characters in Kosi-Gola Piedmont

In this soil-geomorphic unit, four undisturbed soil thin-sections (Table 4.1, Appendix IV) have been described from two different pedons in a N-S traverse. Development of pedality has not taken place, as the soils show apedal and massive structure (Fig. 4.1, 4.2) in most of the area, except in the distal part, where very weakly developed peds are seen. C/F ratio ranges from 80/20 to 60/40. The coarse fractions are usually fresh unaltered, poorly sorted, mostly of 400 - 500 µm size. These

TABLE 4.1 : TYPICAL MICROMORPHOLOGICAL CHARACTERS OF SOILS FROM DIFFERENT SOIL-GEOMORPHIC UNITS

Soil-Geomorphic Unit Samp. No. Depth (cm) Horizon	Structure	Grade	Voids and their surface	Microstructure	c/f limit c/f ratio	Argillans	b-fabric	Calcrete	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Kosi-Gola Piedmont									
PA3-4 103-128 cm C horizon	Apedal Massive	--	Rough intergrain channels & vughs	Compact grain channel microstructure	80/20 gefuric chitonic	---	Undifferentiated, Speckled and parallel	---	cr.f. is 300-400 μm fresh mineral grains
PA4-2 36-50 cm B horizon	Apedal massive	--	Rough channels and vughs	Cpmapact grain vughy microstructure	60/40 Enulic	---	Undifferentiated Weak poro- and grano striated	---	high humas, cr.f. is 300-400 μm fresh minerals
PA4-3 50-73 cm B horizon	Apedal to subangular	Very weak	Rough channels vesicles	Inter grain channel and vesicular	40/60 enulic porphyric	---	weak to moderate poro- and cross striated	---	---
Gholia-Dhobania-Bhambhar Piedmont									
PC16-2 34-66 cm C horizon	Apedal massive	--	Rough channel & vughs	Vughy and spongy microstructure	30/70 porphyric	---	Moderate cross & porostriated	---	cr. f. is 150-200 μm fresh to weakly altered mineral grains
PC16-3 66-99 cm C horizon	Apedal	--	Channels and vughs	Channel & vughy microstructure	40/60 porphyric	---	Moderate cross and poro striated	sparatic nodules	cr. is 100-200 μm fresh to weakly altered mineral grains
PC16-4 99-120 cm C horizon	Apedal	--	Channels and vughs	Channel & vughy microstructure	30/70 porphyric	---	Moderate reticulate and porostriated	hypocoatings and nodules	cr. f. 100-200 μm weakly altered mineral grains
Rapti Floodplain									
PB14-2 45-74 cm C horizon	Apedal massive	--	Vesicles & channels	Vesicular channel microstructure	40/60 porphyric	---	Strong porostriated & parallel striated	sparatic nodules & prismatic calcite crystals	cr. f. 100-150 μm fresh to weakly altered mineral grains
PB14-3 74-82 cm C horizon	Apedal massive	--	Rough channels	Compact grain microstructure	60/40 monic and gefuric	---	Moderate cross-, poro-, and parallel	Nodules and hypocoatings of sparite	cr. f. 100-200 μm fresh to weakly altered mineral grains

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Ghaghra Floodplain									
PB10-2 72-118 cm C horizon	Apedal massive	--	Simple packing voids	Compact grain bridged grain microstructure	80/20 monic, gefuric	---	Undifferentiated poro and grano- striated	Sparartic nodules and prismatic crystals	---
PB10-3 72-118 C horizon	Apedal massive	--	Vughs and channels	Vughy micro- structure	40/60 gefuric, chitonic	---	Moderate porostriated & stipple speckled	Sparatic nodules prismatic crystals	---
Old Ghaghra Plain									
PC10-2 11-21 cm B horizon	Subangular	Weak	Rough to smooth channels	Channel and vughy micro structure	60/40 enulic and chitonic	20-30 μm hypocoatings	Moderate poro & grano striated	--	cr.f. 300-400 μm fresh to weakly altered mineral grains
PA14-2 25-60 cm B horizon	Apedal massive	--	Simple packing voids	Compact grain bridged grain microstructure	70/30 monic and gefuric	---	Weak stipple and cross-striated		---
PA14-4 77-103 cm C horizon	Subangular	weak	Rough channels	Channel micro- structure	30/70 porphyric	20-30 μm silty clay hypocoatings	Strong poro- and cross-striated	Micritic to sparatic hypocoating and nodule	Strong animal activity
PA13-3 62-89 cm B2 horizon	Subangular	Weak	Smooth channels	Channel and vughy micro- structure	40/60 porphyric	30-40 μm hypocoatings	Strong cross- and porostriated	---	---
PA13-5 110-135 cm C horizon	Apedal massive	--	Vesicles	Vesicular microstructuure	---		Strong reticulate & cross-striated	--	Strong animal activity
Old Sihali-Mohan-Kandra Piedmont									
PA15-2 18-47 cm B2 horizon	Subangular	Weak to moderate	Smooth channels & vughs	Channel and vughy micro- structure	40/60 porphyric enulic	40-50 μm hypocoating	Moderate stipple speckled	---	cr. f. 50-100 μm weakly altered mineral grains
Upper Kosi-Gola Plain									
PA5-4 60-85 cm B21 horizon	Subangular	Weak to moderate	Rough and smooth channels	Vughy and cha- nnel microstr- ucture	40/60 enulic porphyric	30-40 μm hypocoatings along voids	Strong reticulate and porostriated	Hypocoatings, micritic to microsparatic nodules	---
PA5-5 85-130 cm B3 horizon	Subangular	Weak	Channels	Channel micro- structure	30/70 porphyric	---	Strong reticulate and porostriated	Sparatic nodules and hypocoatings	---

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
PB3-4 81-110 cm B22 horizon	Subangular	Weak	Smooth channels and vughs	Channel and vughy micro-structure	40/60 porphyric enulic	30-40 µm hypocoatings along voids	Moderate poro-striated and stipple speckled	--	cr. f. 100-200 µm weakly altered mineral grains, and >2000 µm micropan
PA0-5 110-128 cm B3 horizon	Apedal to subang-angular	Very weak	Rough vughs & channels	Compact grain bridged grain	80/20 gefuric, chitonic	---	Weak cross- and porostriated	---	
PA6-2 30-70 cm B1 horizon	Subangular	Weak	Rough channels and vughs	Intergrain channel and vughy micro-structure	60/40 chitonic gefuric	20-30 µm hypocoatings	Weak to moderate cross and reti-culate striated	micritic hypocoatings and sparatic nodules	cr. f. 200-300 µm weakly altered mineral grains
PA6-3 70-80 cm B21 horizon	Subangular	Weak to modrate	Smooth channels and vughs	Channel micro-structure	30/70 porphyric	30-40 µm hypocoatings	Moderate cross and poro-striated	Micritic hypocoatings, sparatic nodules & crystic plasmic	cr. f.60-100 µm weakly altered mineral grains
PA6-6 127 cm C horizon	Apedal	--	Rough channels	Intergrain channel	60/40 enulic chitonic	--	Undifferentiated	Impure nodules and hypocoatings of sparaite	cr. f. 200-300 µm fresh to weakly altered minerals
PA9-3 48-73 cm B2 horizon	Subangular	Moderate	Compound packing voids	Intergrain channel and vesicular	60/40 enulic, chitonic	30-40 µm hypocoatings	Moderate cross and poro-striated	---	cr. f. 150-200 µm weakly altered mineral grains
Old Ghaghra Bar									
PB9-3 60-118 cm B21 horizon	Subangular	Moderate	Channel, vesicles	Intergrain channel	40/60 enulic porphyric	60-80 µm microlamin-nated	Moderate to strong cross-, reticulate striated	----	cr. f. 150-200 µm weakly altered mineral grains
PB9-4 118-145 cm B22 horizon	Subangular	Moderate	Smooth channels and vughs	Channel and vughy microstructure	50/50 porphyric, enulic	40-50 µm hypo and quasi coat-ings	Weak to moderate stipple speckled and cross striated	--	Feruginous micropans
Lower Kosi-Gola Plain									
PA7-3 42-66 cm B21 horizon	Subangular	Moderate	Compound packing voids	Channel micro-structure	40/60 porphyric, enulic	50-60 µm hypocoatings	Modrate cross and poro- and retic-culate striated	--	cr. f. 100-300 µm weakly altered
PA7-6 110-128 cm C horizon	Apedal massive	--	Vughs	Intergrain, and pellicular	60/40 chitonic	--	Moderate cross and reticulate striated	Impure sparatic nodules	

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
PB2-2 34-54 cm B21 horizon	Subangular	Moderate to strong	Smooth channels and vughs	Channel microstructure	40/60 porphyric, enulic and chitonic	30-40 µm hyupocoatings	Moderate reticulate poro- and granostriated	--	cr. f. 200-250 µm weakly altered mineral grains
PB2-3 54-90 cm B22 horizon	Subangular	Moderate	Smooth channels and vughs	Channel and vughy microstructure	40/60 porphyric enulic	60-80 µm microlaminated hypocoatings	Strong stipple speckled and porostriated	--	cr. f.100-150 µm moderately mineral grains
Upper Rapti-Ghaghra Interfluve									
PB12-2 18-43 cm B21 horizon	Subangular	Weak	Rough to smooth vughs	Compact grain pellicular grain microstructure	60/40 chitonic enulic	50-60 µm hypocoatings	Moderate speckled and cross striated	--	cr. f. 100-300 µm weakly altered mineral grains
PB12-4 82-130 cm C horizon	Apedal massive	--	Rough	Intergrain channel microstructure	80/20 monic gefuric	--	--	---	---
Upper Deoha/Ganga-Ghaghra Interfluve									
PB4-3 60-95 cm B2 horizon	Subangular (pn iv 23)	Moderate	Smooth channels, vughs	Channel and vughy micro-	30/70 porphyric enulic	50-60 µm hypocoating	Strong cross poro- and parallel	--	cr, f 100-150 µm moderately altered mineral grains
PB4-4 95-140 cm C horizon	Apedal massive	Very weak	Rough channels	Massive compact	40/60 porphyric		Moderate speckled cross-,	Impure sparatic nodules and hypocoatings	---
Lower Rapti-Ghagra Interfluve									
PC12-2 18-40 cm B21 horizon	Subangular	Strong	Smooth channels	Vughy and channel microstructure	30/70 porphyric and enulic	100-200 µm microlaminated hypocoatings	Strong cross-reticulate and poro-striated	--	Intensely altered mineral grains
PC12-4 78-123 cm B22 horizon	Subangular	Moderate to strong	Smooth vughs and channels	Vughy and channel microstructure	40/60 porphyric and enulic	100-120 µm microlaminated hypocoatings	Strong cross-reticulate and poro-striated	--	intensely altered mineral grains
Middle Deoha/Ganga-Ghaghra Interfluve									
PB6-4 55-85 cm B23 horizon	Subangular (i-1)	Moderate to strong	Smooth channel and vughs	Channel microstructure	40/60 porphyric	100-150 µm microlaminated hypocoatings	Strong reticulate cross and poro striated	--	intensely altered mineral grains papules (> 1000 µ)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
PB6-5 85-120 cm B24 horizon	Subangular	Moderate (iv-24)	Smooth channel and vesicles	Channel and vesicular microstructure	50/50 porphyric enulic	100-150 µm microlaminated hypocoatings	Strong poro cross and reticulate striated	--	Strong animal activity (isotubles)
PB7-3 38-84 cm B22 horizon	Subangular	Very strong	Smooth channels	Channel microstructure	40/60 porphyric enulic	150-200 µm microlaminated hypocoatings	Strong reticulate grano and poro-striated	---	intensely altered mineral grains
PC4-2 22-47 cm B1 horizon	Subangular	Weak	Rough vughs and vesicles	Compact grain microstructure, intergrain vughy micro structure	60/40 chitonic and gefuric	30-40 µm hypocoating	Weak poro-, grano cross striated	---	---
PC4-4 78-116 cm B2 horizon	Subangular	Moderate of strong	Smooth channel vughs	Channel and vughy microstructure	40/60 porphyric and enulic	80-100 µm hypocoating	Moderate to strong grano, poro, reticulate and parallel striated	---	---
PC1-3 29-80 cm B21 horizon	Subangular	Strong	Compound packing voids, channels and vughs	Channel and vughy microstructure, platy microstructure	40/60 porphyric and enulic	100-120 µm microlaminated hypocoatings	Strong reticulate parallel and speckled	pure, cylindrical to rounded nodules of micrite	strong animal activity (isotubles)
PC1-4 80-125 cm B22 horizon	Subangular	Moderate to strong	Smooth channel and vughs	Compact grain microstructure, bridged grain microstructure	60/40 gefuric chitonic	30-40 µm hypocoatings	Moderate cross striated and speckled b-fabric	crystic plasmic b-fabric	---
Lower Deoha/Ganga-Ghaghra Interfluve									
RC-11 22-66 cm B21t horizon	Subangular blocky	weak to moderate	Smooth channels and vughs	Spongy, channel and vughy	30/70 porphyric	80-100 µm hypocoatings	Common strong cross striated rarely moderate poro, grano and parallel striated		---
RC-43 28-48 cm B21t horizon	Subangular	Moderate to strong	Smooth channels and vughs	Channel and vughy	40/60 enulic porphyric	60-80 µm hypocoatings	Commonly strong cross striated and reticulate striated	Micritic hypocoatings and nodules	---
RC-42 48-71 cm B22t horizon	Subangular	Moderate to strong	Smooth channels and vughs	Channel and vughy	40/60 porphyric	100-150 µm microlaminated hypocoatings	Common moderate to strong cross, poro- and reticulate striated	Micritic hypocoatings and nodules	---

Fig. 4.1 Apedal, massive and intergrain channel microstructure. Pedon PA3, C horizon, marker is 1 cm., ordinary light

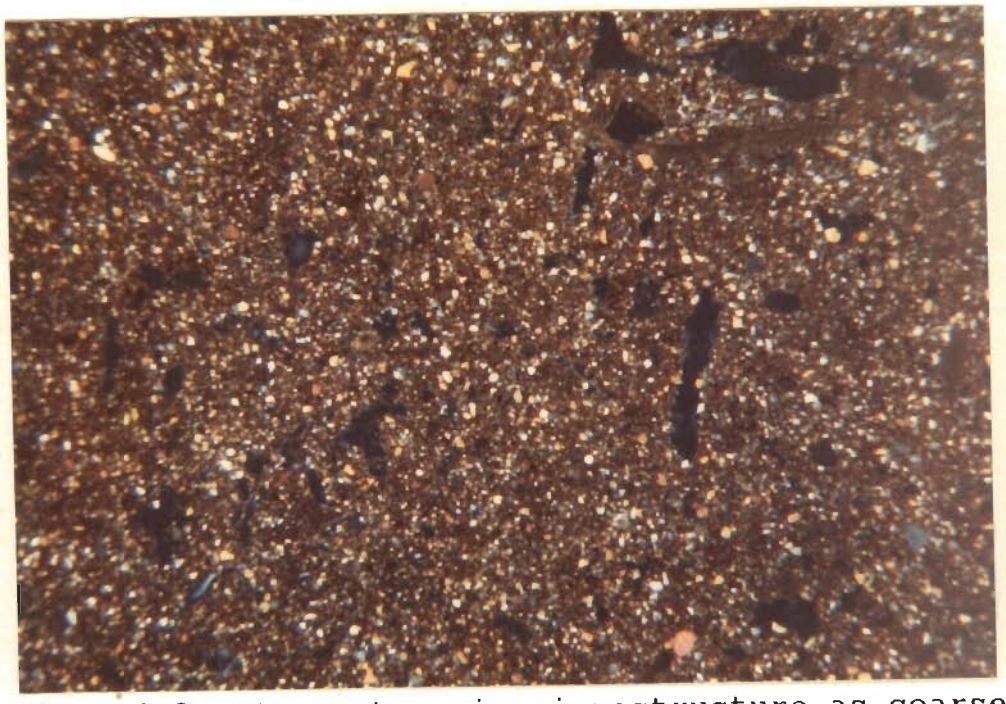

Fig. 4.2 Compact grain microstructure as coarse grains are closely packed along with high humus. Intergrain channel voids show extremely rough surface. Pedon PA3, C horizon, Kosi-Gola Piedmont, Frame length 20 mm, XPL.

consists of quartz, mica and felspar and a few lithorelicts. The soils in thin section show bridged grain and pellicular grain microstructures (Fig. 4.3).

C/F related distribution is usually gefuric and chitonic and occasionally monic distribution also occurs (Fig. 4.3). Finer fraction consists of fine micaceous silt and impure clays and fine discrete organic matter. Plasma separation is weak as undifferentiated b-fabric (isotic plasmic b-fabric) is commonly noted. Also at places weakly to moderately developed stipple speckled, grano-, and poro-striated b-fabrics are rarely observed.

Translocation of clay in these soils has not taken place, as there are no illuvial clay pedofeatures. Humus content in upper part of soils profiles is large and also a few partially decayed fibrous roots (Fig. 4.4) are seen.

4.2.2 Micromorphological characters of Gholia-Dhobania-Bhambhar Piedmont

Three thin-sections have been described in detail (Table 4.2 Appendix IV). Soil of this piedmont shows apedal and massive soil structure. Continuity of the apedal mass is broken by a few vughs and channels. At places weakly developed subangular blocky peds are also seen.

C/F ratio generally varies from 30/70 to 40/60. Coarse fraction is poorly sorted and ranges from 200 to 400 μm in size. It consists of quartz and micas and other minerals in small amount. Fine matter usually is fine silt, which is sometimes mixed with humus and calcareous matter. Plasma separation is weak

to moderate. Cross reticulate and striated b-fabrics are seen (Fig. 4.5).

C/F related distribution is usually porphyric and sometimes enulic. Translocation of clay has not taken place as no argillans were observed. Other pedofeatures include various types of calcrete features such as septaric micrtic nodule (Fig. 4.6) and strongly developed crystillitic b-fabric due to micritic groundmass (Fig. 4.7). These are classified as type III calcretes. Concentric ferruginous nodules and channel infillings by fine sand sized particles are also observed.

4.2.3 Micromorphological characters of Ghaghra Floodplain

Soils thin section from this floodplain show apedal to weakly developed subangular blocky soil structure. Voids are mainly intergrain channels and vughs and at places simple packing voids are also noted. Microstructures observed include compact grain, intergrain channel and bridged grain microstructures, coarse fraction is generally high and C/F limit ranges from 60/40 to 80/20. The coarse fraction is usually moderately sorted and is of 200 - 400 μm size. It consists of fresh to slightly altered grains of quartz, mica and feldspar and others in minor amounts. The fine fraction is usually low and is mainly of micaceous fine silt and clays. Sometimes it is ferruginous and calcareous. It occurs as groundmass and thin coatings along coarse mineral grains. Pellicular grain microstructure is noticed. Plasma separation is moderate to strong as parallel and porostriated b-fabrics are commonly observed.

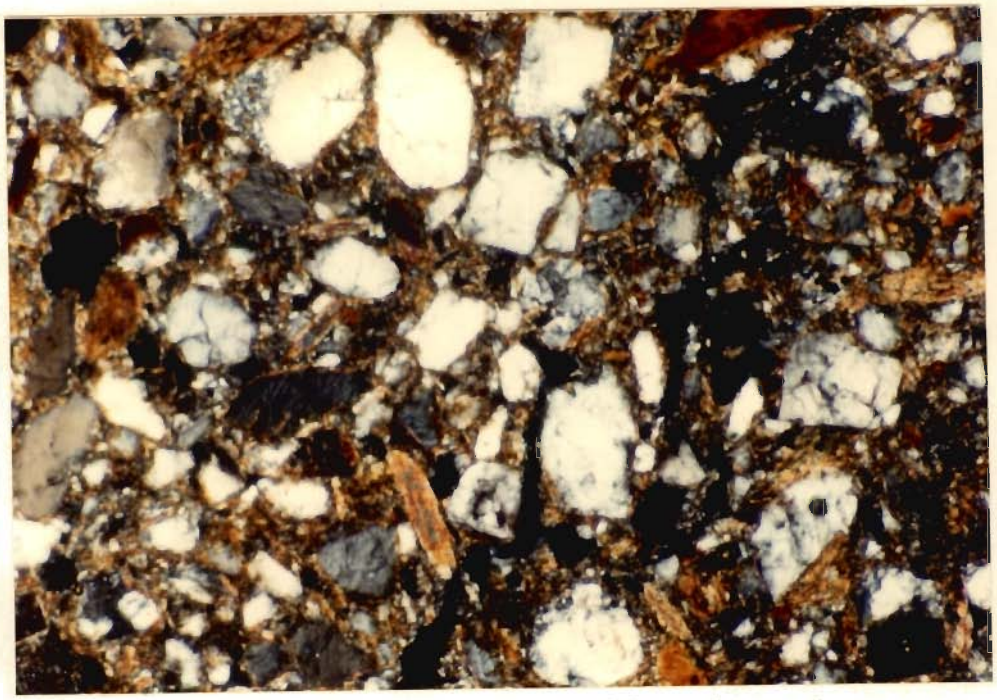

Fig. 4.3 Fresh to very weakly altered coarse and fine fraction. Coarse mineral grains are partially coated with fine mass. C/F related distribution is gefuric and chitonic. Pedon PA3, C horizon, Kosi-Gola Piedmont, Frame length 1.4 mm, XPL

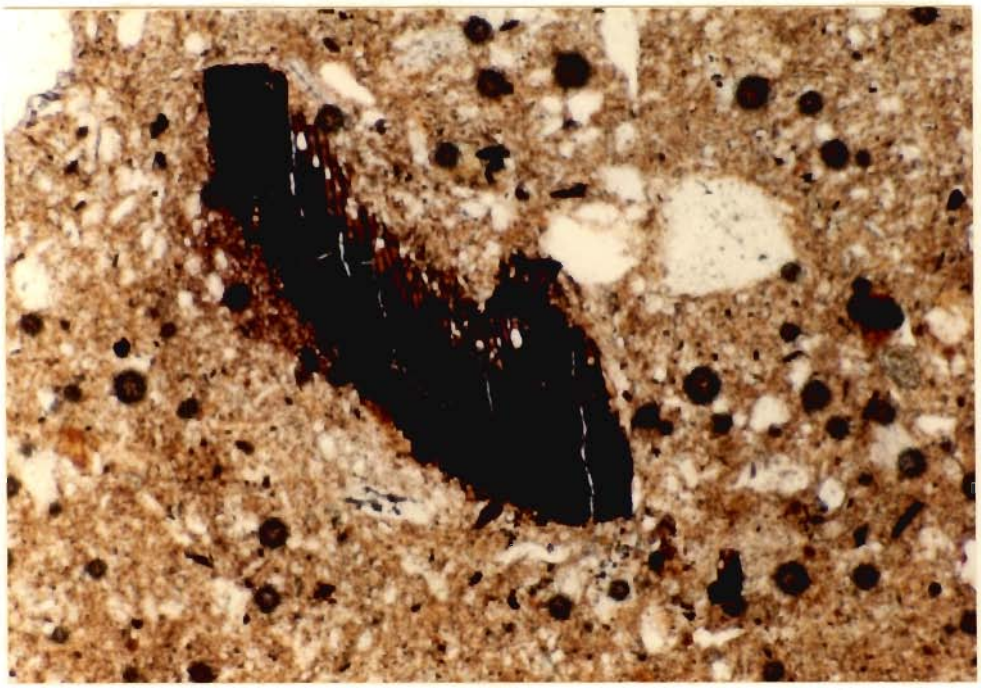

Fig. 4.4 Partially decayed fibrous root in Kosi-Gola Piedmont Pedon PA4, A horizon, Frame length 1.4 mm, PPL

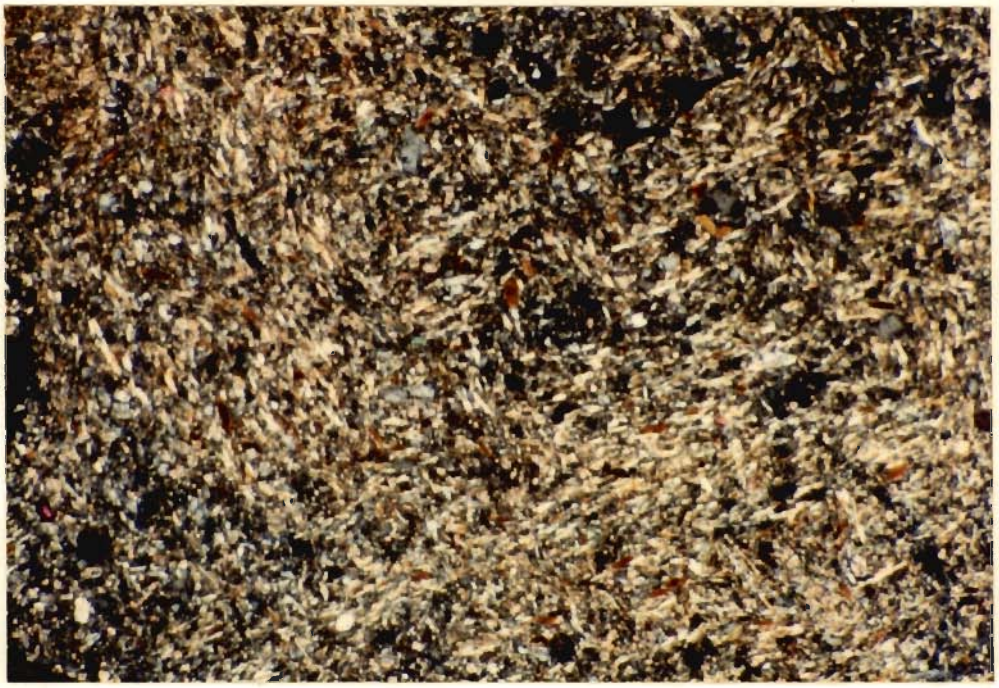

Fig. 4.5 Strongly developed reticulate striated b-fabric, Pedon PC16, C horizon, Gholia-Dhobania-Bhambhar Piedmont, frame length 1.4 mm, XPL.

Fig 4.6 Geodic, septaric, strongly impregnated calcareous nodules, Type III calcrete, Pedon PC16, C horizon, Gholia-Dhobania-Bhambhar Piedmont, Frame length 7.5 mm, XPL.

Illuviation pedofeatures are absent. Other observed pedofeatures include loose complete channel infillings (Fig. 4.8), diffused mottles of sesquioxides, isotubles due to animal activities and diffused organic matter. Various calcareous pedofeatures such as crystic plasmic fabric, fresh water gastropod and coarsely crystalline, typic orthic nodules and large prismatic crystals of calcite forcing apart the soil ground mass (Fig. 4.9) are also observed. These are classified as type III calcretes.

4.2.4 Micromorphological characters of Rapti Floodplain

Two thin-sections showing characteristics of this floodplain are described in detail (Table 4.1, Appendix iv). Soil of this floodplains show that pedality development has not taken place. Soils are massive and compact. Continuity of apedal soil mass is broken by various vesicles and channels. Microstructures observed are compact grain and bridged grain type.

C/F ratio ranges from 80/20 to 60/40. Coarser fraction is usually moderately sorted and mostly it consists of 100-150 μm sized grains of fresh, unaltered quartz, micas and feldspars and other minerals in small amounts.

Fine fraction is mostly silty in nature. It generally occurs as groundmass. Plasma separation is moderate to strong, as parallel striated b-fabric is noted (Fig. 4.10). C/F related distribution is monic and gefuric (Fig. 4.11).

Calcareous impregnation pedofeatures include sparitic hypocoating along rounded voids (Fig. 4.12) and coarsely crystalline

calcite in a ferruginous bow shaped fabric feature. Also at places crystic plasmic b-fabric is seen. The calcrete feature belong to the type III category.

4.2.5 Micromorphological Characters in Upper Kosi-Gola Plain

Eight soil thin-sections (Table 4.1, Appendix IV) from this soil-geomorphic unit have been described under microscope in detail. The soils characteristically show weak to moderately developed subangular blocky peds (Fig. 4.13, 4.14). The size of the peds range from 0.5 mm to 1 cm. The peds usually are not very well separable and are bound by irregular shaped voids. Voids are mainly channels, vughs and vesicles, producing channel and vughy and microstructure. C/F ratio varies from 70/30 to 40/60. The coarse fraction (200 - 300µm) is moderately sorted (Fig. 4.15, 4.16) and it consists of quartz, mica and felspars and other minerals. They are usually fresh, sometimes weakly altered. C/F related distribution is mainly gefuric and chitonic in C horizon and enulic to porphyric related distribution (Fig. 4.17) in soils of B2 horizon.

Finer fraction is distributed as groundmass and thin coatings. It consists of micaceous fine silt and clay and sometimes it becomes ferruginous and calcareous. Plasma separation is moderate to strong. Strongly developed reticulate striated b-fabric (Fig. 4.18, 4.19) is commonly observed. Other b-fabrics commonly observed include moderately developed cross-striated, parallel striated and speckled types.

Translocation of clay has taken place in these soils. A few

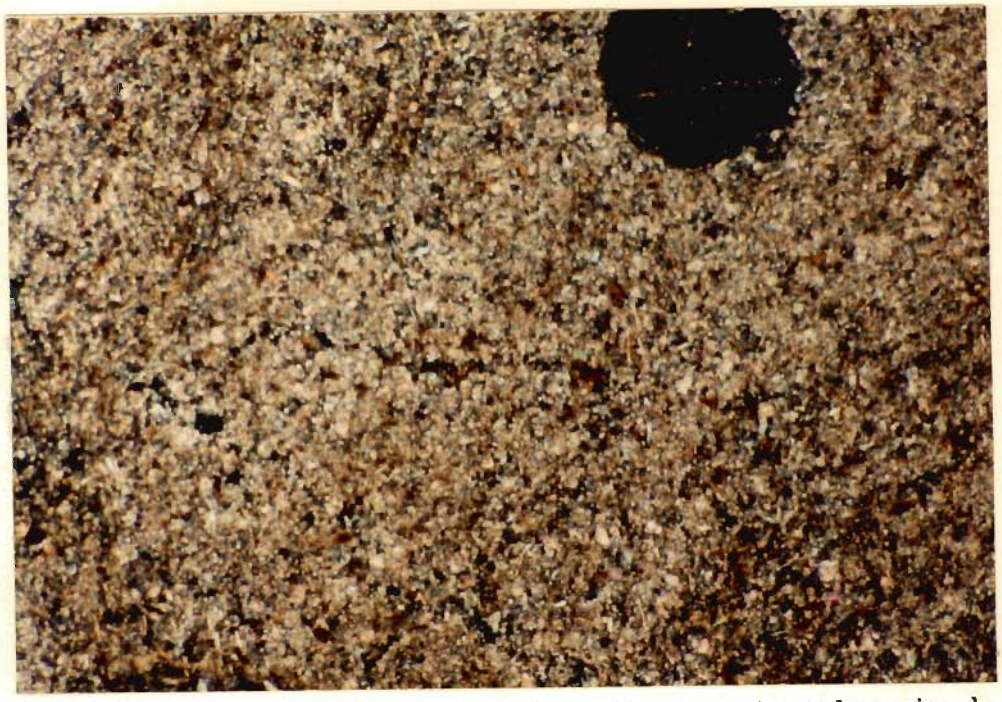

Fig. 4.7 Strongly developed crystic plasmic b-fabric. Pedon PC16, C Horizon, Gholia Dhobania Bhambhar Piedmont, frame length 1.4 mm, XPL.

Fig. 4.8 Loose complete infilling of a large channel void by fine sand silt, Pedon PB10, C horizon, Ghaghra Floodplain, Frame length 1.4 mm, XPL.

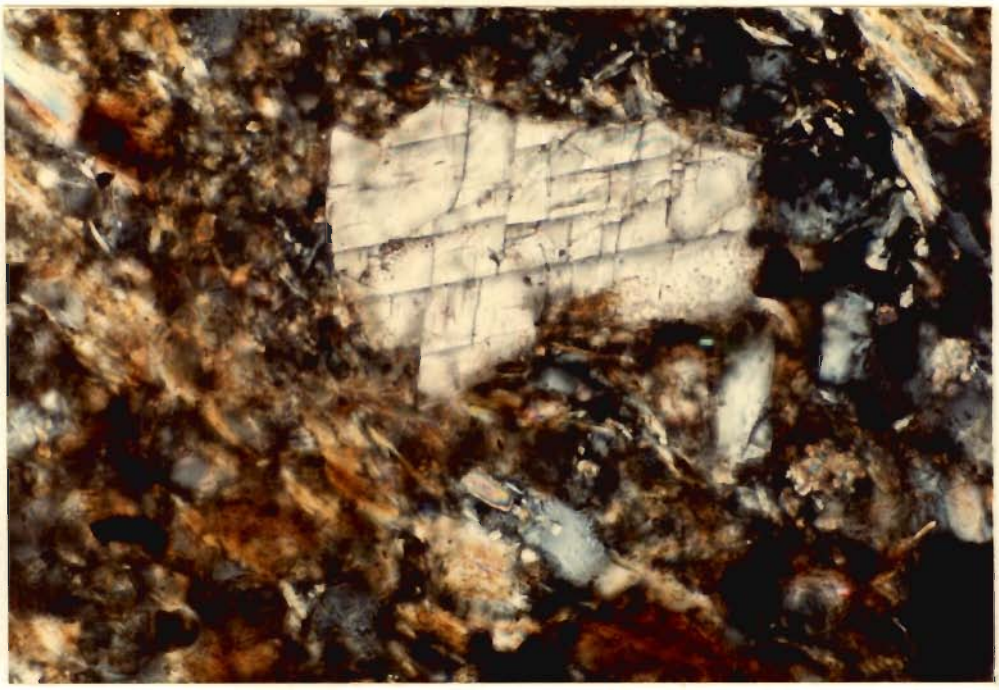

Fig. 4.9 Coarsely crystalline calcite with sharp boundaries. The calcite grain is forcing apart the adjacent ground mass. Type III calcrete,Pedon PB10, C horizon, Ghaghra Floodplain, Frame length 0.3 mm, XPL.

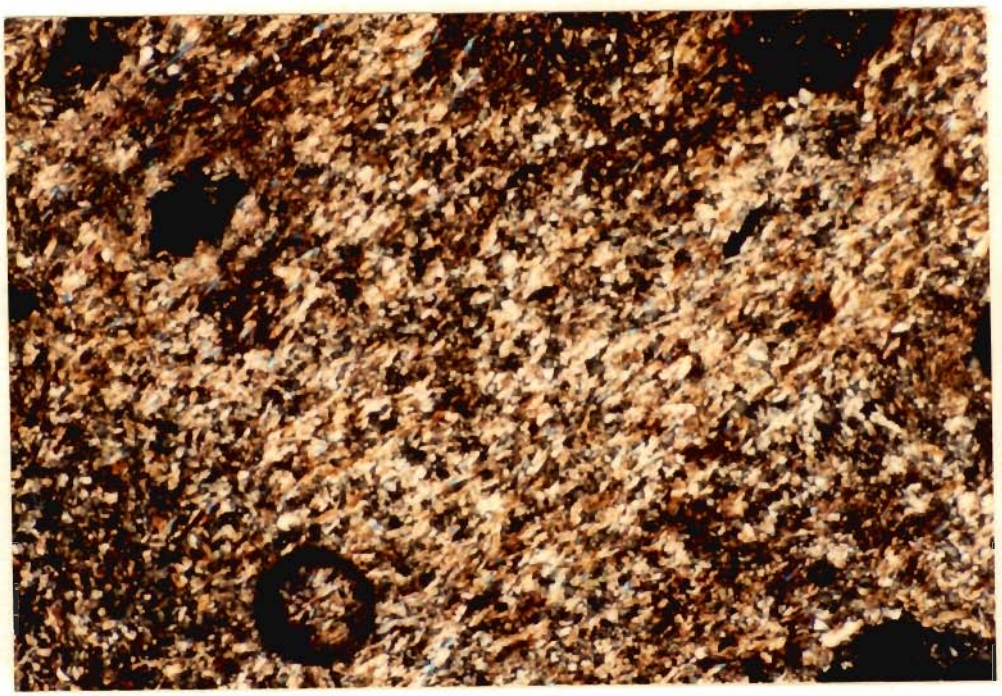

Fig. 4.10 Strongly oriented parllel striated b-fabric. Pedon PB14, C horizon, Rapti Floodplain, Frame length 1.4 mm, XPL.

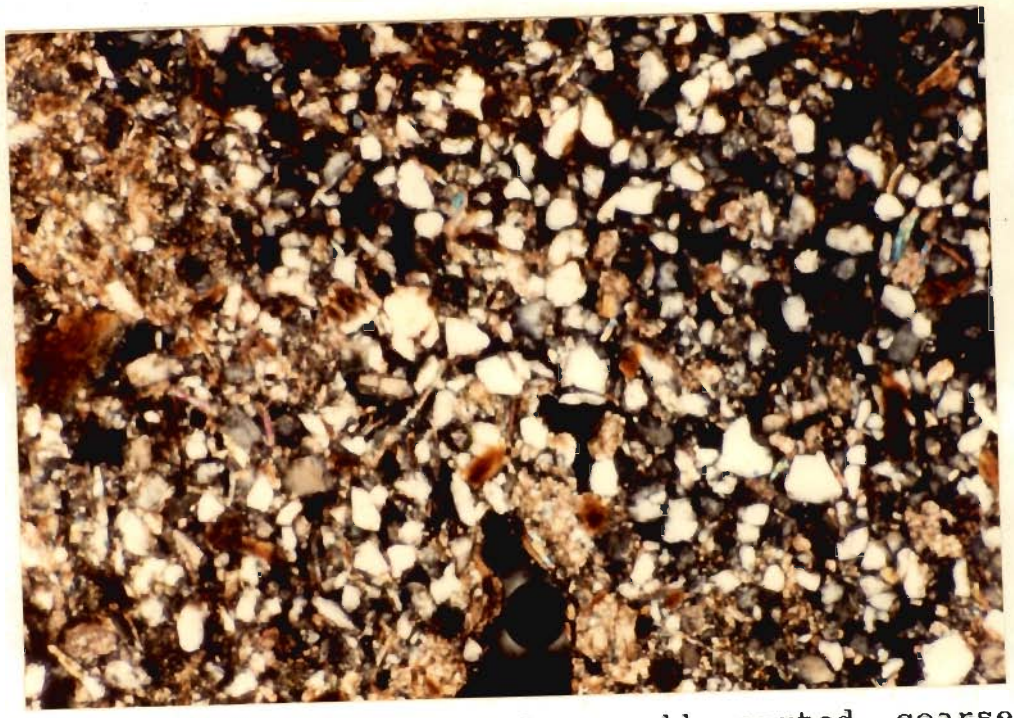

Fig. 4.11 Moderately well sorted coarse fraction showing monic and gefuric related distribution. Pedon B14, C horizon Rapti Floodplain, Frame length 1.4 mm, XPL.

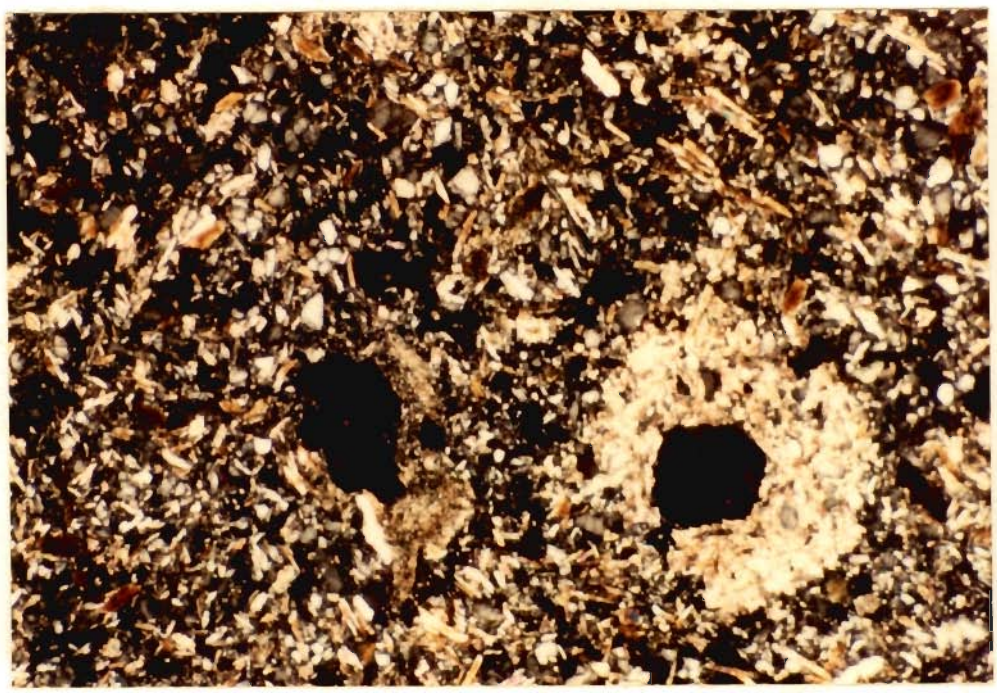

Fig. 4.12 Hypocoatings along rounded voids by sparitic calcit-e, Pedon PB14, C horizon Rapti Floodplain, Frame length 1.4 mm, , XPL.

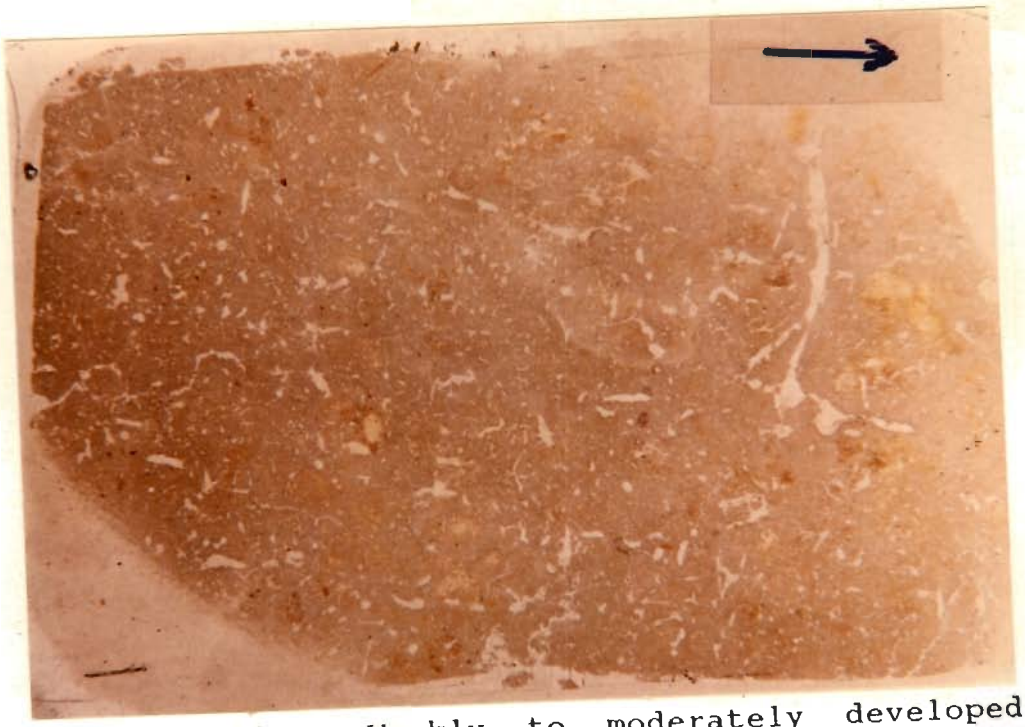

Fig. 4.13 Weakly to moderately developed subangular blocky soil structure. Calcrete nodules up to 0.5 cm. are also seen. Pedon PA5, B horizon, Marker 1 cm., ordinary light.

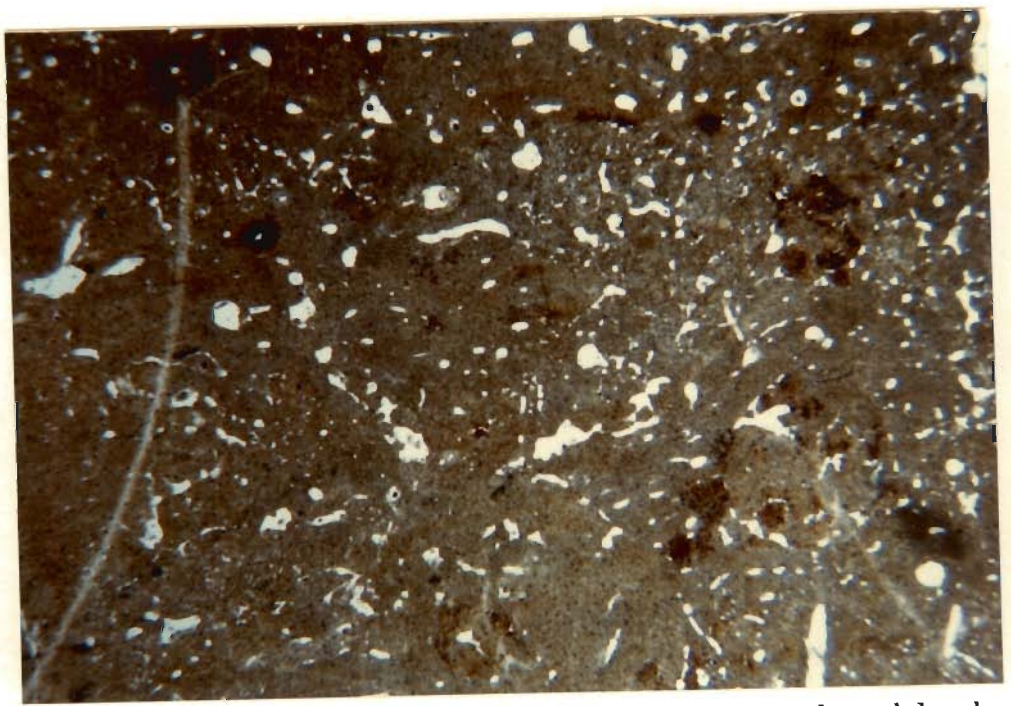

Fig. 4.14 Moderately developed subangular blocky structure, peds are partially separable, many elongated arched smooth walled channels producing channel microstructure. Pedon, PA6, B1 horizon, Upper Kosi-Gola Plain, Frame length 20 mm, PPL.

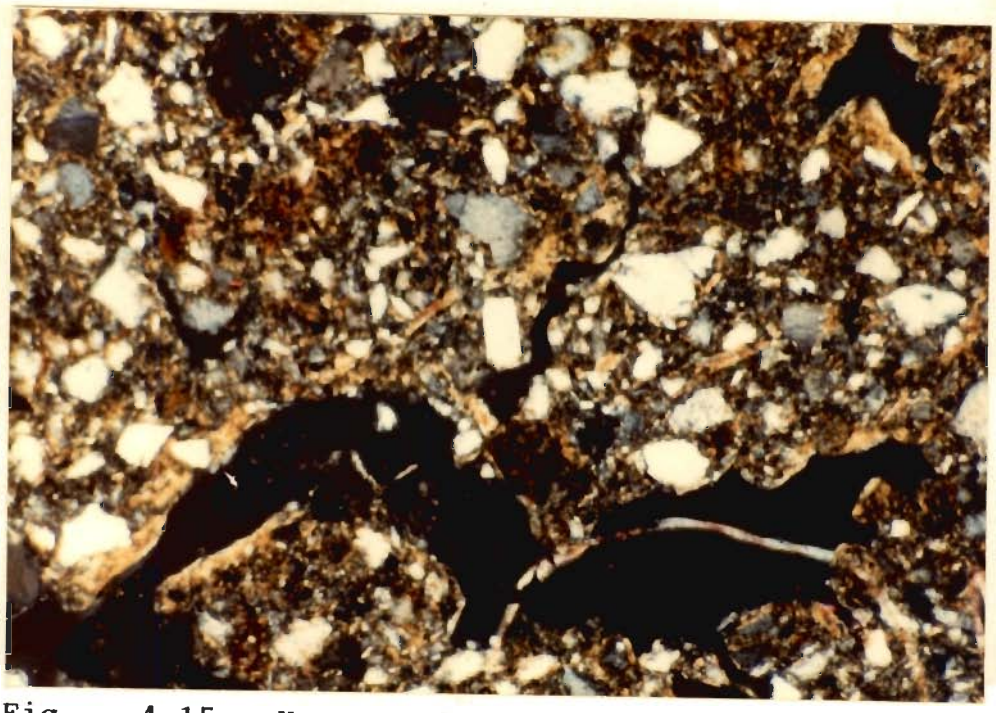

Fig. 4.15 Hypocoat-ings (30-40 µm) by speckled to limpid clays. Coarse fraction is weakly altered, Pedon PA0, B2 horizon, Upper Kosi-Gola Plain, Frame length 1.4 mm, XPL

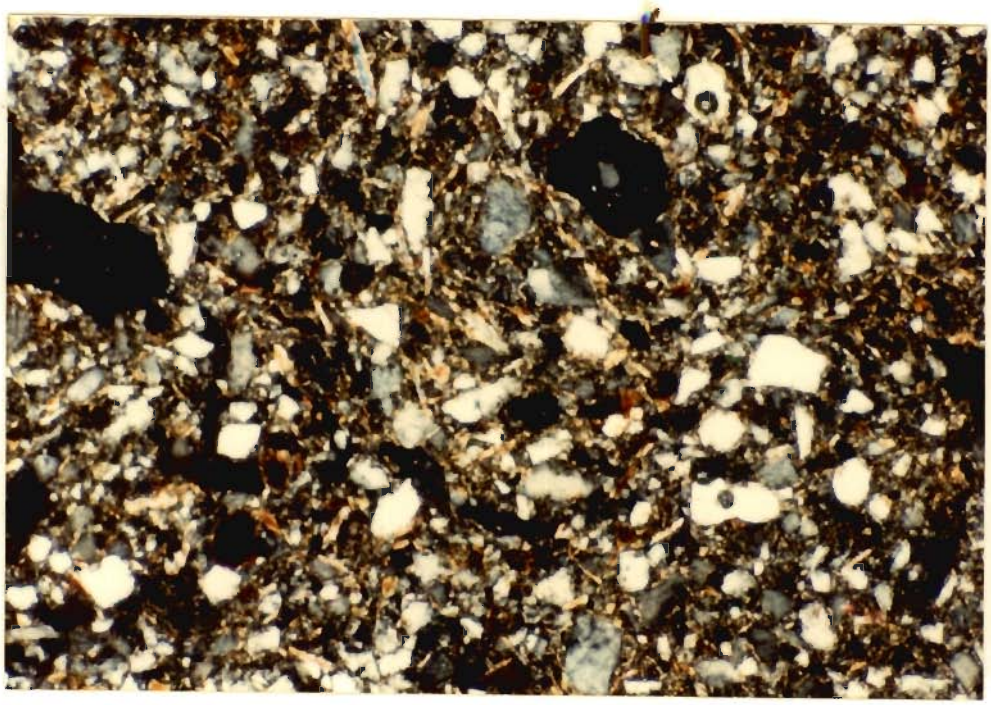

Fig. 4.16 Moderately sorted coarse fraction partially coated with finer silty matter, showing chitonic C/F related distribution and pellicular grain microstructure, Pedon PA0, C horizon, Upper Kosi-Gola Plain, Frame length 1.4 mm, XPL.

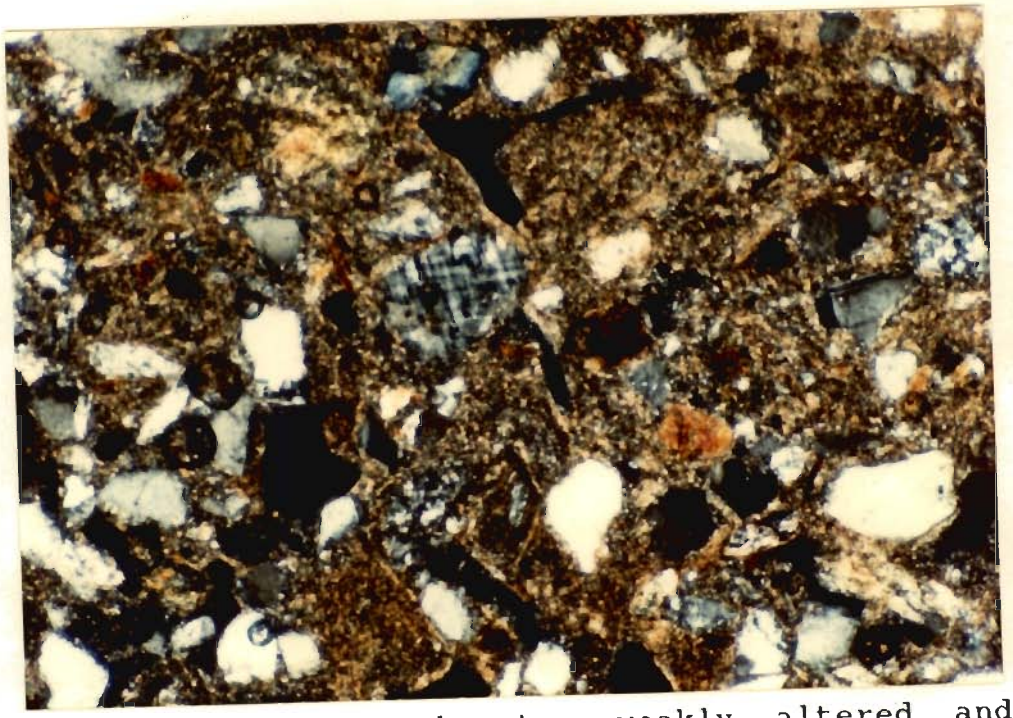

Fig. 4.17 Fresh to weakly altered and moderately sorted grains showing close spaced porphyric related distribution. Pedon PA6, B1 horizon, Upper Kosi-Gola Plain, Frame length 1.4 mm., XPL.

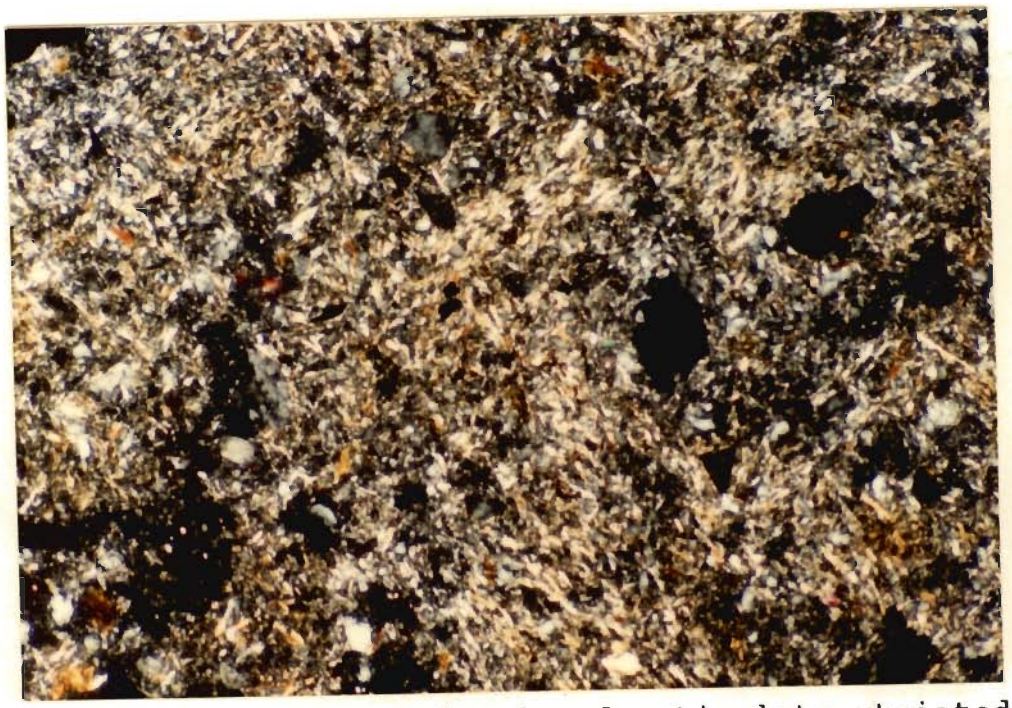

Fig. 4.18 Strongly developed reticulate striated b-fabric due preferred ori-entation of finer particles at right angles Pedon PA5, B2 horizon, Upper Kosi-Gola Plain, Frame lenth 1.4 mm, XPL>

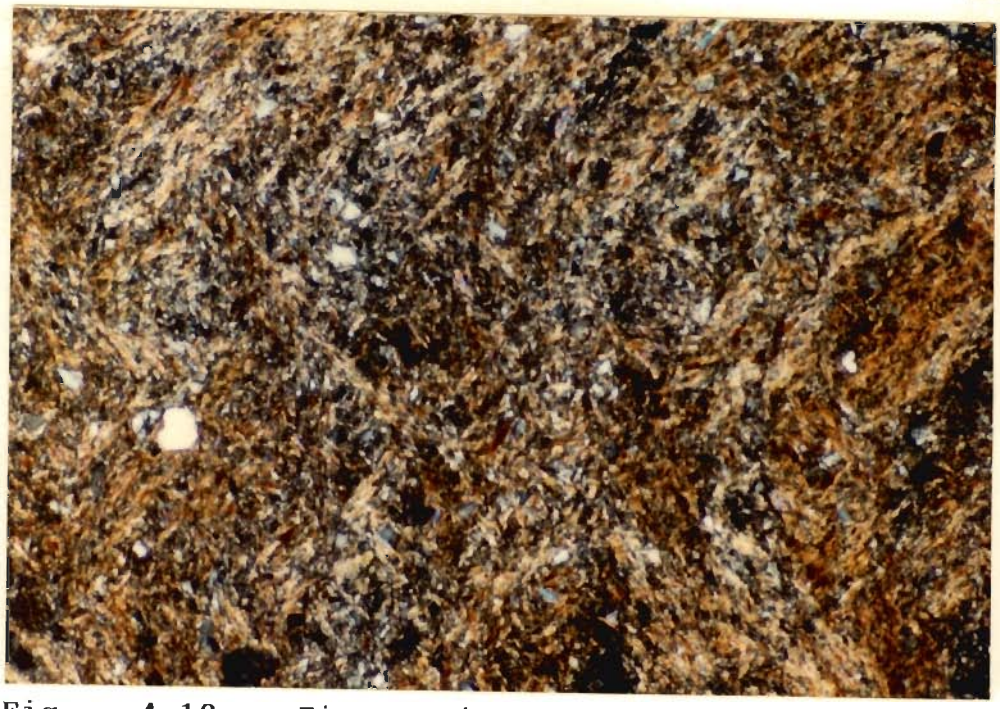

Fig. 4.19 Finer micaceous clay material is strongly oriented at right angles, showing strongly developed reticulate striated b-fabric. Pedon PA5, C horizon, Upper Kosi-Gola Plain, Frame length 1.4 mm, XPL

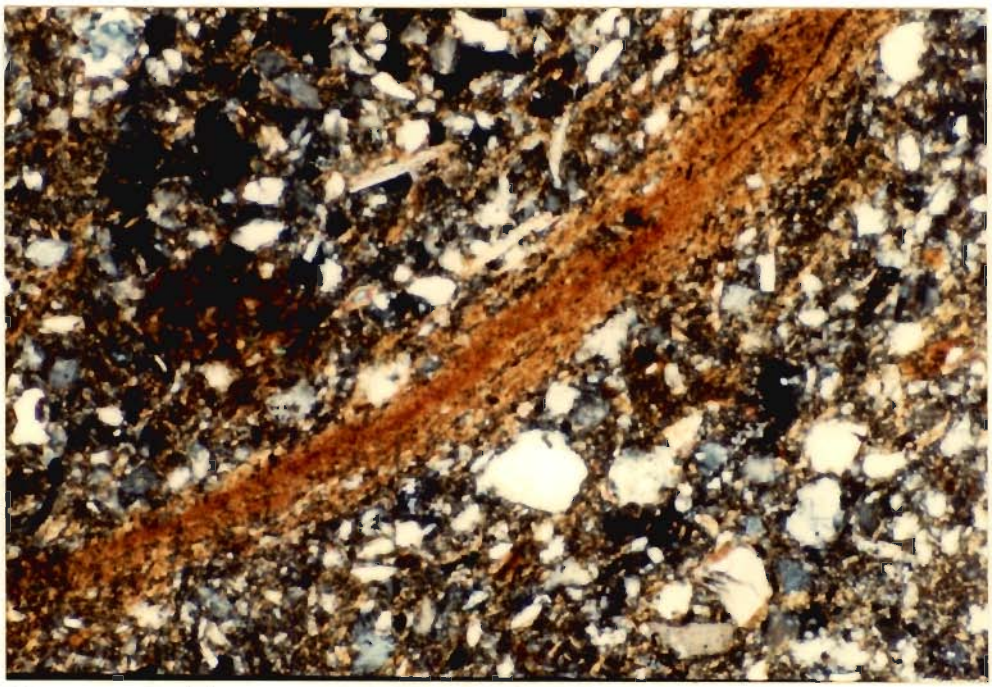

Fig. 4.20 Ferruginous micropan in moderately sorted coarse grains, diffused ferruginous mott-les are also seen. Pedon PA0, B2 horizon, Upper Kosi-Gola Plain, Frame length 1.4 mm., XPL.

argillans in form of thin (30-40 μm) hypocoatings along voids (Fig. 4.15) are observed. These coatings are not microlaminated. Micropans of ferruginous impure clays (<2000 μm in length and <200 μm wide) (Fig. 4.20) occur as discrete pedofeatures.

Calcareous pedofeatures are common in these profiles. They occur in form of spar tic hypocoating and micritic to spar tic nodules. These nodules show calcification and decalcification features along the voids and formation of prismatic calcite in dense calcareous groundmass (Fig. 4.21) is noted. Occasionally fine calcareous groundmass shows crystic plasmic fabric (Fig. 4.22). these are considered to be type III calcretes.

Strong animal activity has been observed. Large isotubles with reworked soils are present.

4.2.6 Micromorphological characters of Old Ghaghra Plain

Three thin-sections from B2 horizon and two from C horizon have been studied in detail (Table 4.1, Appendix IV). The soils in B2 horizon show weakly to moderately developed subangular blocky peds (Fig. 4.23). Voids are mainly channels and are rarely interconnected as packing voids along peds. Intergrain channel and massive structure are commonly observed. The C/F ratio varies from 60/40 to 40/60. The coarse (mostly 200-300 μm) fraction consists of fresh to weakly altered quartz, micas and feldspars and other minerals in small amount. The finer fraction consisting of fine silt and clays commonly shows weakly to moderately developed cross striated b-fabric and moderately to strongly developed poro- and parallel striated b-fabrics are rarely

observed at places (Fig. 4.24, 4.25, 4.26). Other major pedofeatures occuring include thin (30-40 μm) hypocoatings of fine silt and clay along voids. Diffused mottles of sesquioxide (Fig. 4.27) and strong animal activity in form of isotubles.

In C horizon the soils show compact grain and intergrain channel soil structure (Fig. 4.28). Surface of the channel voids is generally very rough. C/F limit varies from 30/70 to 40/60. Coarse as well as finer fraction are unaltered (Fig. 4.29).

4.2.7 Micromorphological Characters of Old Sihali-Mohan-Kandra Piedmont

Soil thin-sections from this unit show apedal to weakly developed sub-angular blocky soil (Fig. 4.30). Voids have rough to smooth surface and show thin (30 - 40 μm) hypocoatings (Fig. 4.31). C/F fraction limit is 40/60 in upper horizons and 60/40 in lower horizons. Coarse fraction mainly consists of fine sand size particles of quartz, mica and feldspar and other minerals in minor amounts. Fine fraction is micaceous, ferruginous and calcareous in nature. Cross and parallel striated b-fabrics are commonly observed (Fig. 4.32). In lower horizons soils are highly calcareous and show typic, orthic strongly impregnated nodules of micritic and sparite. These are classified as type III calcretes.

4.2.8 Micromorphological characters in Lower Kosi-Gola Plain

Four characteristic thinsections representing the soil geomorphic unit have been described in detail. Most of the soil shows moderately to strongly developed subangular blocky structure, (Fig. 4.33, 4.34). The peds are partially

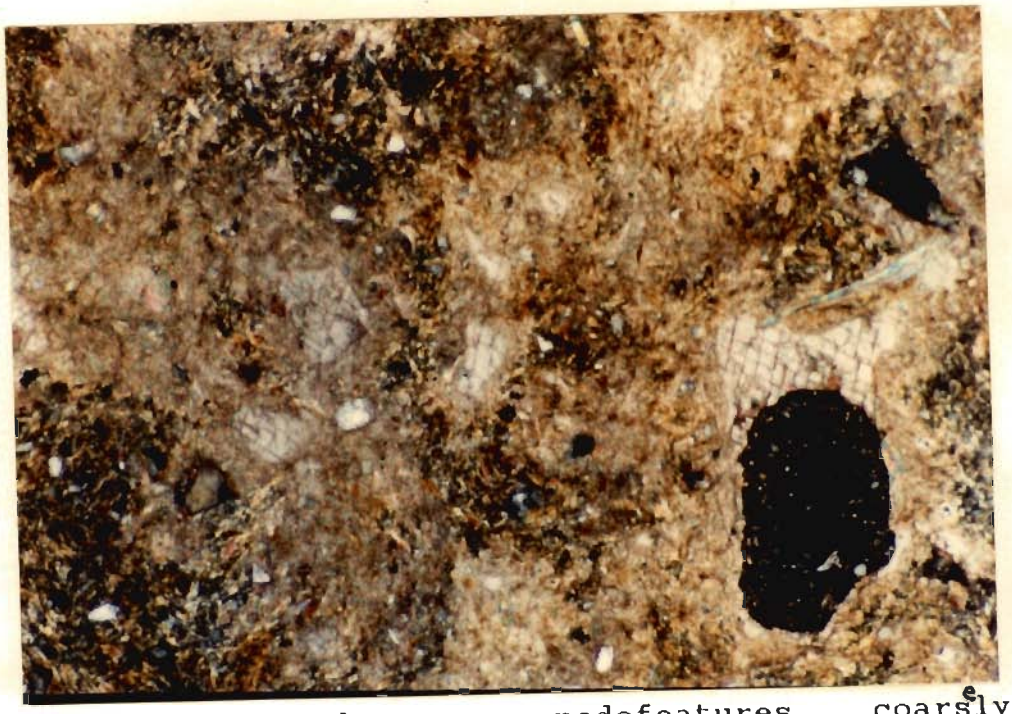

Fig 4.21 Calcareous pedofeatures, coarsely crystalline pure spartic calcites and strongly developed crystic plasmic b fabric. Type III calcrete, Pedon PA5, C horizon, Upper Kosi-Gola Plain, Frame length 1.4 mm, XPL.

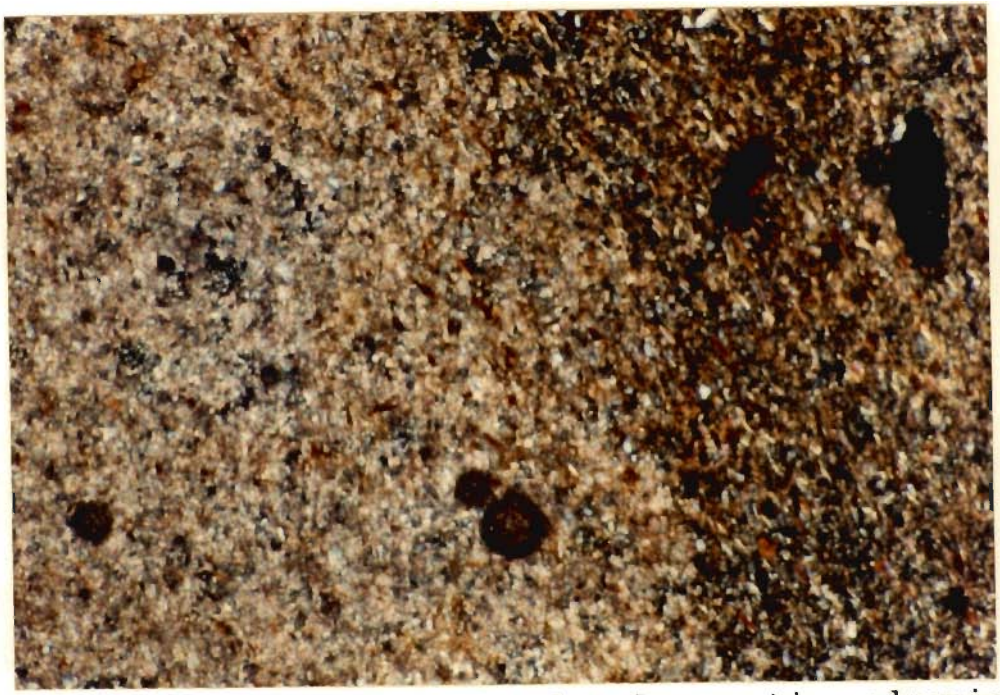

Fig. 4.22 Strongly developed crystic plasmic fabric and monostriated b-fabric. Pedon A15, C horizon, Old Sihali-Mohan-Kandra Piedmont, Frame length 1.4 mm, XPL.

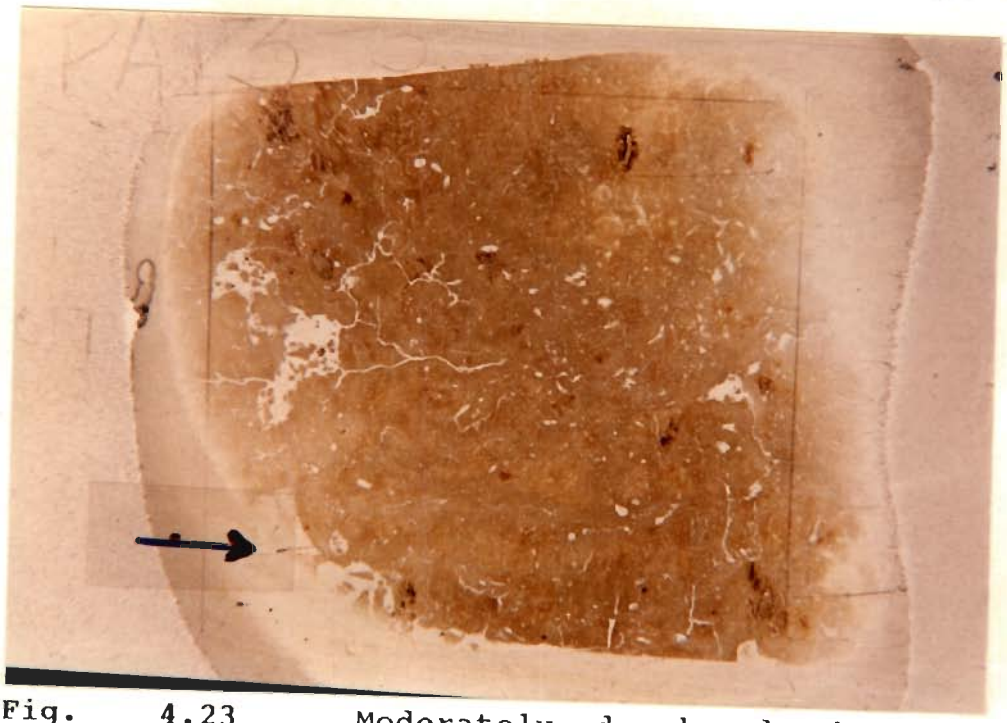

Fig. 4.23 Moderately developed subangular blocky soil structure. The peds range in size from 2 mm. to 1 cm., B2 horizon, Pedon PA 15, Upper Kosi-Gola Plain, marker 1 cm., Ordinary Light.

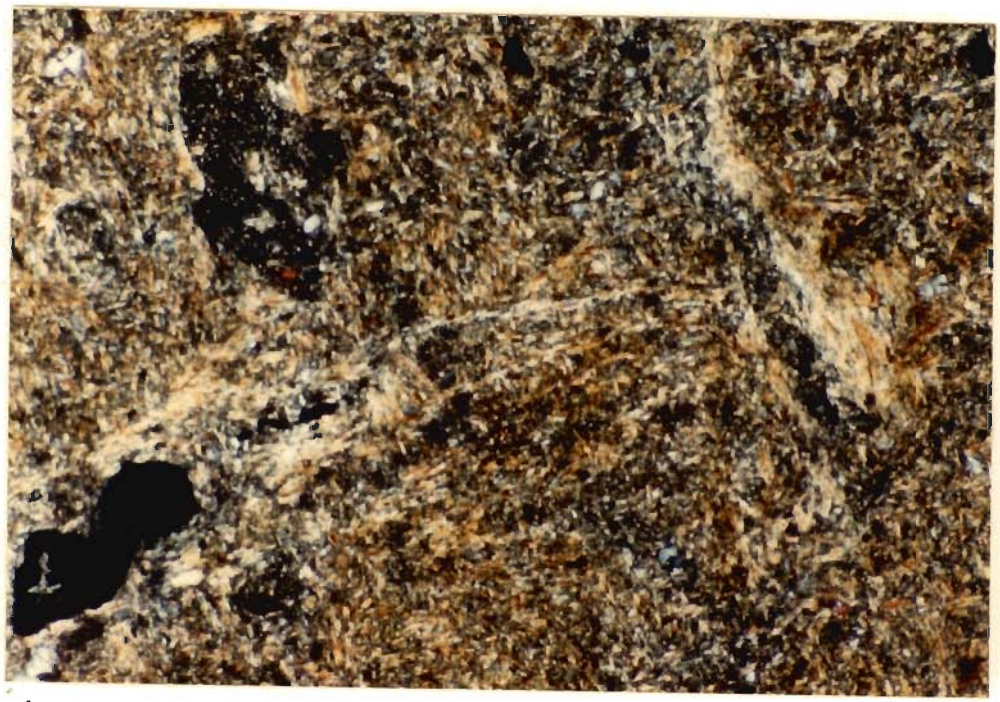

Fig. 4.24 Strongly developed porostriated and reticulate striated b-fabric. Pedon PA13, B1 horizon, Old Ghaghra Plain, frame length 1.4 mm, XPL.

Fig. 4.25 Moderately developed, parallel striated b-fabric. Pedon PC10, C horizon, Old Ghaghra Plain, Frame length 1.4 mm, XPL.

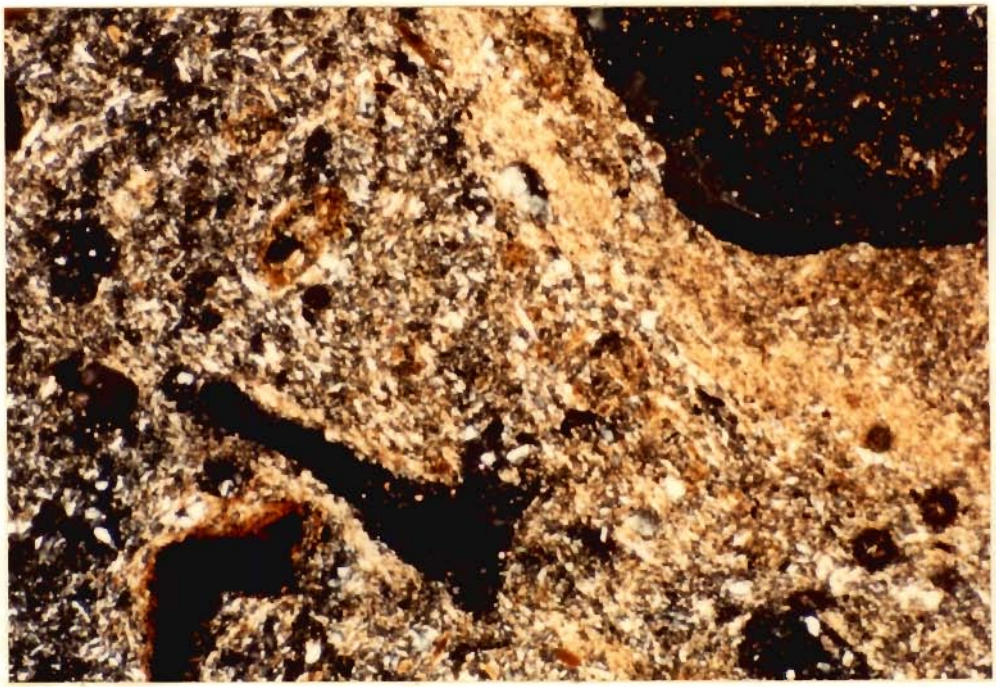

Fig. 4.26 Strongly oriented poro-striated b-fabric also hypocoating of ferruginous matter along void, Pedon PC10, C horizon, Old Ghaghra Plain, Frame length 1.4 mm, XPL.

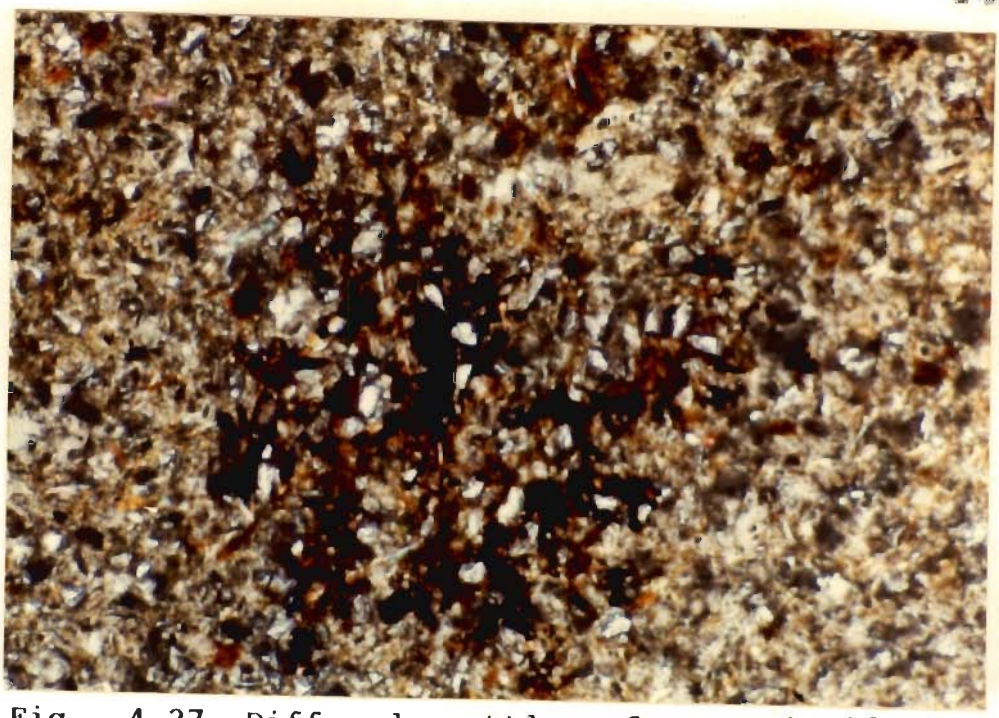

Fig. 4.27 Diffused mottle of sesquioxide in a calcareous groundmass. Pedon PA13, B1 horizon, Old Ghaghra Plain, frame length, 1.4 mm, XPL.

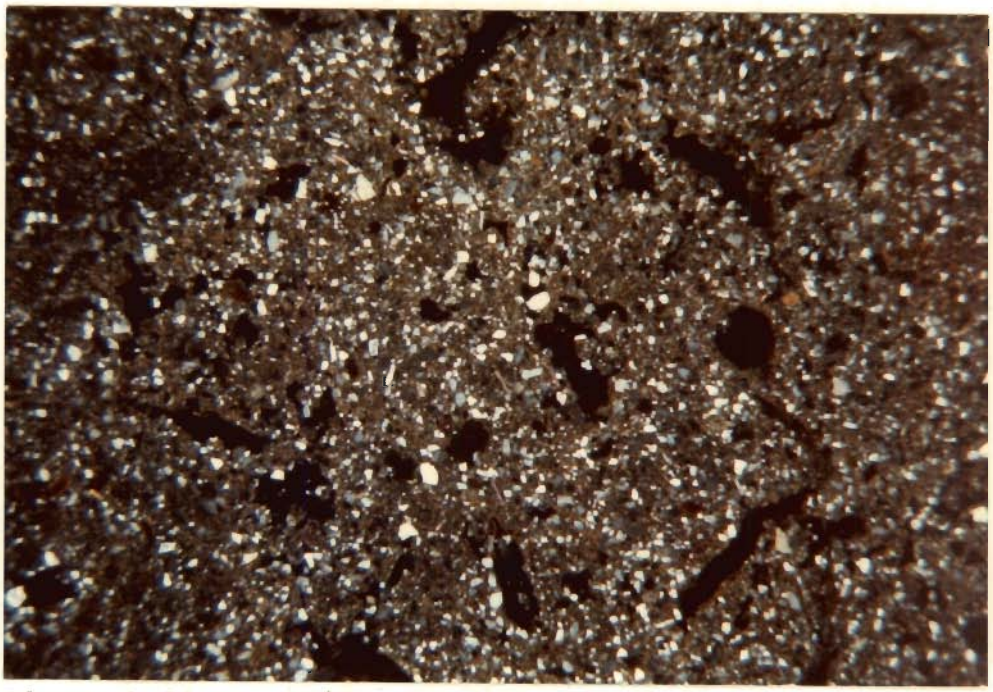

Fig. 4.28 Apedal coarse textured soil showing compact grain and intergrain channel microstructure, Old Ghaghra Plain, Pedon PC10, C horizon, Frame length 20 mm, XPL.

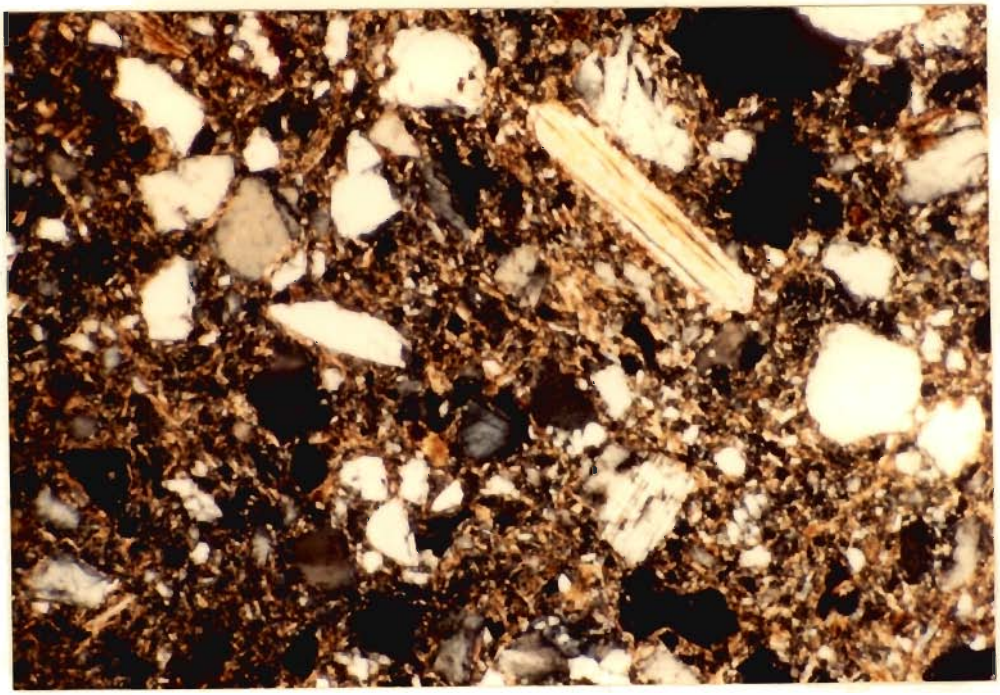

Fig. 4.29 Fresh to weakly altered coarse fraction is showing porphyric related distribution, Old Ghaghra Plain, Frame length 1.4 mm Pedon PC10, C horizon, XPL.

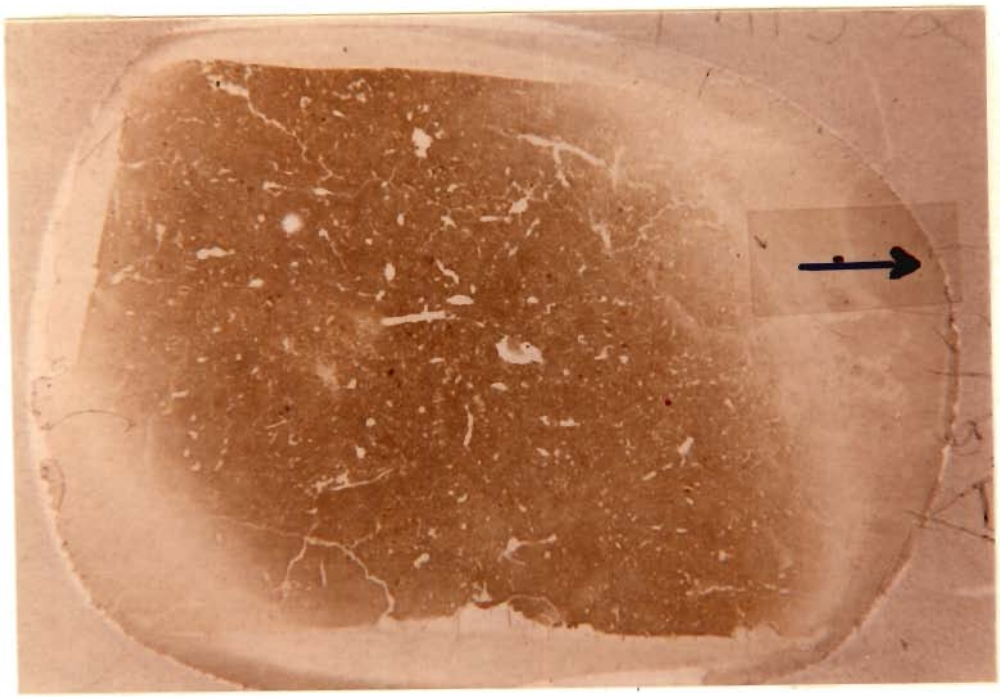

Fig. 4.30 Weakly developed subangular blocky soil structure Pedon PA 15, B2 horizon, Old Sihali-Mohan-Kandra Piedmont, marker 1cm., ordi nary light.

Fig 4.31 Strongly developed parallel striated b-fabric, Pedon PA15, B1 horizon, Old Sihali-Mohan-Kandra Piedmont, frame length 1.4 mm, XPL.

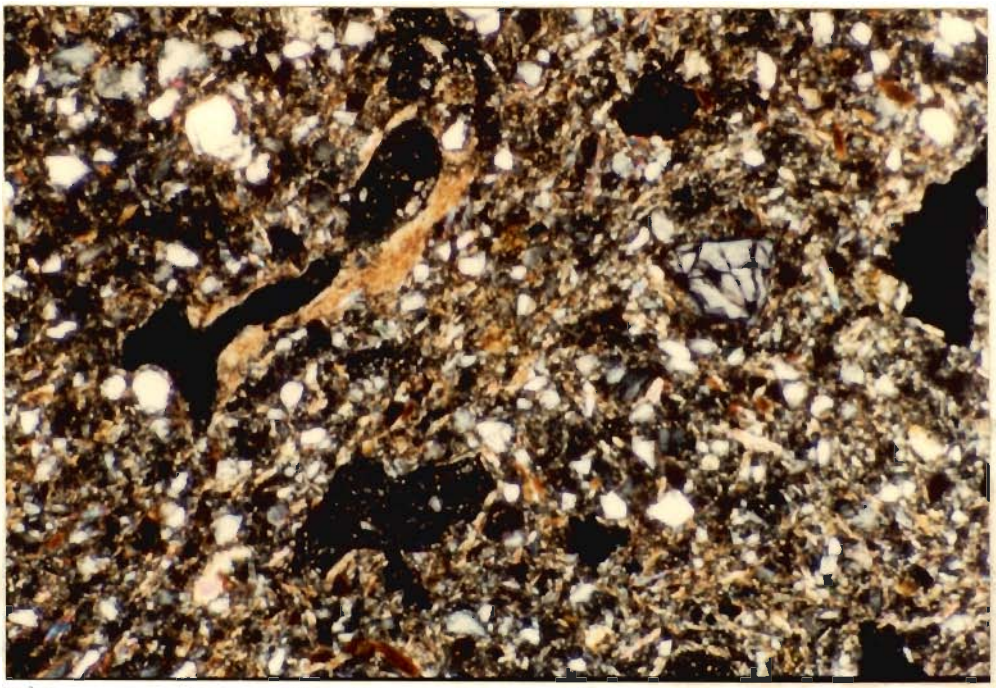

Fig. 4.32 30-40 µm thick hypocoating by limpid clay along a channel void. Pedon PA15, B1 horizon, Old Sihali-Mohan-Kandra Piedmont, frame length 1.4 mm, XPL.

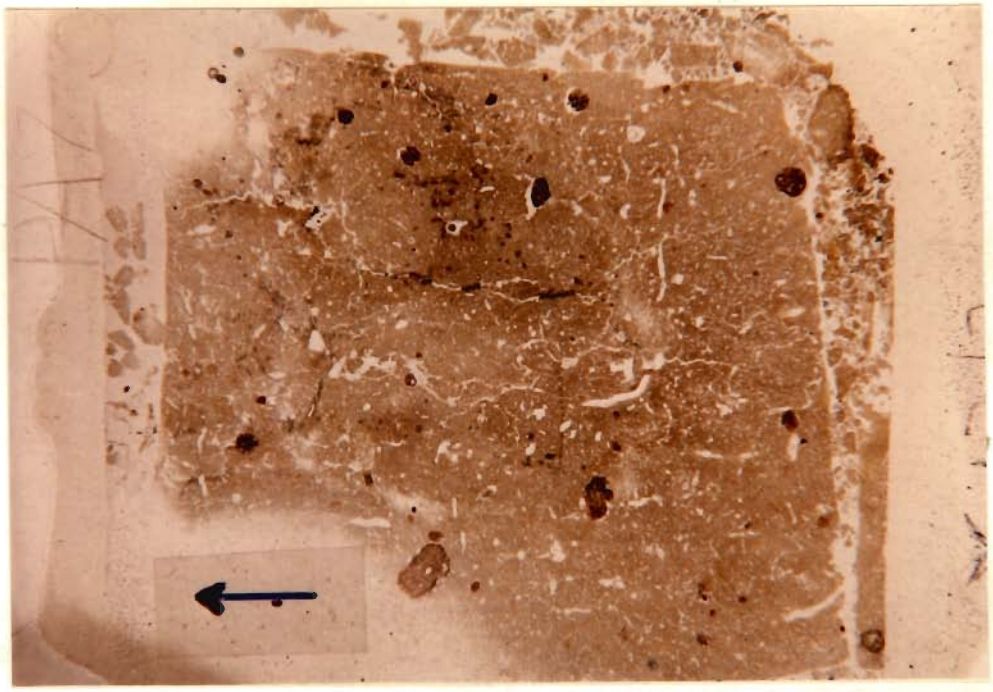

Fig. 4.33 Moderately to strongly developed subangular blocky soil structure. Pedon PA 7, Lower Kosi-Gola Plain, marker 1 cm., ordi-nary light.

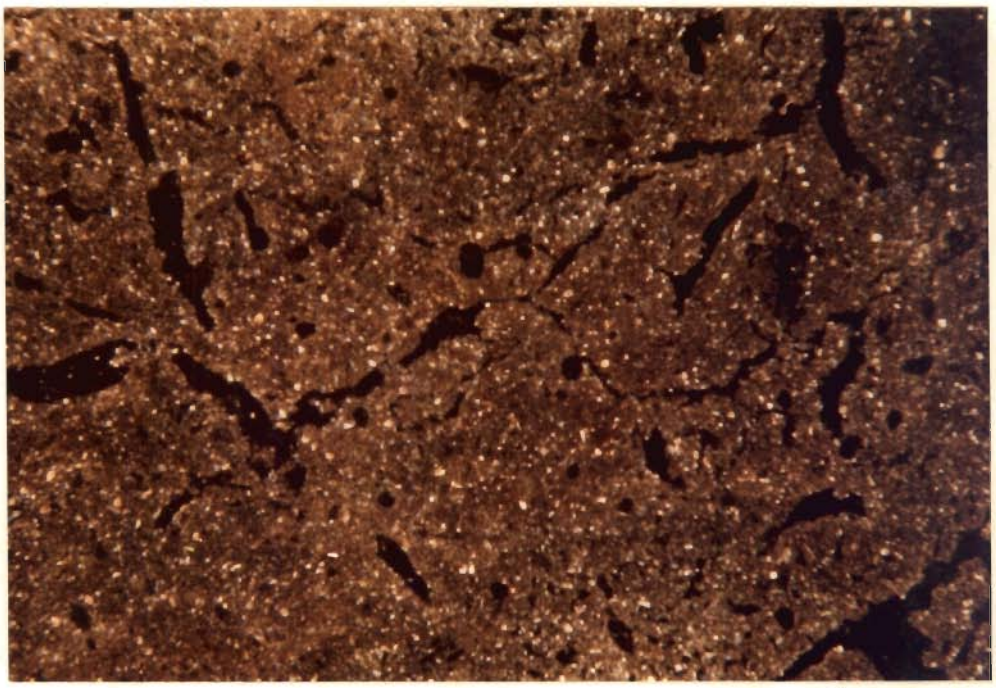

Fig. 4.34 Moderately to strongly developed subangular blocky structure, ped walls are well separable and accommodating. Lower Kosi-Gola Plain, Pedon PB2, B2 horizon, XPL.

accommodating and are bound by smooth to irregular surfaced voids. Voids are mainly compound packing voids, and channels, vughs and vesicles are also seen. Vughy and channel microstructures are also observed.

C/F ratio is generally 40/60. Coarse fraction is moderately sorted consists of medium sized sands (150-200 µm). It generally consists of quartz, micas and a few felspars with other minerals in minor amount. C/F related distribution is usually porphyric (both close and open). At places chitonic and enulic distributions are also seen.

Clay translocation pedofeatures are common in these soils. Thick (60-70 µm) micro laminated limpid to speckled clay coatings are observed (Fig. 4.35, 4.36, 4.37, 4.38). Plasma separation is moderate to strong. Moderately to strongly developed cross-striated b-fabric commonly occurs and also grano- and poro-striated b-fabrics have been noticed. In C horizon strongly developed parallel striated b-fabric has been observed (Fig. 4.39).

Calcareous pedofeatures are not very prominent feature in these soils. Only in one thin-section from C horizon, various calcareous pedofeatures recognised are thick sparitic, semirounded, strongly impregnated nodules. These are impure and are mixed with soils and ferruginous matter. Dissolution and precipitation of calcite (Fig. 4.40) along voids of the nodules is also observed. These calcretes are considered to be of type III category. Strongly impregnated, semirounded Fe-Mn

concretions, with sharp, and prominent boundaries (Fig. 4.41) are observed.

4.2.9 Micromorphological Characters of Upper Deoha/Ganga - Ghaghra Interfluve

Two representative thin-sections (Table 4.2, Appendix iv) from this soil-geomorphic unit have been studied in detail. The soils under microscope show pedality to be moderately to strongly developed with partially separable accommodating peds (Fig. 4.42, 4.43). Voids are mainly channels, vughs and a few vesicles. The void pattern produce vughy microstructure (Fig. 4.44). The voids have typically smooth internal surface. C/F ratio generally is 30/70. Coarse fraction is moderately sorted, medium sized sand (150-200 μm) widely distributed in fine silt clay sized fine fraction and showing porphyric related distribution.

Clay translocation pedofeatures are common feature of these soils, as thin (50-60 μm) coatings by impure silty clay along voids, ped faces and voids (Fig. 4.46) occur.

Fine fraction usually consists of micaceous fine silt and clays. It is densely distributed as groundmass. Plasma separation is strong, as cross-striated b-fabric (Fig. 4.45) is widely developed and porostriated b-fabric has been observed at places. Calcareous pedofeatures are restricted to B3 horizon and in C horizons. Main pedofeatures associated with calcareous impregnation include impure sparitic nodules which are associated with voids. They show dissolution along the voids within the

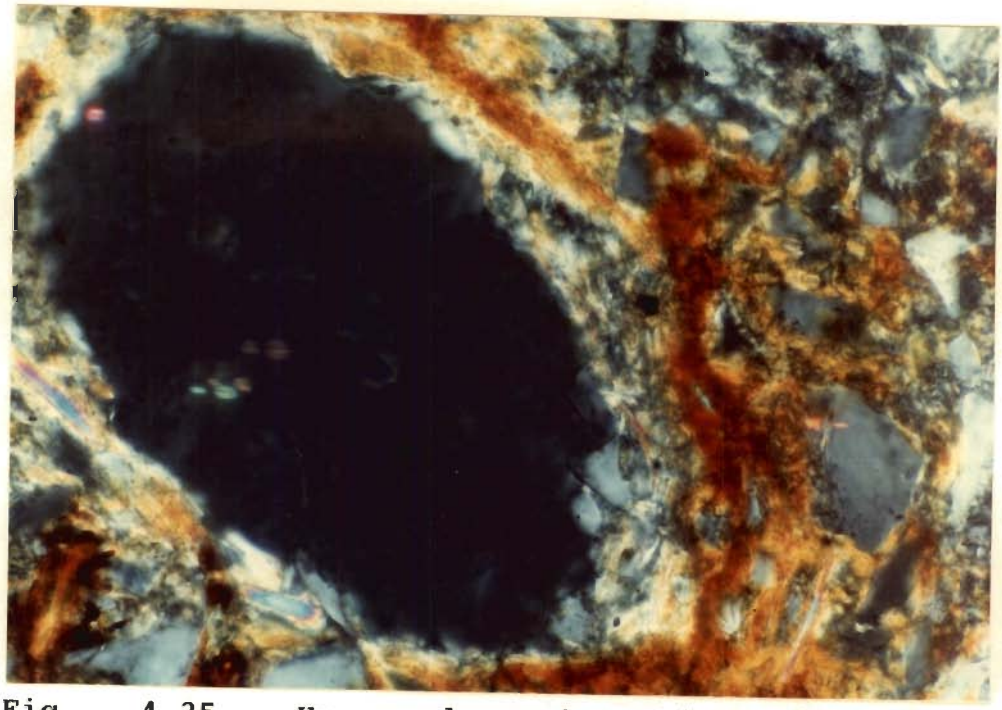

Fig. 4.35 Hypo and quasi coatings along voids by ferruginous clay . Pedon PA7, B2 Horizon, Lower Kosi-Gola Plain, Frame length 0.3 mm., XPL

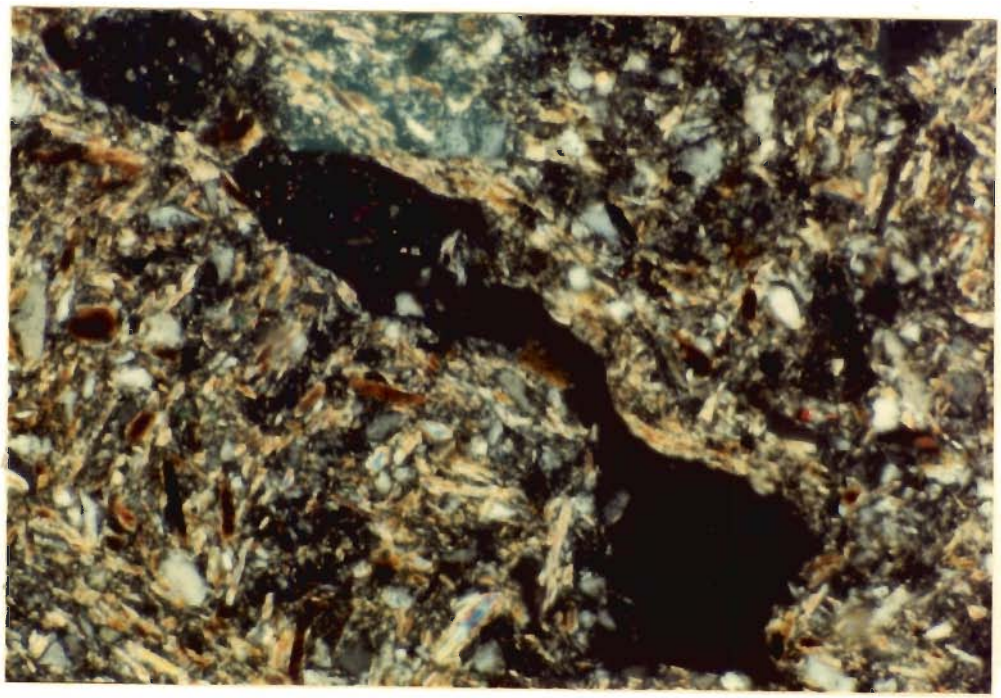

Fig. 4.36 Silty clay hypocoatings along a channel void, Pedon PA 7, B2 horizon, Lower Kosi-Gola Plain, Frame length 1.3 mm., XPL.

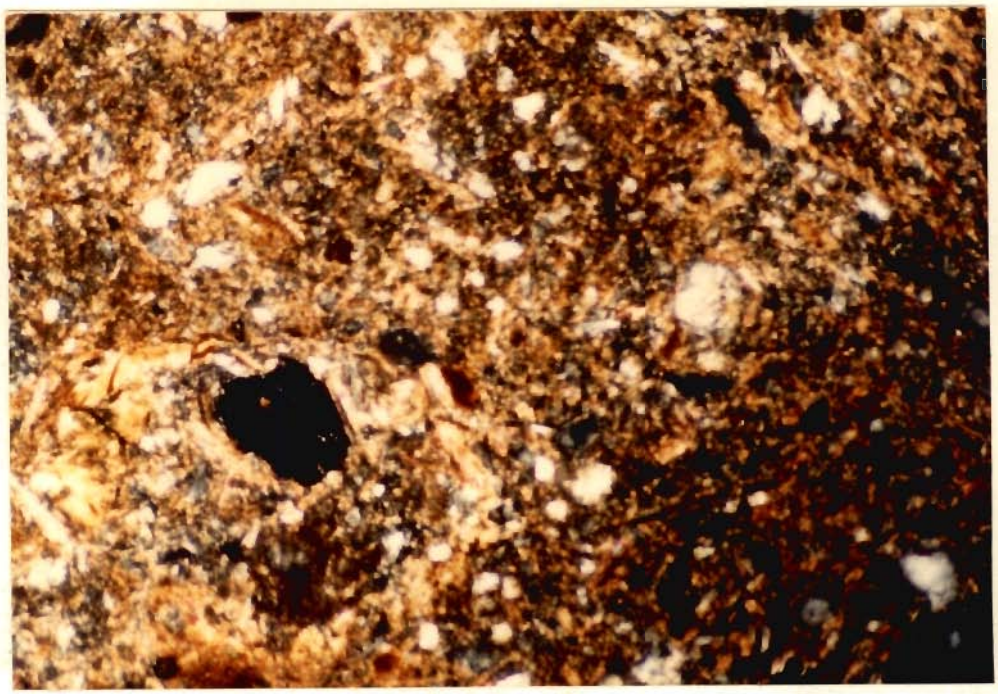

Fig. 4.37 Thick (50-60 µm) limpid clay hypocoating along void, Lower Kosi-Gola Plain. Pedon PB2, B2 horizon, Frame length 1.4 mm, XPL.

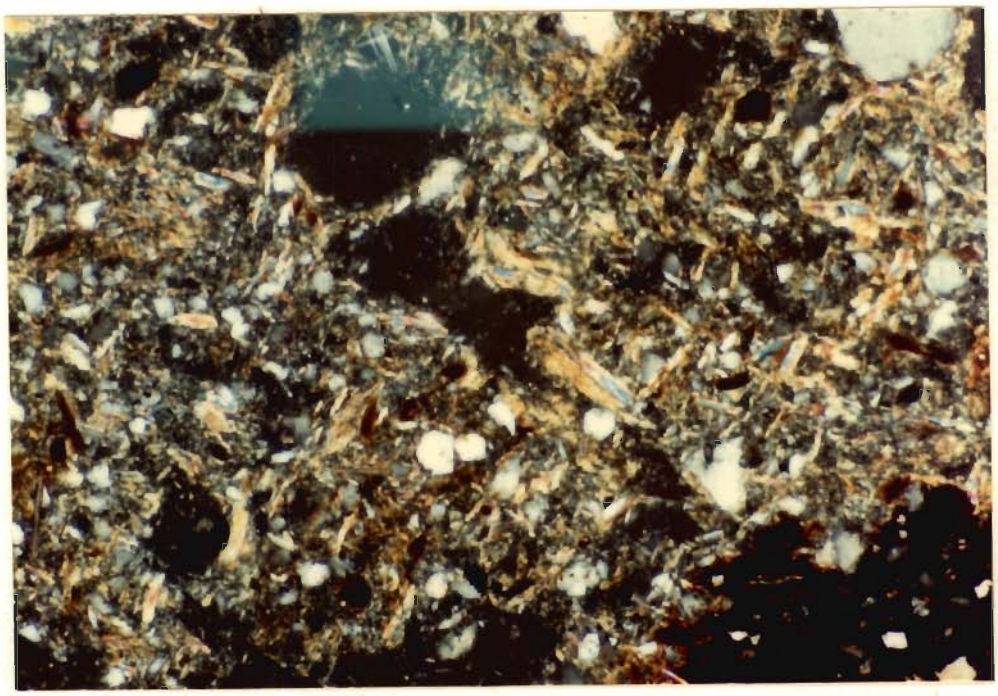

Fig. 4.38 30-50 µm thick impure clay coatings along voids, strongly impregnated sesquioxide nodule and cross striated b-fabric. Pedon PB2, Lower Kosi-Gola Plain, Frame length, 1.4 mm., XPL.

Fig. 4.39 Strongly oriented parallel striated b-fabric in C horizon of the Lower Kosi-Gola Plain, Pedon PA7, XPL, Frame length 1.4 mm.

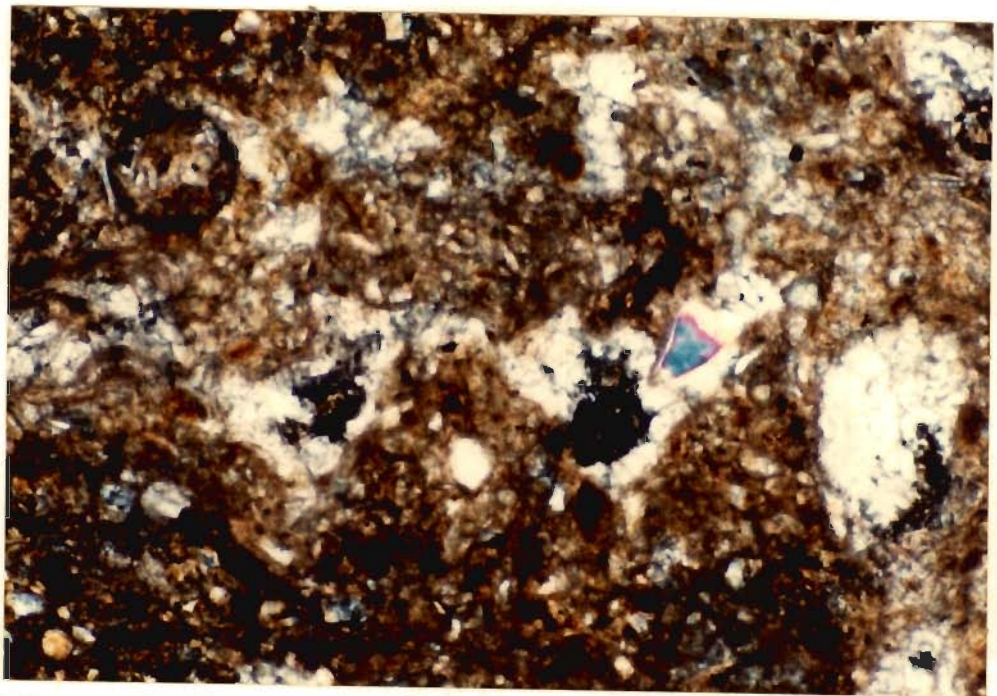

Fig. 4.40 Calcification and decalcification along voids in large impure calcareous nodule, Lower Kosi Gola Plain. Pedon PA7, C horizon, Frame length 1.4 mm, XPL.

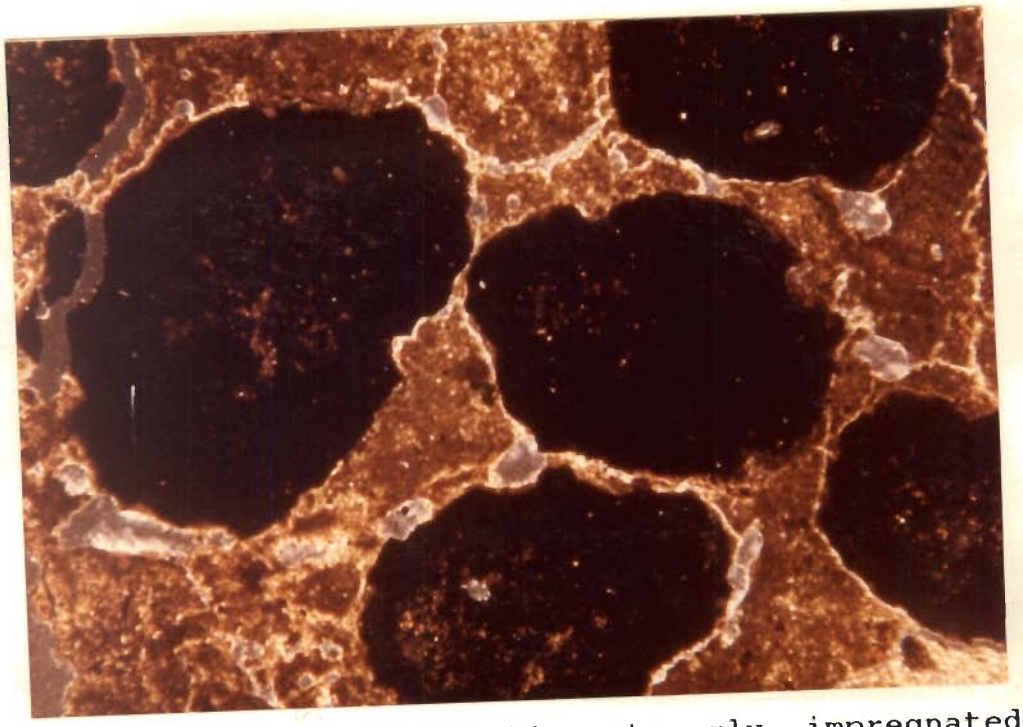

Fig. 4.41 Typic, orthic strongly impregnated sesquioxide concretions in C horizon of soil profile, Lower Kosi-Gola Plain, Pedon PA7, Frame Length 1.4 mm.

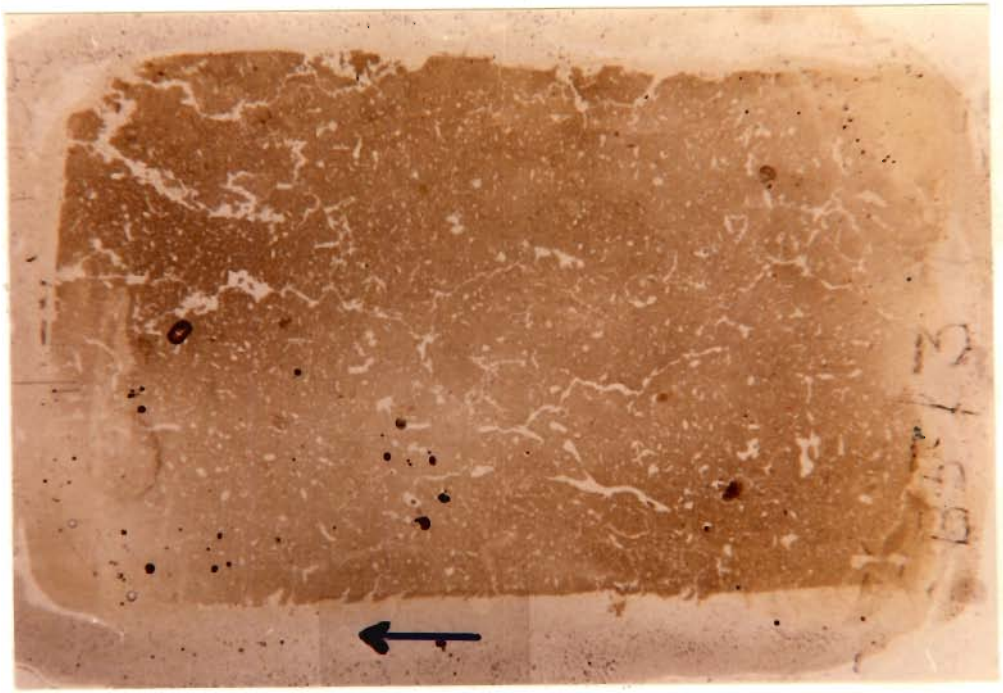

Fig 4.42 Moderately to strongly developed subangular blocky soil structure. The peds range in size from 0.2 cm. to 0.5 cm. The peds are partially to well separable. Pedon PB4, Upper Deoha/Ganga-Ghaghra Interfluve.

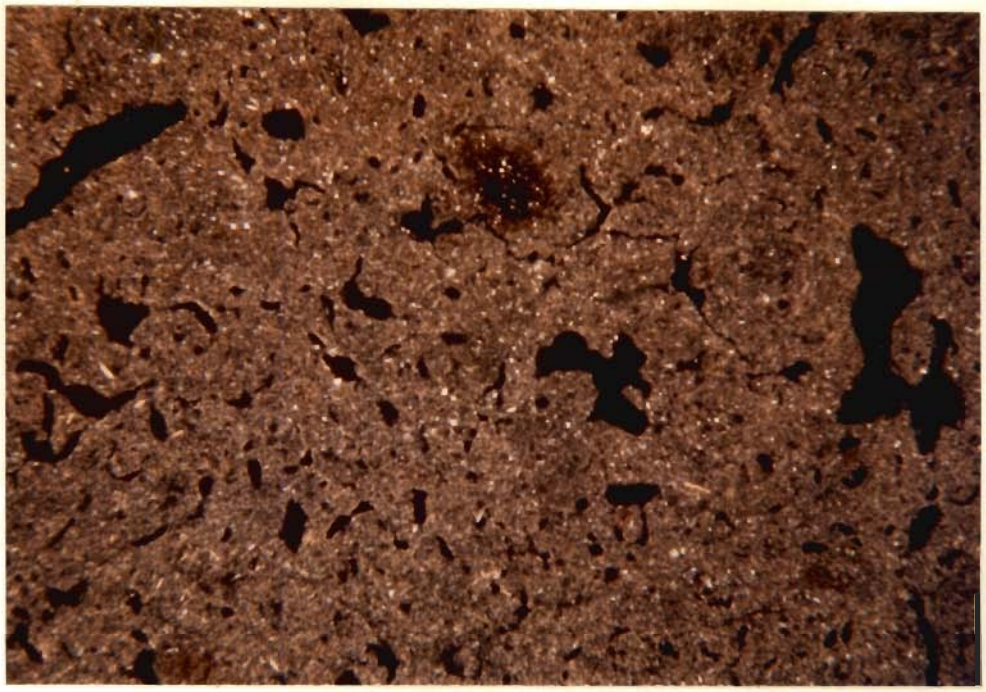

Fig. 4.43 Moderately to strongly developed angular and subangular blocky structure, few large irregular shaped vughs showing vughy microstructure, Upper Deoha/Ganga-Ghaghra Interfluve, frame length 20 mm, Pedon PB4, B2 horizon, XPL.

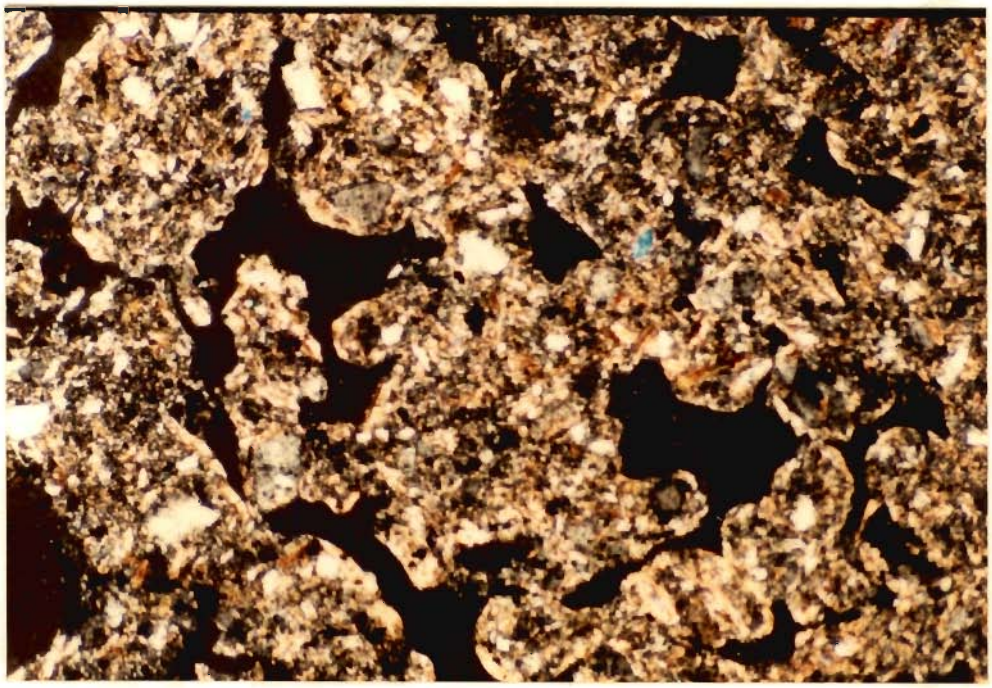

Fig. 4.44 Numerous irregular shaped vughs, often interconnected, producing vughy microstructure, Upper Deoha/Ganga Ghaghra Interfluve. Pedon PB4, B2 horizon, Frame length 1.4 mm, XPL.

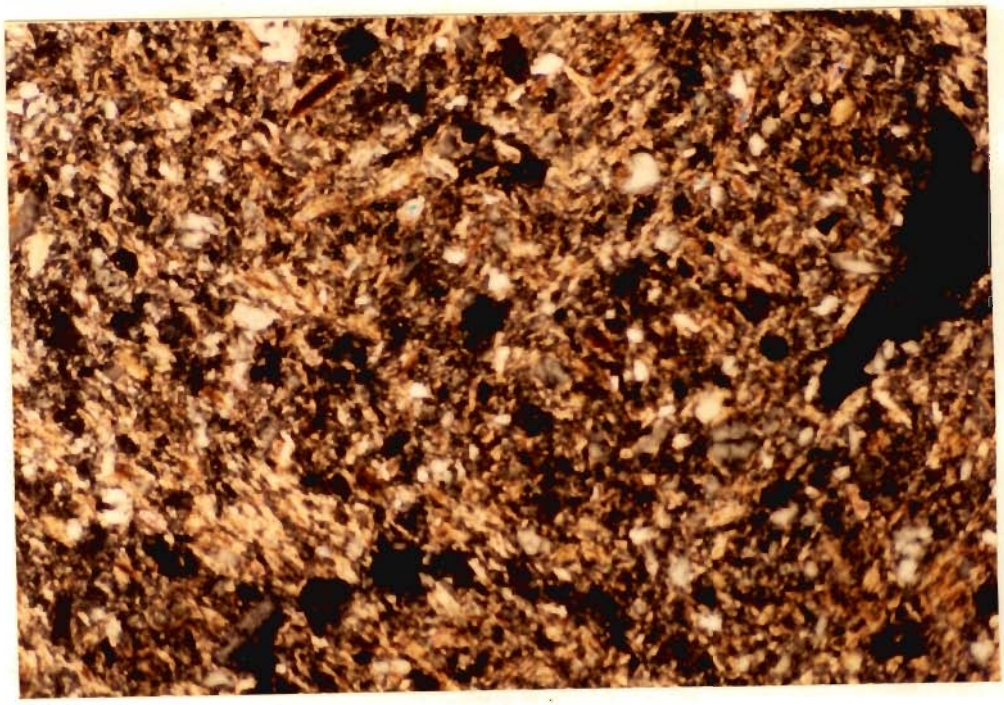

Fig. 4.45 Strongly oriented silty clay at right angle, showing reticulate striated b-fabric, Upper Deoha/Ganga Ghaghra Interfluve, Pedon PB4, B2 horizon, Frame length 1.4 mm, XPL

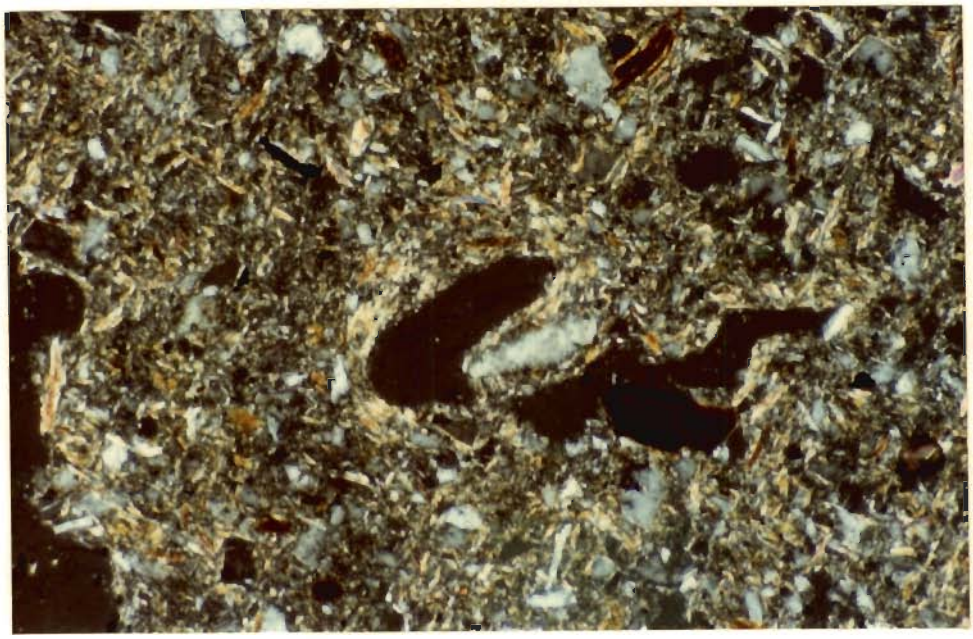

Fig. 4.46 Hypocoatings and quasi coatings along smooth voids. and moderately developed cross striated b-fabric. Pedon PB4, B2 horizon, Upper Deoha/Ganga-Ghaghra Interfluve, Frame length 1.4 mm., XPL

nodules (Fig. 4.47). At places crystic plasmic b-fabric is noted due to impregnation of ground mass by micrite. These are defined as type III calcretes.

4.2.10 Micromorphological Characters of Upper Rapti Ghaghra Interfluve

Two thin sections representing the soil characteristics of this soil geomorphic-unit are described in detail. These soils under microscope show moderately developed subangular blocky structure. The ped walls are irregular and partially separable. Voids present are channels and vughs showing channel and vughy microstructure. C/F ratio generally is around 60/40. Coarse fraction is usually moderately well sorted and is medium sized sand (150-200 µm). Coarse grains are often thinly coated and sometimes fine fraction occur as braces inbetween coarse grains showing chitonic and gefuric related distribution.

Fine fraction, usually mineralic in nature, consists of silty and impure clays, often distributed as groundmass and occasionaly as thin coatings along grains and voids. The fine fraction is discretely mixed with amorphous and ferruginous matter masking the grains and other features.

Illuvial pedofeatures are not very prominent. Soils show a few 40-60 µm hypocoatings along voids and grains. These coatings are characteristically not laminated. Plasma separation is moderate. Moderately developed stipple speckled, cross- and poro-striated b-fabrics are commonly observed.

In lower horizons i.e. in C horizons, concentration of sesequioxides increases and apart from moderately impregnated

diffused mottles, very large (2 cm) magnans or manganese concretions are observed.

4.2.11 Micromorphological characters of Old Ghaghra Bar

Soils thin-sections from this unit show moderately developed subangular blocky soil structure. Channel and vughy microstructures are commonly seen. Voids are smooth surfaced channels and vughs. Coarse fraction is usually moderately sorted and ranges in size 100-200 μm. It consists of slightly to moderately altered grains of quartz, mica and other minerals in minor amounts. Fine fraction is of fine micaceous silt and clay. It occurs as groundmass and coatings along voids. Plasma separation is moderate as moderately developed stipple speckled and cross-striated b-fabrics are commonly seen (Fig. 4.48).

Pedofeatures observed include 50-60 μm thick limpid to speckled clay hypocoatings and quasicoatings along channel voids and vesicles (Fig. 4.49, 4.50). Other pedofeatures include micropan and diffused mottles of sesquioxides.

4.2.12 Micromorphological characters of Middle Deoha/Ganga Ghaghra Interfluve

Seven thin sections showing typical soil profile development characters have been studied in detail. The soils of this soil geomorphic unit show that the pedality is very strongly developed, the peds being well accommodating and separable (Fig. 4.51, 4.52). The voids are mainly compound packing voids, channels and vughs. The soils show channel and vughy microstructures. At places platy microstructure also occurs. C/F ratio generally is 40/60 (range from 30/70 to 60/40). The

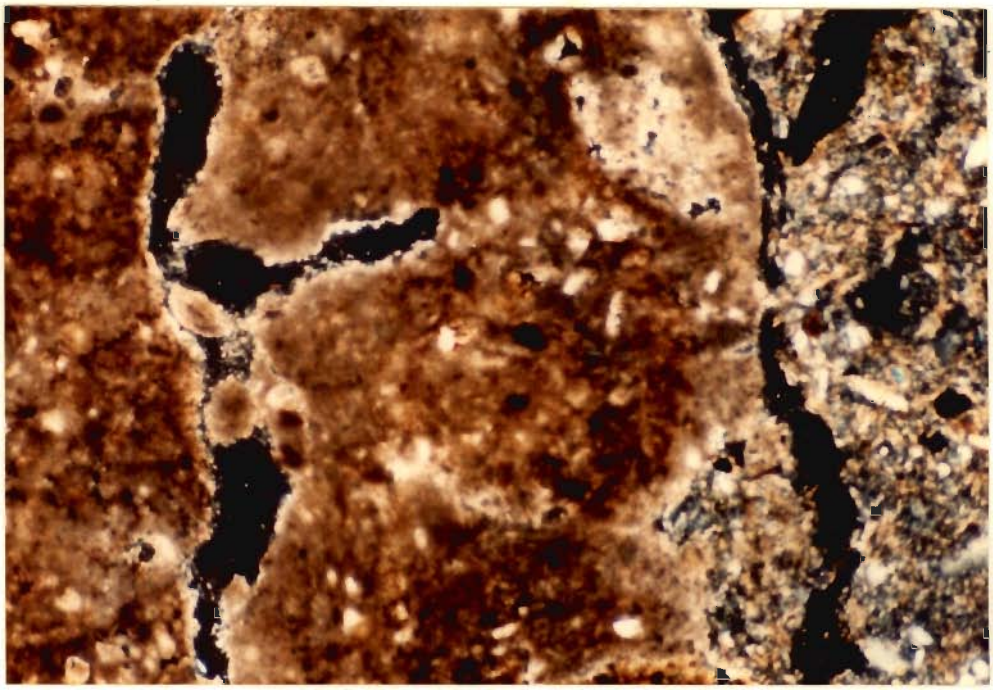

Fig. 4.47 Part of a impure, micritic nodule, showing calcification and decalcification, Type III calcrete, Upper Deoha/Ganga-Ghaghra Interfluve, Pedon PB4, C horizon, Frame length 1.4 mm, XPL.

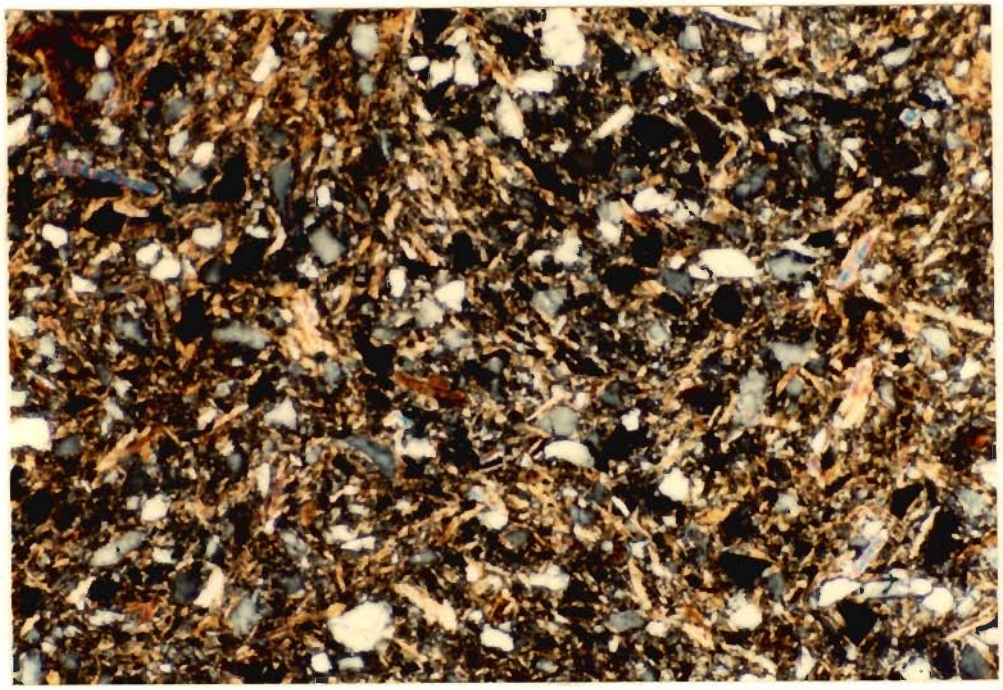

Fig. 4.48 Moderately sorted coarser fraction is partially coated with silty clay, showing chitonic C/F related distribution, Old Ghaghra Bar, Pedon PB9, B22 horizon, Frame length 1.4 mm, XPL.

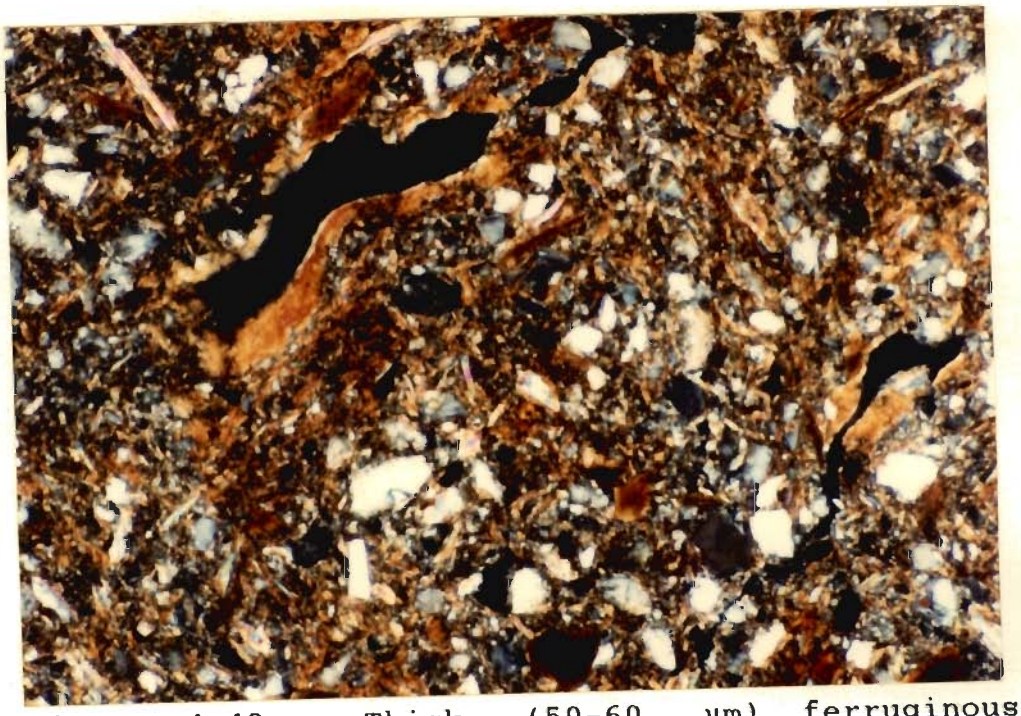

Fig. 4.49 Thick (50-60 µm) ferruginous hypocoatings along voids, Old Ghaghra Bar, Pedon PB9, B22 horizon, Frame length 1.4 mm, XPL.

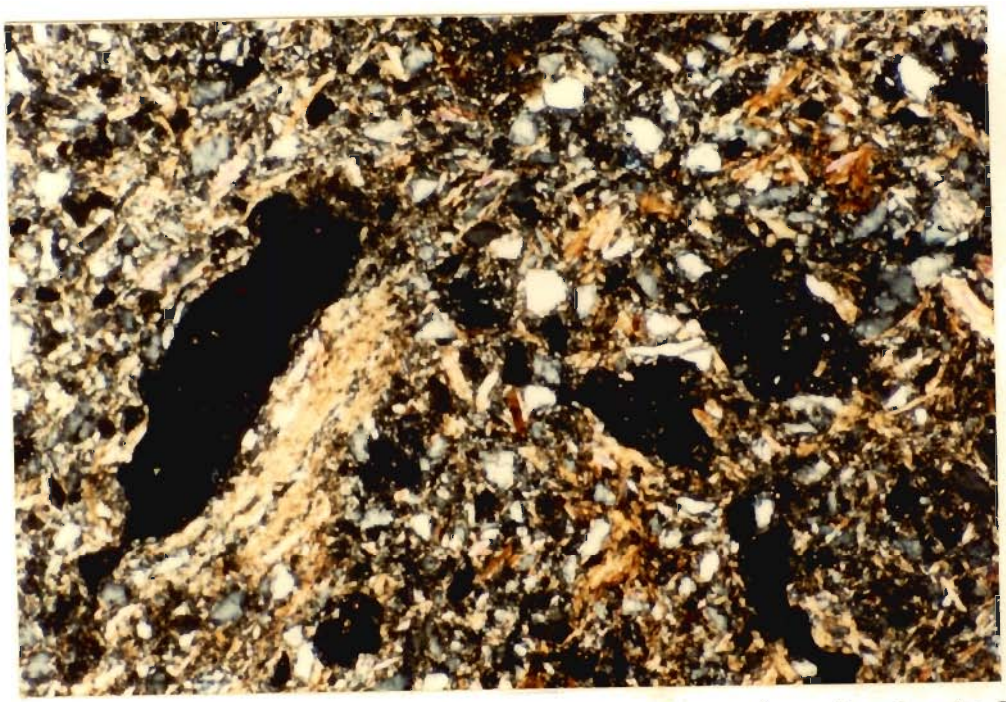

Fig. 4.50 Strongly oriented, microlaminated quasi coating along a channel void, Old Ghaghra Bar, Pedon PB9, B22 horizon, Frame length 1.4 mm, XPL.

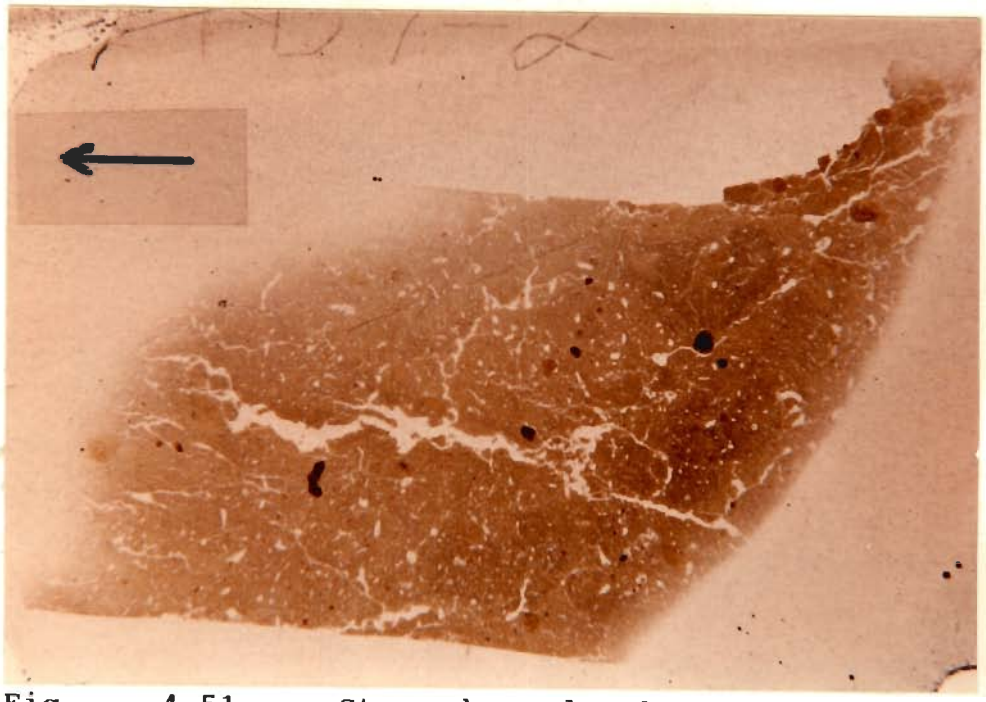

Fig. 4.51 Strongly developed angular to subangular blocky soil structure. Pedon PB7, B2 horizon, Middle Deoha/Ganga-Ghaghra Interfluve. Marker 1 cm., ordi-nary light.

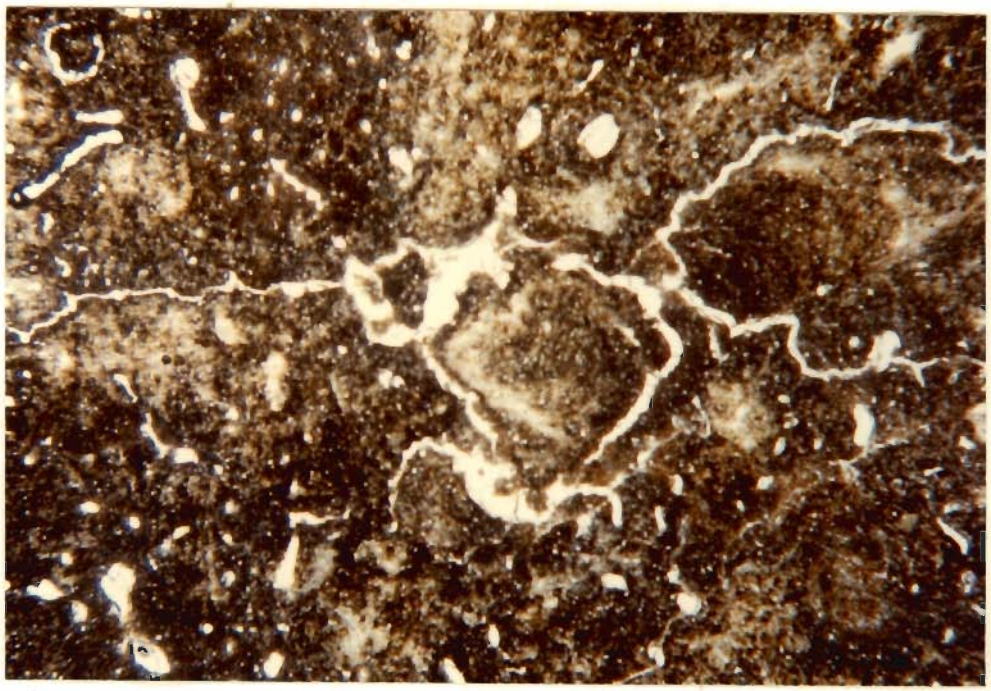

Fig 4.52 Strongly developed, well accomodating and well separable subangular blcoky peds. Pedon PB6, B23 horizon, Middle Deoha/Ganga Ghaghra Interfluve, frame length 20 mm.

coarser fraction is mainly of quartz and micas, and other minerals occur in smaller amount. Mineral grains are usually moderately to intensely altered. C/F related distribution is mainly porphyric. Also chitonic and gefuric related distributions are noted (Fig. 4.53).

Clay illuviation is a common phenomena of these soils. As very thick (100 to 200 µm) microlaminated limpid to speckled clay coatings occur along channels and voids. Argillans are very abundant and thick (150 - 200 µm) in soils free of $CaCO_3$ (Fig. 4.54, 4.55, 4.56 and 4.57), whereas soils showing $CaCO_3$ accumulation show (80 - 100 µm) thick cutans (Fig. 4.58). Some papules are also observed (Fig. 4.59).

Finer fraction is usually of very fine micaceous silt clay. Plasma separation is strong as strongly developed reticulate and cross-striated are commonly observed and also moderately developed parallel and porostriated b-fabric are rarely observed (Fig. 4.60, 4.61, 4.62).

Calcareous pedofeatures are common. Two types of calcrete type I & II are recognised from this unit. Type I calcretes occur as hypocoatings and thin cylindrical and rounded nodules of micrite and microsparite (Fig. 4.62, 4.63 and 4.64) in B2 horizons. These nodules are typically pure orthic and strongly impregnated. Type II calcretes are coarsely crystalline and occur in B3 and C horizon in form of impure calcareous nodules of various shapes.

Ferro-manganese mottles and concretions are commonly

observed. The ferro-manganese concretions are orthic and strongly impregnated and are rounded to subrounded in shape (Fig. 4.65).

4.2.13 Micromorphological characteristics of Lower Rapti-Ghaghra Interfluve

Three sections describing the important characteristics of this soil geomorphic were studied in detail (Table 4.2, Appendix iv).The soils under microscope show moderately to strongly developed subangular blocky structure (5 mm to 2 cm) (Fig. 4.66, 4.67). The peds are accommodating and are bounded by irregular to smooth surfaced compound packing void, which are often interconnected. Other voids present are vughs and channels, showing at places vughy and channel microstructure.

C/F ratio usually varies from 30/70 to 50/50. The coarse fraction is usually 200-300 µm in size and occasionally large (>400 µm) minerals grains are seen. These show porphyric distribution (Fig. 4.67 to 4.68). At places very well developed enulic distribution pattern also occur.

Finer fraction usually consist of fine silt and clays of micaceous nature are distributed as groundmass and coatings. Plasma separation is strong as cross- and reticulate- striated b-fabrics are strongly developed and commonly distributed. At places moderately developed porostriated b-fabric also occurs.

Clays illuviation pedofeatures are common in these soils. 100 to 200 µm thick microlaminated limpid clay hypocoatings (Fig. 4.68, 4.69 and 4.70) are seen. A few fine silty hypocoatings along large voids are also noted (Fig. 4.71).

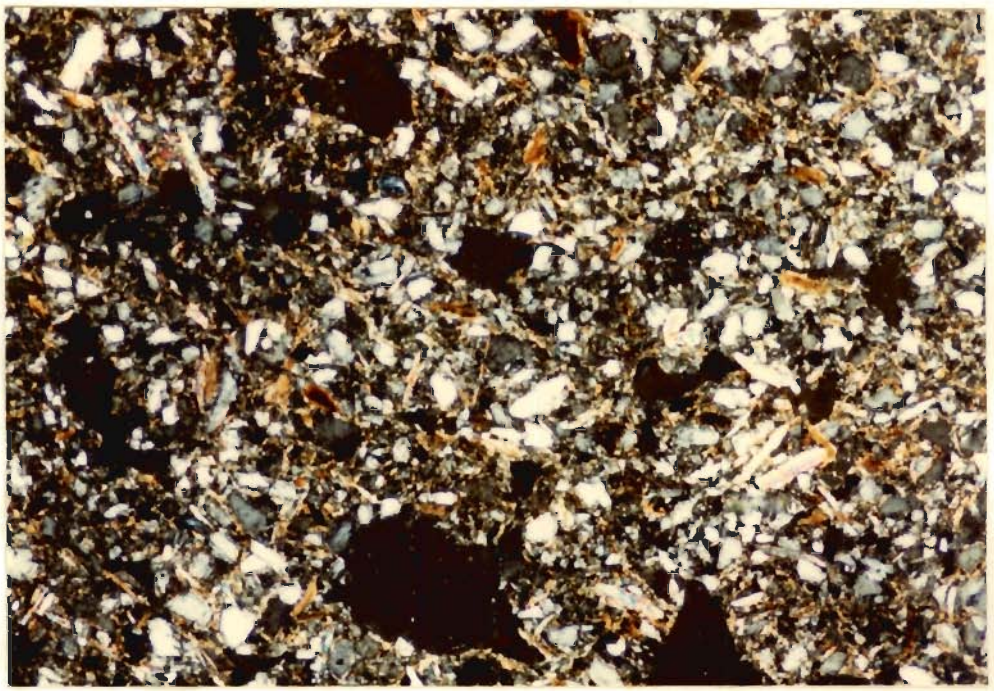

Fig. 4.53 Moderately sorted coarser fraction often bridged by finer fraction also sometimes thinly coated with finer fraction, showing gefuric and chitonic C/F related distribution pattern, Pedon PC1, B22 horizon, Middle Deoha/Ganga-Ghaghra Interfluve frame length 1.4 mm, XPL.

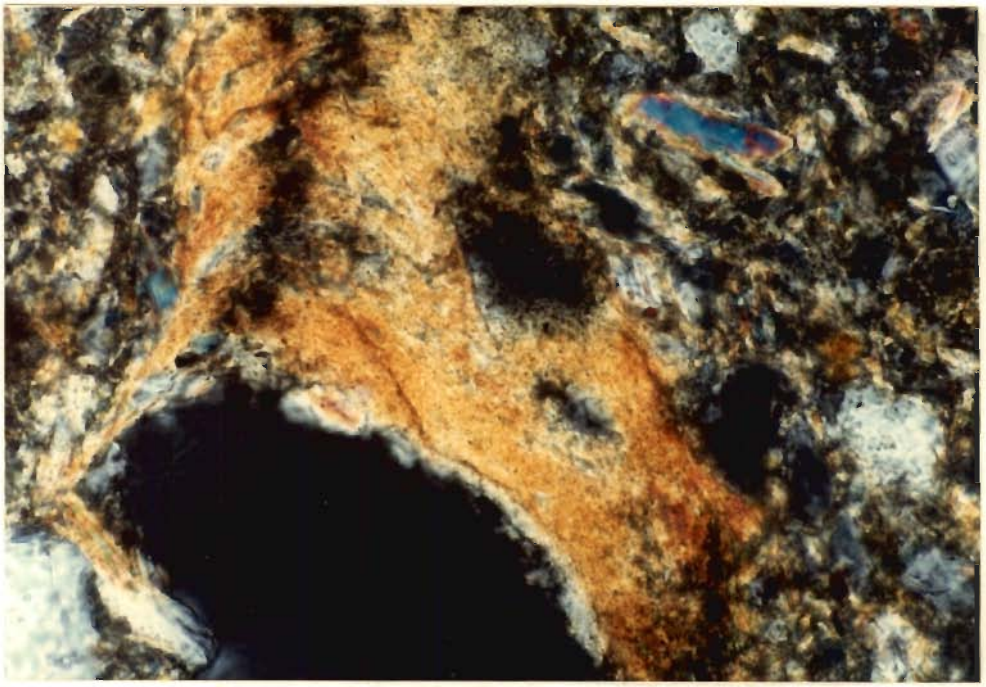

Fig 4.54 Thick (200 µm) microlaminated, hypoclay coating along void by limpid to dott-ed clay. Pedon PB7, B21 horizon, Middle Deoha/Ganga-Ghaghra Interfluve. Frame length 0.3 mm, XPL.

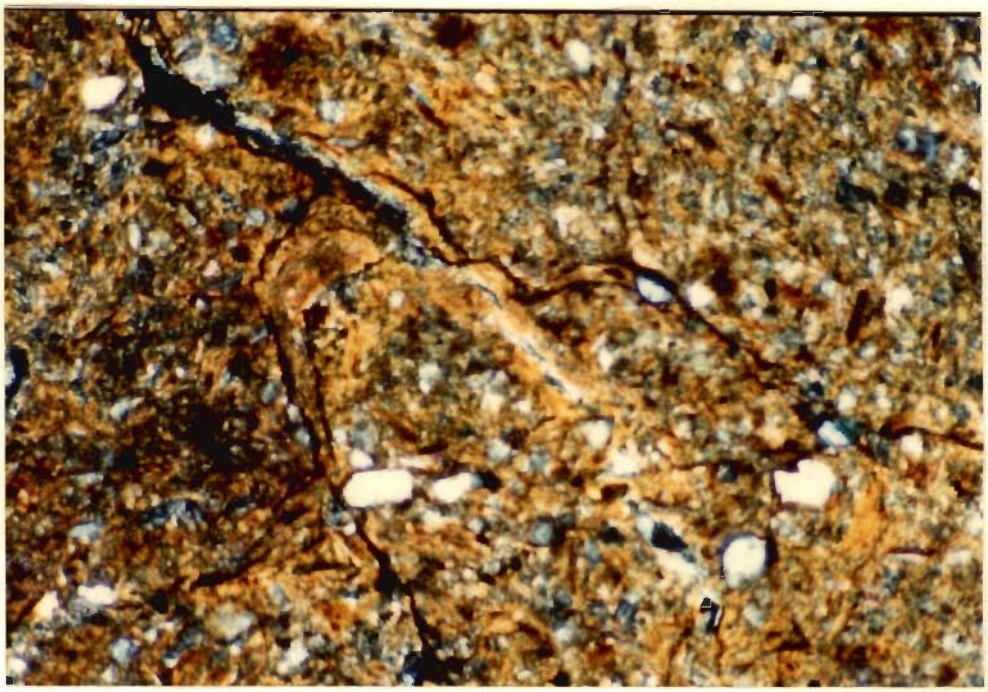

Fig. 4.55 Thick clay intercalations and microlaminated hypo coatings. Pedon PB7, B21 horizon, Middle Deoha/Ganga-Ghaghra Interfluve. Frame length 1.4 mm, XPL.

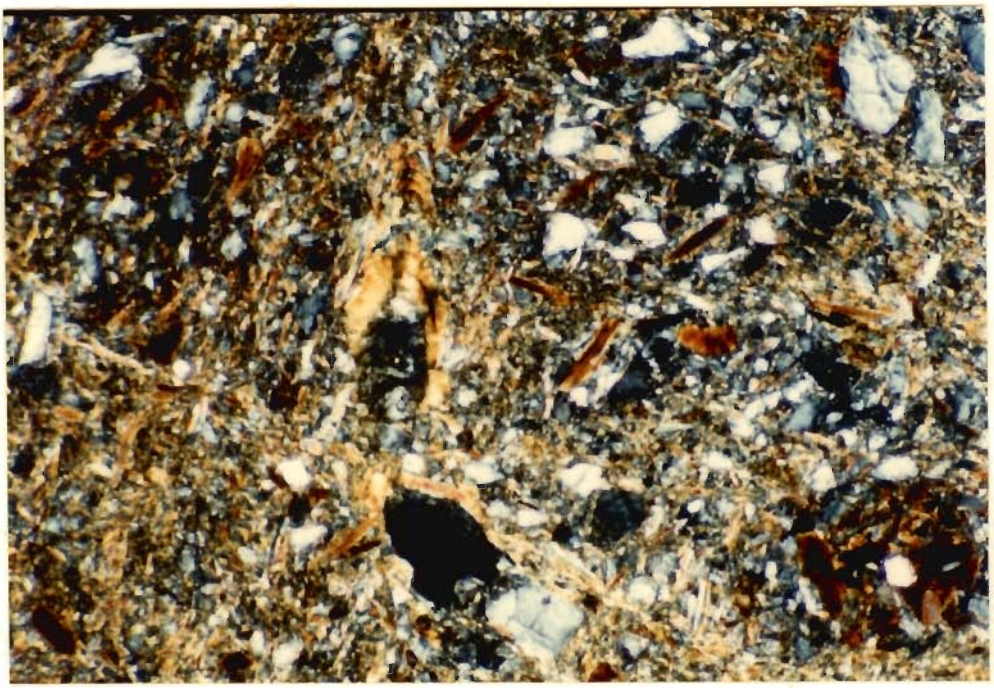

Fig. 4.56 Hypocoating along channel void, and infilling of a channel void by strongly oriented thick limpid clay, also diffused mottles of sesquioxide, Pedon PB7, B21 horizon Middle Deoha/Ganga-Ghaghra Interfluve. Frame Length 1.4 mm, XPL.

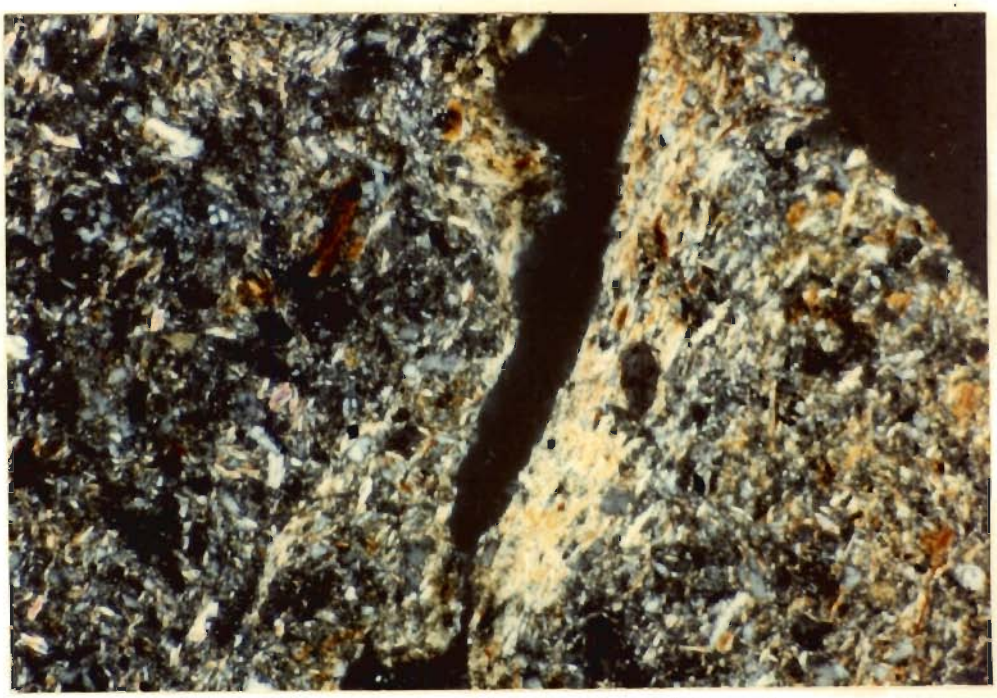

Fig. 4.57 Strongly oriented silty clay coatings (>100 μm) along a channel void, Pedon PB7, B2 horizon, Middle Deoha/Ganga-Ghaghra Interfluve. Frame length 1.3 mm., XPL.

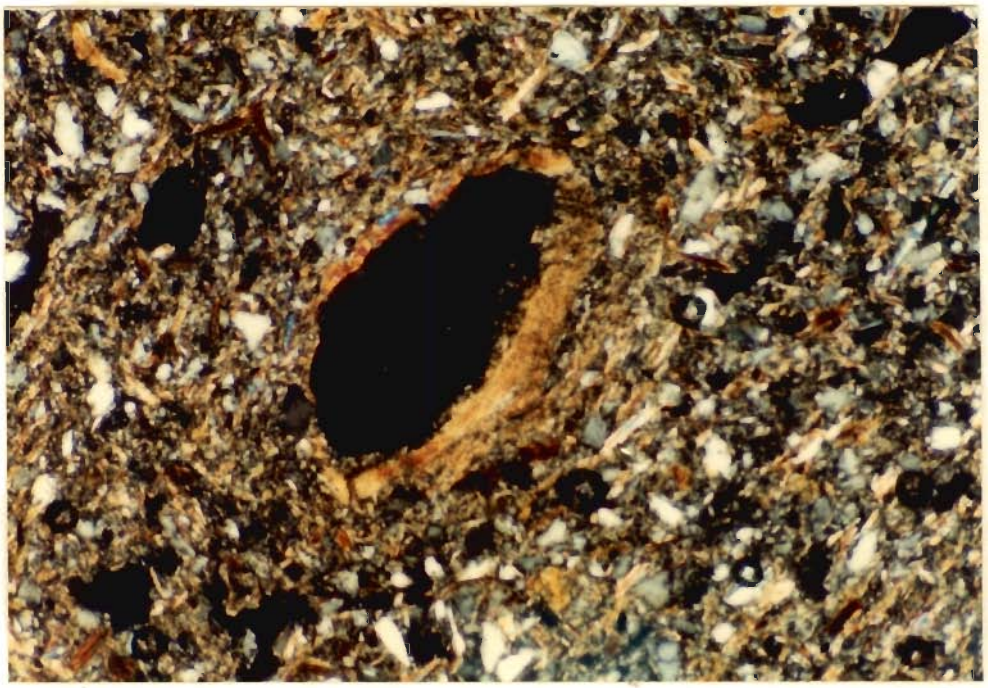

Fig. 4.58 Thick hypocoating by dotted clay along a channel void. Middle Deoha/Ganga Ghaghra Interfluve, Pedon PC1, B22 horizon, Frame length 1.4 mm, XPL.

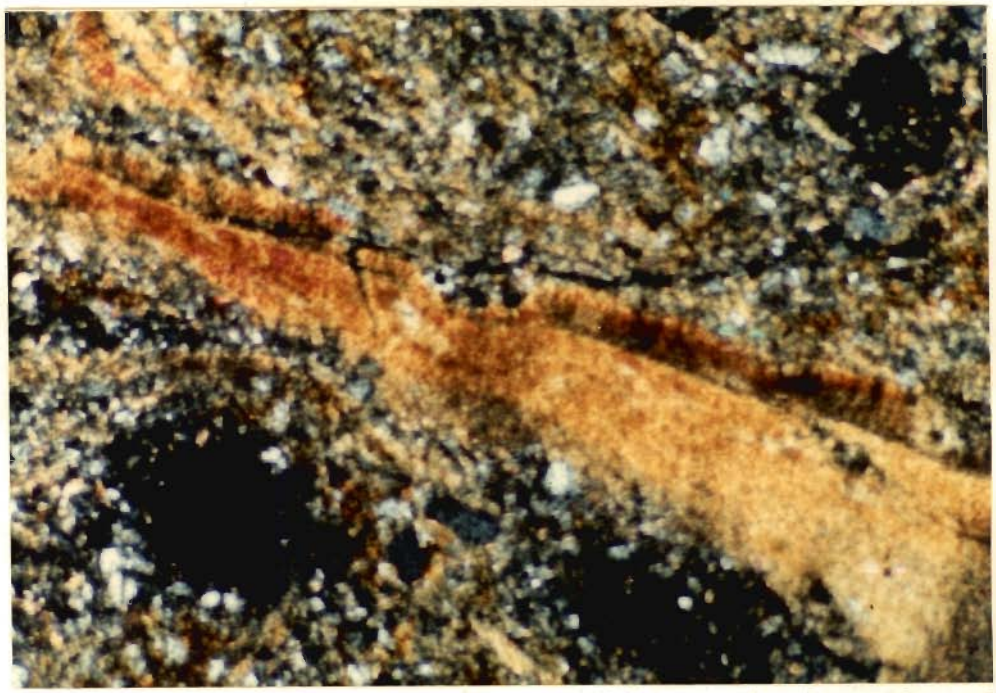

Fig. 4.59 Large papule (> 1300 µm in length and 100 to 300 µm in width) of limpid to speckled clay, Pedon PB6, B23 horizon, Middle Deoha/Ganga-Ghaghra Interfluve, frame length 1.4 mm, XPL.

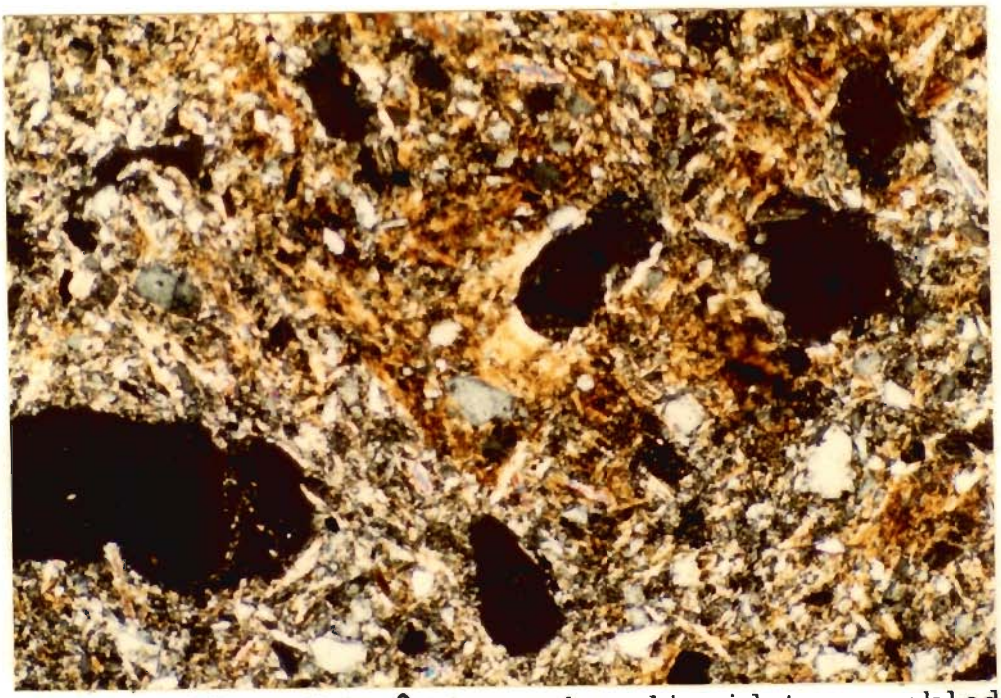

Fig. 4.60 Hypocatings by limpid to speckled clay along voids. Strongly developed cross-striated b-fabric is also seen. Pedon PB6, B2 Horizon, Middle Deoha/Ganga-Ghaghra Interfluve, Frame length 1.3 mm., XPL.

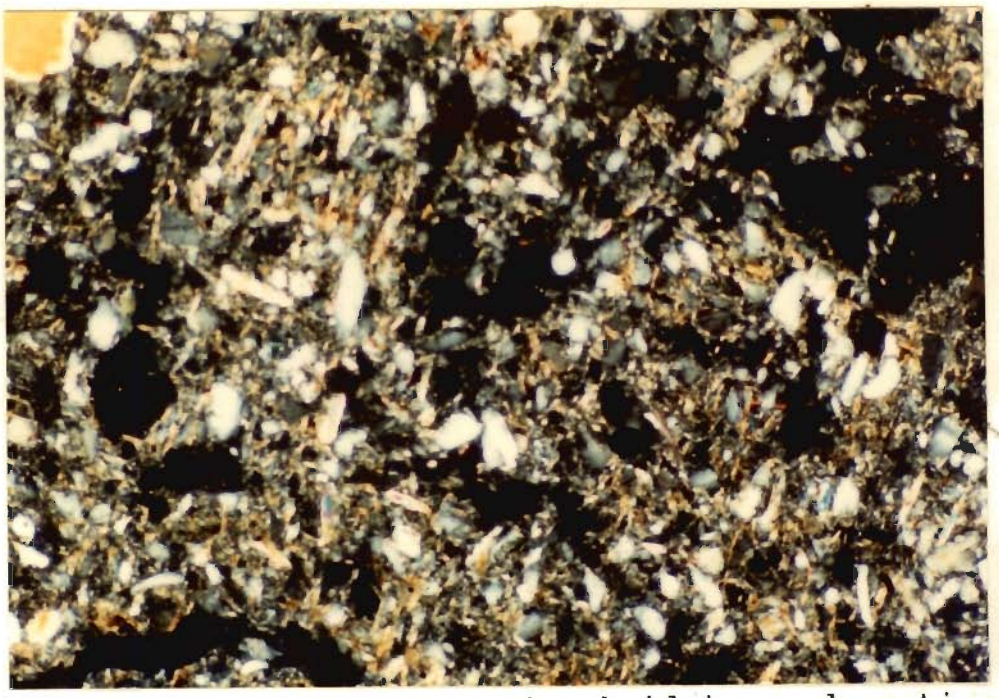

Fig. 4.61 Finer fraction bridging and coating the coarse grains, showing gefuric related distribution, also fine fraction of clay show weak to moderate parallel striations Pedon PC4, B1 horizon, Middle Deoha/Ganga-Ghaghra Interfluve. Frame length 1.4 mm, XPL.

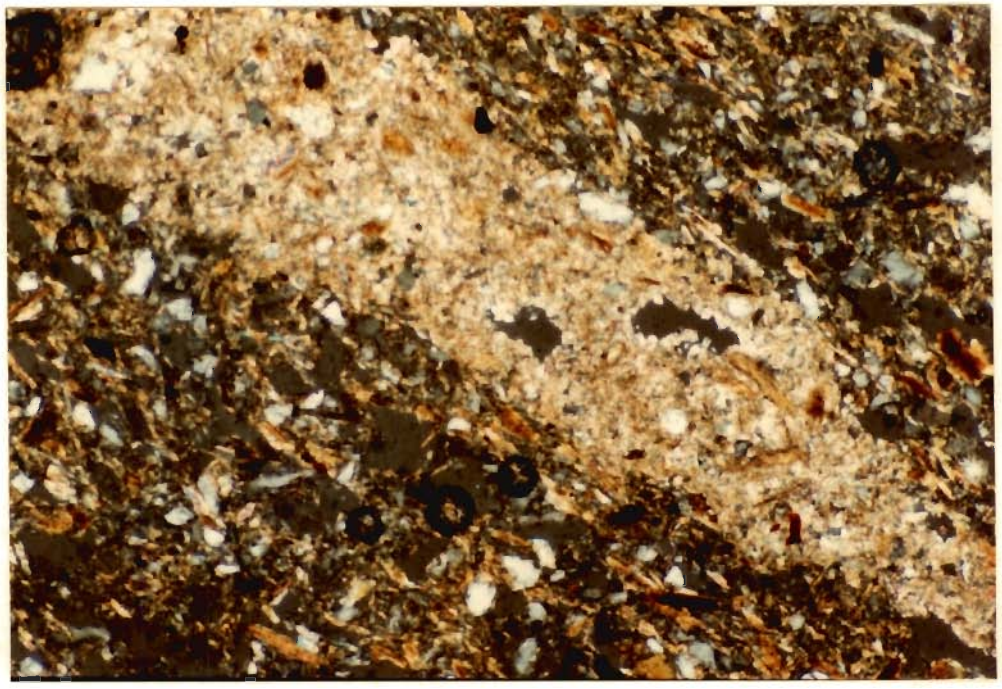

Fig. 4.62 Elongated thin, typic, orthic strongly impregnated nodule of micritic to sparatic calcite, Type I calcrete, Pedon C1, B22 horizon, Middle Deoha/Ganga-Ghaghra Interfluve, Frame length 1.4 mm, XPL.

Fig. 4.63 Typic, orthic, septaric strongly impregnated rounded nodule of micrite. Type I calcrete, Pedon PC1, B22 horizon, Middle Deoha/Ganga-Ghaghra Interfluve, Frame Length 1.4 mm, XPL.

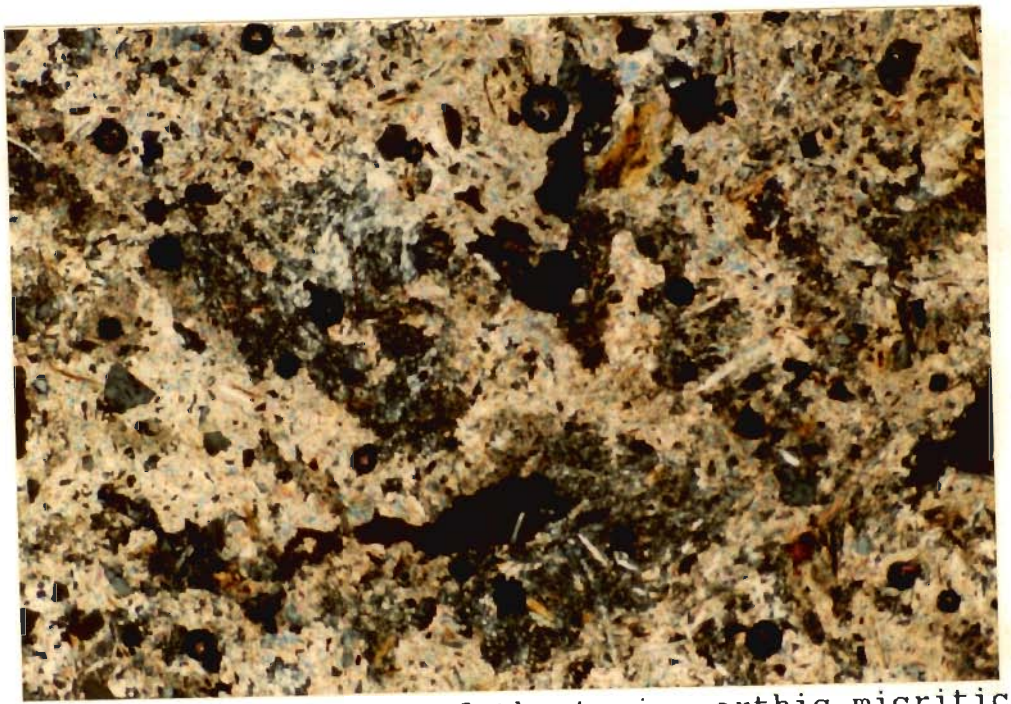

Fig. 4.64 Part of the typic, orthic micritic nodule showing that no crystals have developed, Type I calcrete, Pedon C1, B22 horizon, Middle Deoha/Ganga-Ghaghra Interfluve, frame length 0.3 mm, XPL.

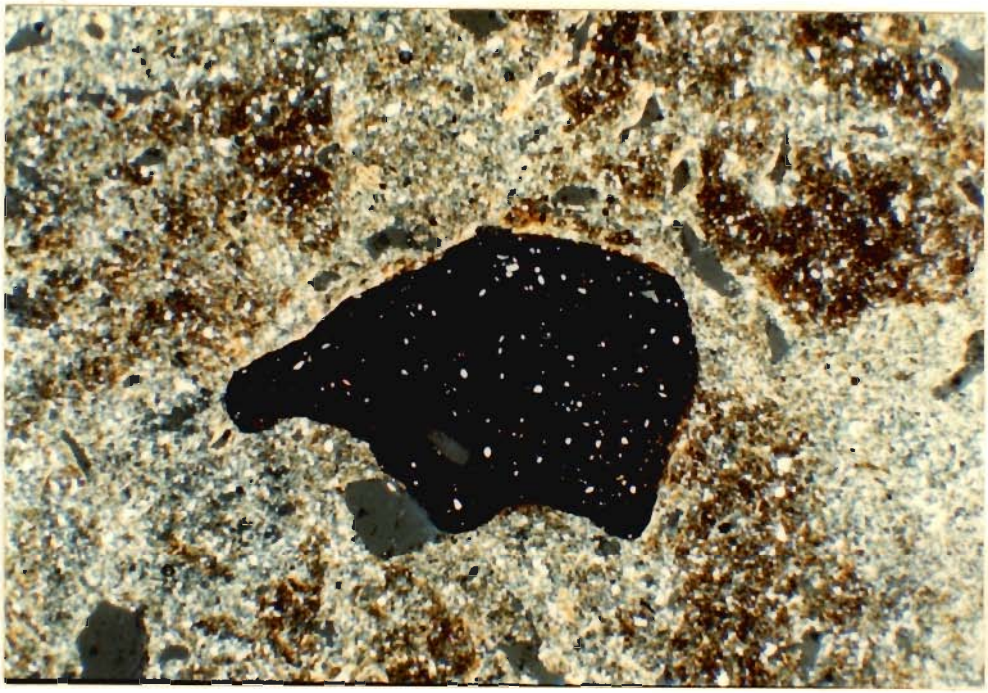

Fig. 4.65 Typic, orthic, strongly impregnated magnan (manganese concretion). Pedon PB6, B23 horizon, Middle Deoha/Ganga-Ghaghra Interfluve. Frame length 1.4 mm, XPL.

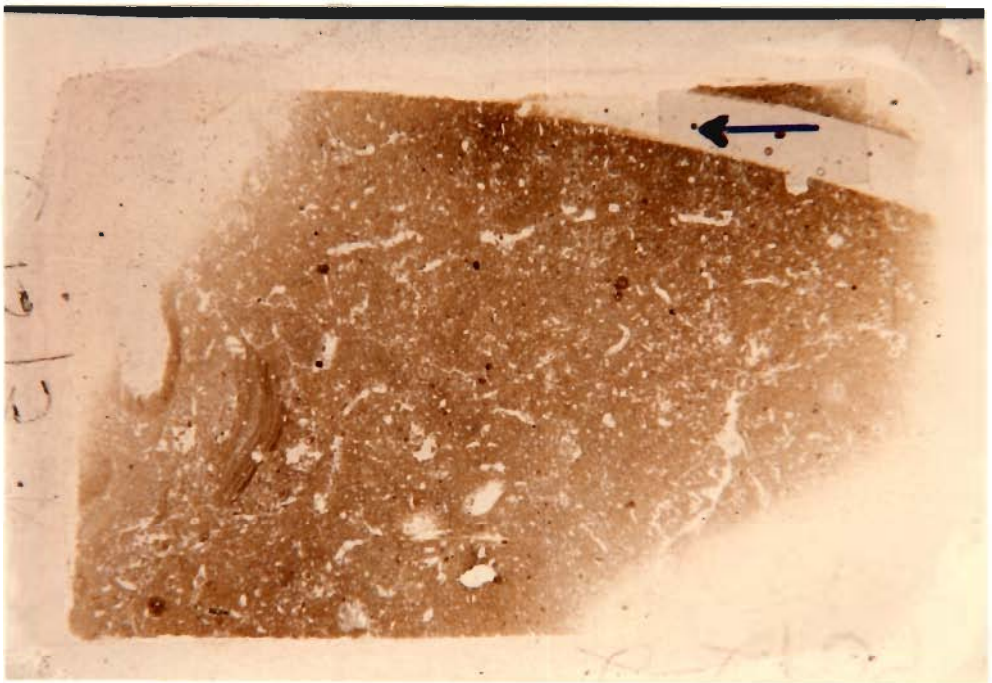

Fig. 4.66 Strongly developed subangular blocky soil-structure, a set of microlaminated micropan is also seen. Pedon PC 12, B21 horizon, marker 1 cm., ordinary light.

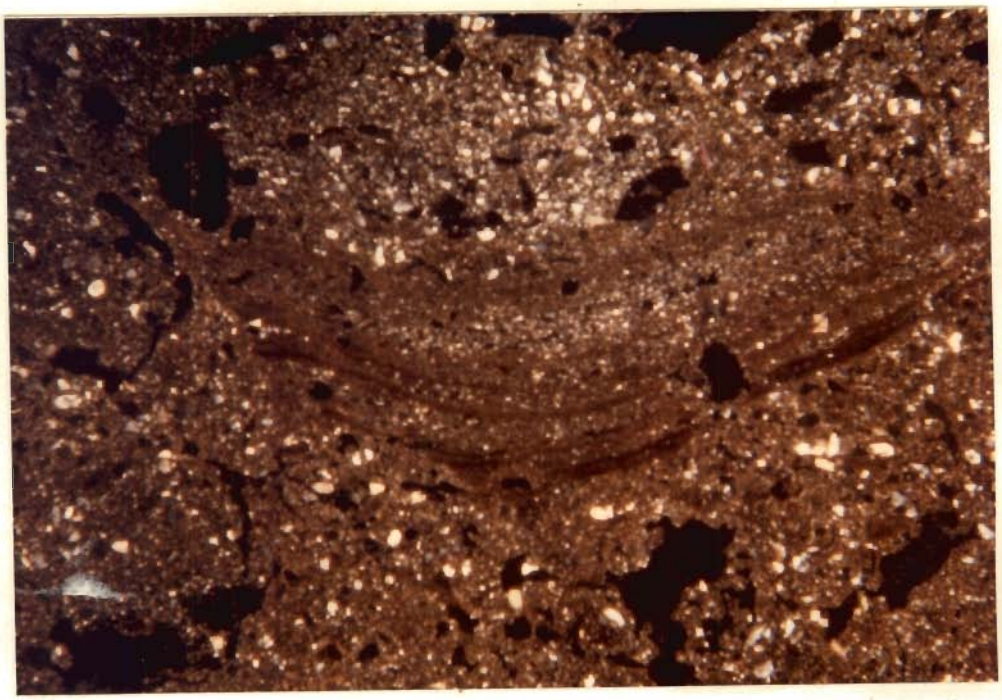

Fig. 4.67 Moderately developed subangular blocky peds, with a large, bow shaped composite micropan Pedon PC12, B21 horizon, Frame length 20 mm, XPL

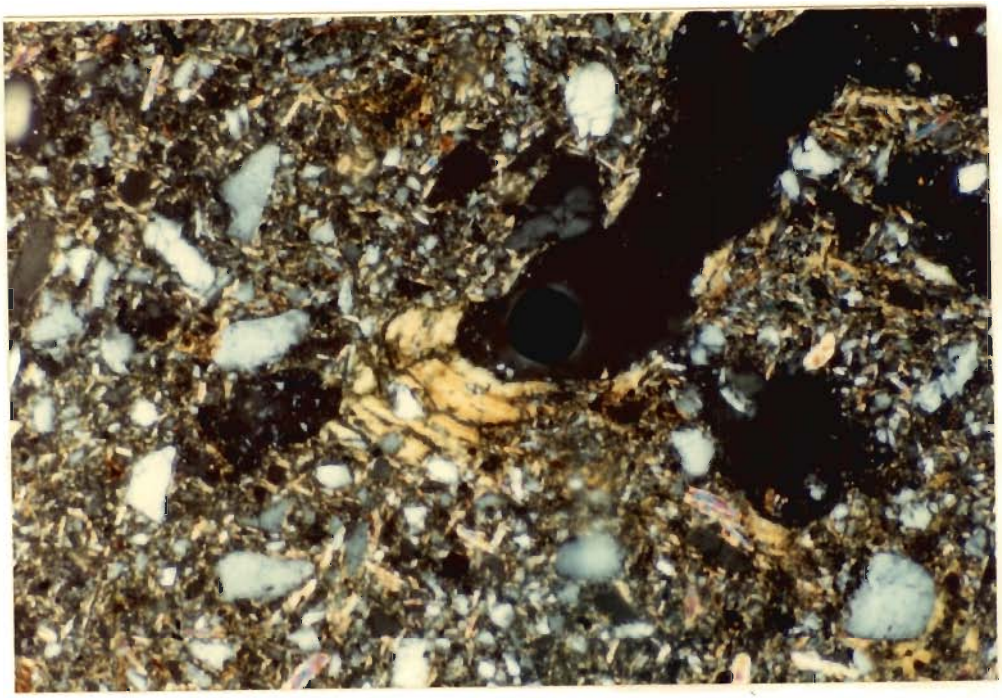

Fig. 4.68 Thick (200 µm) microlaminated hypocoating in a channel void. Pedon PC12, B21 horizon, Lower Rapti-Ghaghra Interfluve, Frame length 1.4 mm, XPL.

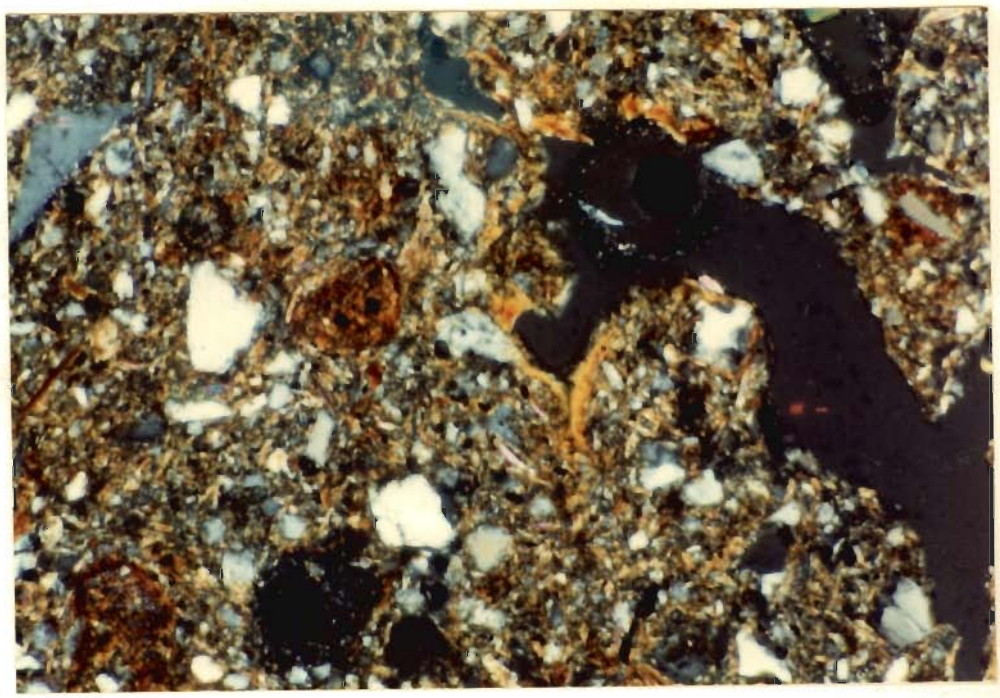

Fig. 4.69 Hypocoatings along voids by strongly oriented clay, Moderately developed stipple speckled bfabric is also seen. Pedon PC12, B2 horizon, Lower Rapti-Ghaghra Interfluve, Frame length 1.3 mm, XPL.

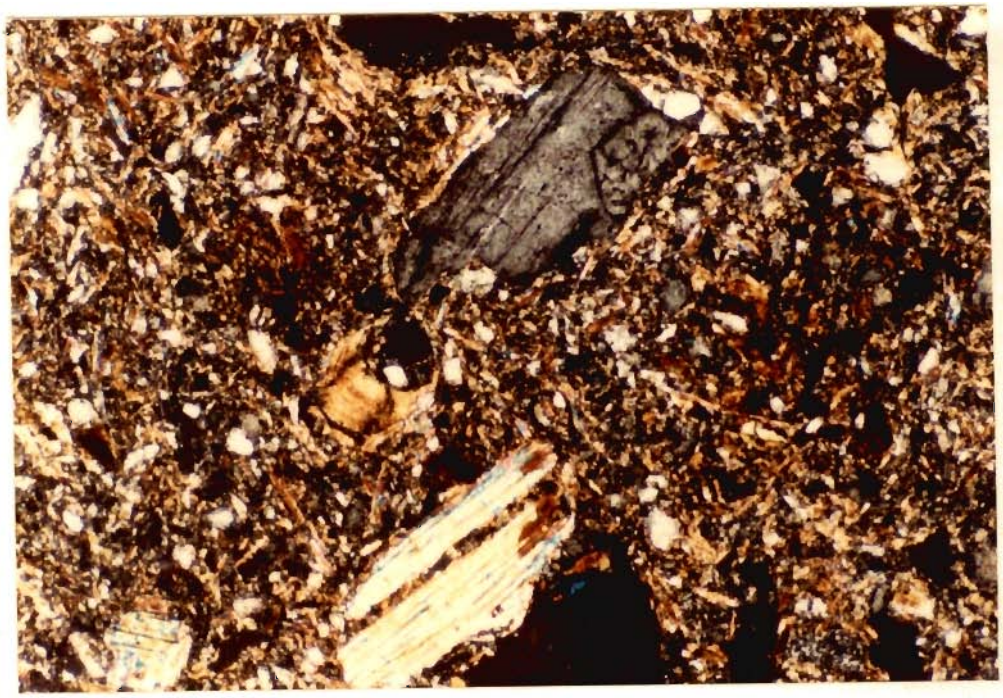

Fig. 4.70 Thick microlaminated concentric (100 µm) hypocoating along a vesicle. Also few large unaltered coarse grains are seen. Pedon PC12. B21 horizon, Lower Rapti-Ghaghra Inter- fluve, Frame length 1.4 mm, XPL.

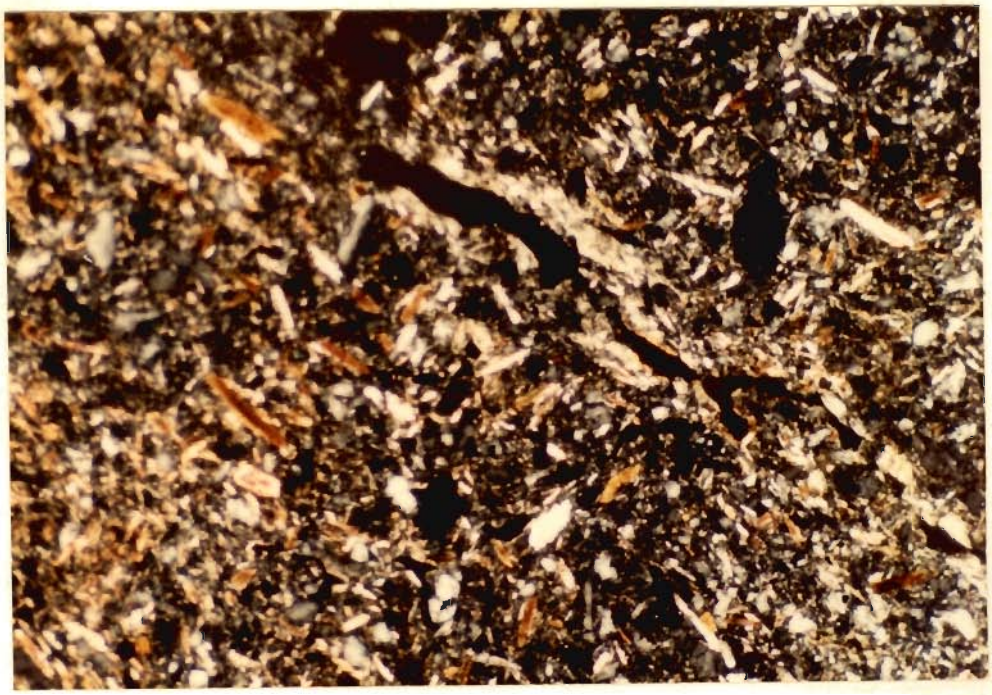

Fig. 4.71 Hypocoating by fine silt along a channel void, Pedon PC12, B23 horizon, Lower Rapti - Ghaghra Interfluve, Frame lenth 1.4 mm, XPL.

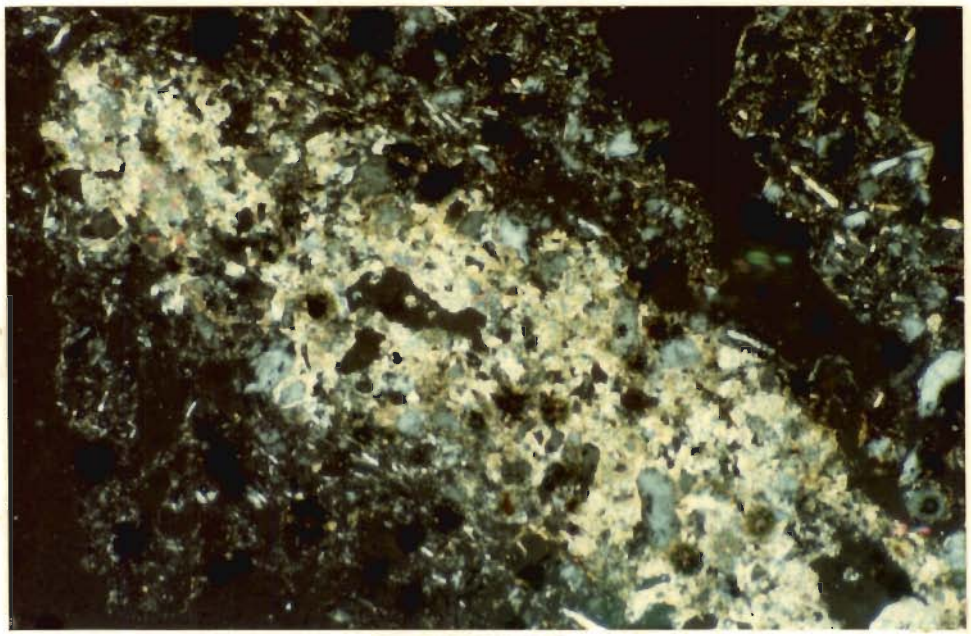

Fig. 4.72 Strongly impreg-nated cylindrical pure micritic nodule. Pedon PC14, B2 Horizon,Lower Rapti-Ghaghra Interfluve. Frame length 1.3 mm., XPL

A set of micropans, arched bend shaped (1 cm in length) consisting of ferruginous and clays matter is seen (Fig. 4.67). Calcareous pedofeatures are found to be associated with B and C horizons. Similar to the Middle Deoha/Ganga Ghaghra Interfluve type I to III calcretic features are recognised. Type I calcrete occurs as thick micritic cylindrical to irregular shaped nodules (Fig. 4.72), micritic hypocoatings along void in B2 horizons. Type II calcrete are associated in voids of B3 & C horizon (Fig. 4.73). These are impure and coarsely crystalline. At places very large bow shaped/cone fabric feature has been observed (Fig. 4.74). Strong animal activity is noted, as a few isotubles which are filled with reworked basic soils (Fig. 4.75) are observed.

4.3 RESUME

Micromorphological investigations of thin-sections show systematic variation in soil characters from various groups recognised in chapter III, from the least developed soils of group I to most developed soils of group V. The changes observed are in features such as grade of pedality, ped separation, roughness of void surfaces, abundance and thickness of cutans, coarse and fine fraction distribution, nature of plasma separation in terms of b-fabric and nature of calcrete pedofeatures (Table 4.2).

It is observed that alluvial parent material for soils developed in the area was deposited by fluvial action. Soils of floodplains and young piedmonts show that pedality development has not taken place, and show massive and compact grain

microstructure. Weak to moderately developed subangular blocky peds with incomplete separations were observed in the Upper Kosi-Gola Plain, Old Ghaghra Plain and in Old Sihali-Mohan-Kandra Piedmont. Moderately to strongly developed pedality has been observed in the Lower Deoha/Ganga-Ghaghra Interfluve. Strongly developed angular blocky and subangular blocky peds occur in Middle Deoha/Ganga-Ghaghra Interfluve and Lower Rapti-Ghaghra Interfluve, whereas in the Upper Deoha/Ganga-Ghaghra Interfluve and in the Upper Rapti-Ghaghra Interfluve moderately developed peds have been noticed.

Various kinds of voids noticed are channels, vughs and vesicles. The voids occur in between peds and within the peds. Also the voids occur in between grains. In floodplains and in young piedmonts generally intergrain voids are observed giving rise to various intergrain microstructures. The voids in these geomorphic units are extremely rough. In the Middle Deoha/Ganga Ghaghra Interfluve and Lower Rapti-Ghaghra Interfluve, the voids generally occur in between peds and also within the peds. The voids observed include channels, vughs and vesicles. The voids of these units are smoothened by thick coatings of very fine silt and clays. In other units the voids are channels, vughs and vesicles, which show rough to smoothed surfaces.

Distribution pattern of coarse and fine fraction and their abundance has given rise to several types of c/f related distributions. Monic and gefuric related distributions are often observed in floodplain and piedmonts, also sometimes enulic and porphyric are observed in these soils. Soils of the Lower

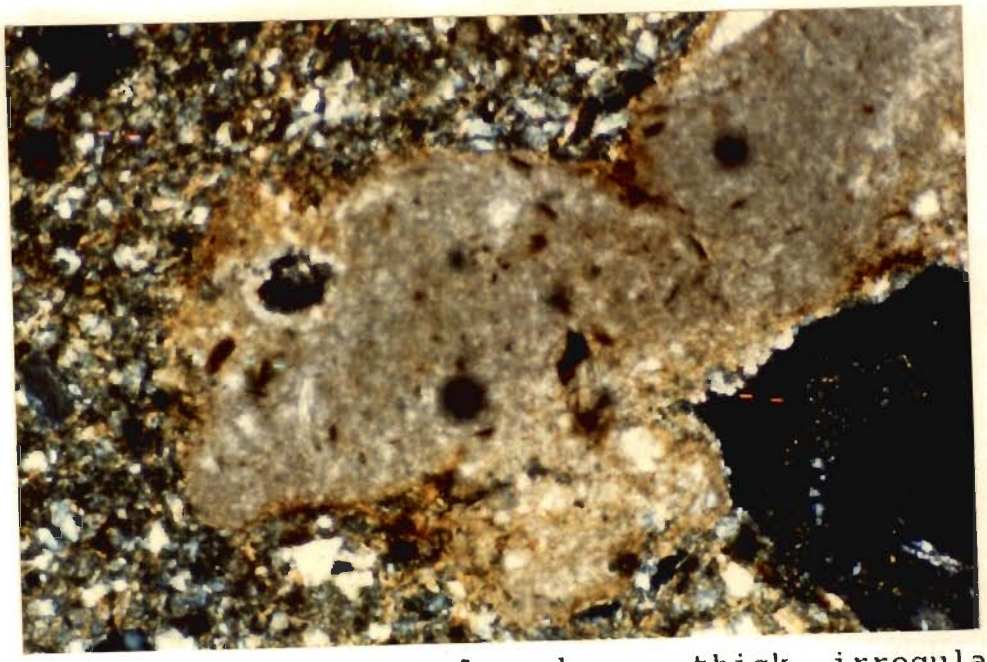

Fig. 4.73 Part of a large, thick, irregular shaped, microcrystalline concretion of calcite, very prominent boundaries with adjacent matrix and coated with voids ferruginous matter inside the calcrete showing dissolution of calcrete, Type II calcrete, Pedon PC14, B24 horizon, Lower Rapti-Ghaghra Interfluve. Frame length 1.4 mm, XPL.

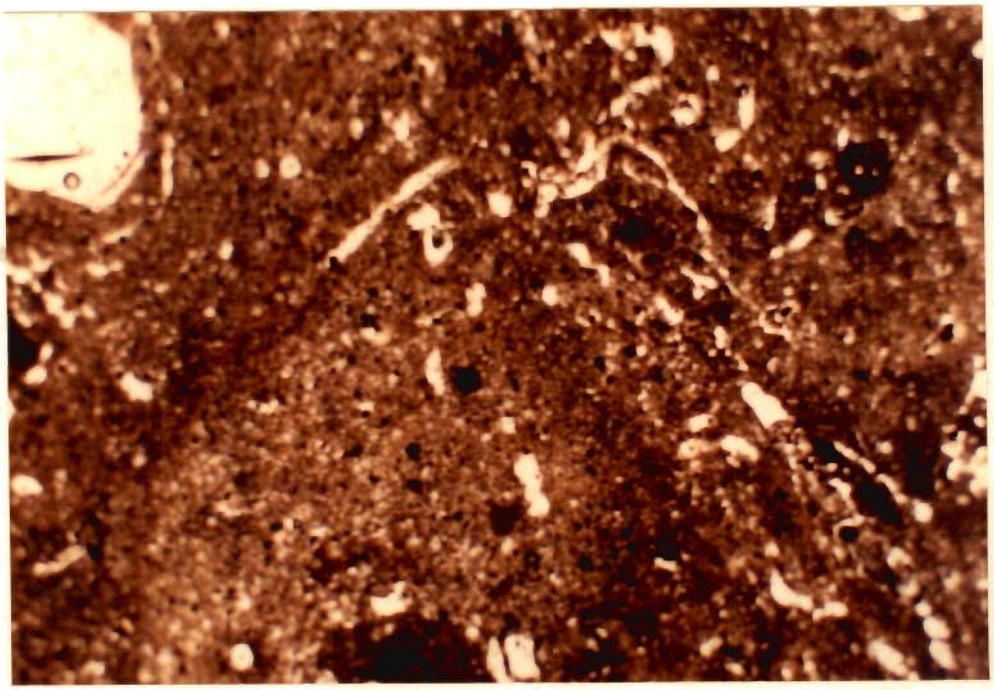

Fig. 4.74 Cone shaped, large pedotuble, filled with basic soil, showing distinct fabric from adjacent matter. Pedon PC14, B22 horizon, Lower Rapti-Ghaghra Interfluve, Frame length 7.5 mm, PPL.

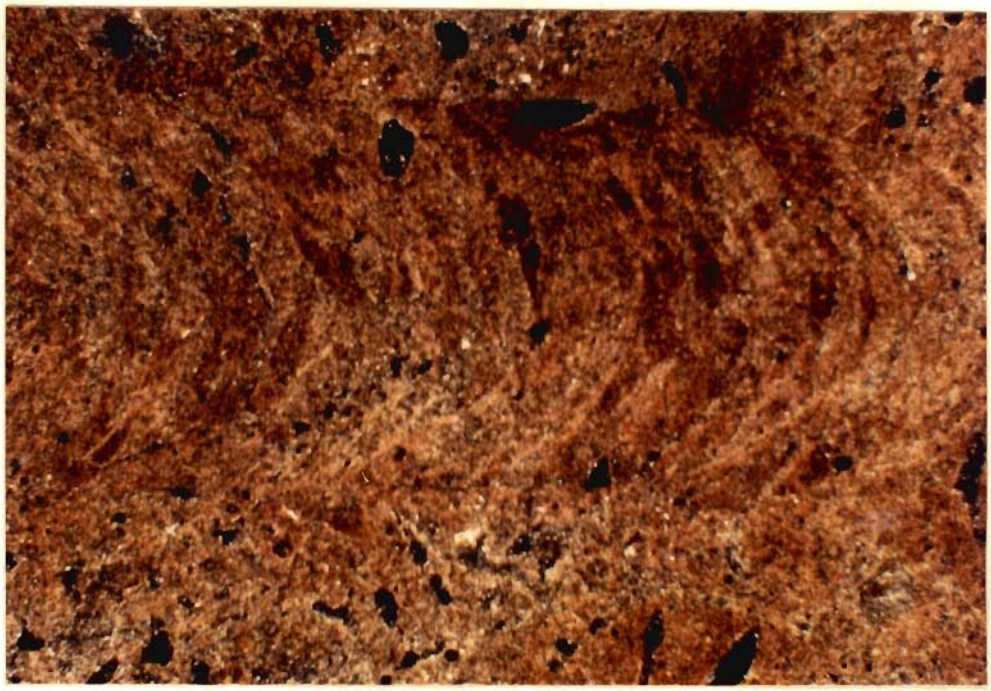

Fig. 4.75 Strong animal activity in form of a large isotuble, which is filled with reworked basic soil matter in crescent shaped manner. Pedon PC12, B2 horizon, Lower Rapti-Ghaghra Interfluve, Frame length 20 mm, XPL.

Deoha/Ganga Ghaghra Interfluve and Lower Rapti Ghaghra Interfluve dominantly show porphyric related distribution. Other units show enulic and porphyric distributions.

The finer fraction (plasma) mainly consists of fine silt and clays. This fraction has undergone different degrees of preferred orientation. In floodplains and young piedmonts (Group I) in upper horizons undifferentiated b-fabric is observed due to fine opaque organic matter, whereas in lower horizons strongly developed parallel striated b-fabric (parallel to bedding) is observed due to sedimentary layering. Rarely weakly to moderate development of stipple speckled and cross b-fabric is observed. The soils of group II commonly show moderate to strong development of cross- and reticulate striated b-fabrics, and weak to moderate development of stipple speckled, poro- and grano-striated is rarely observed at places. Soils of group III show moderate to strong development of cross- and reticulate striated b-fabrics which are more common than in soils of group II. Rarely weakly to moderately developed concentric and parallel (normal to bedding) striated b-fabrics are also observed at places. Soils of Group IV commonly exhibit strong development of cross and reticulate striated b-fabrics and rarely strongly developed parallel striated b-fabric (normal to bedding). Grou V soils are marked by commonly occuring strongly to very strongly developed cross and reticulate striated b-fabrics and parallel striated (normal to bedding) is more strongly and commonly developed than in Group IV

The coarse fraction minerals (mainly quartz, mica, and

feldspars) are fairely fresh to very weakly altered in QGH1 and QGH2 soils. Feldspars show alteration to sericite and biotite exofoliates and weathers to release iron oxide on a large scale in the soils of QGH5. The other soils show intermediate degree of alteration of feldspars and biotites.

Development of argillan particularly along voids and also along grains, due to illuviation has been observed. Strongly oriented, microlaminated 100-200 µm clay cutans are quite common in Middle Deohara/Ganga-Ghaghra and Lower Rapti-Ganga Interfluves. Also clay papules of limpid to speckled clay are observed in these soils. Thickness of the cutans and abundance decreases with decrease in age of soils. In soils of floodplain and piedmonts cutans do not occur.

Various calcrete feature are observed. These include type I, II and type III calcretes. In older soils such as in the Middle Deoha/Ganga-Ghaghra, Lower Rapti-Ganga Interfluves and in Lower Deoha/Ganga-Ghaghra Interfluve calcrete occurs in B horizon as well as in C horizons. In B2 horizons pure micritic hypocoatings and thin cylindrical to rounded nodules are observed. These are classified as type I calcretes. But in B3 & C horizons calcretes are coarsely crystalline and they occur in form of sparitic nodules. These sparitic nodules are mixed with basic soils which often show dissolution & precipitation along void surfaces. These are classified as type II calcretes. In other units (Upper Kosi-Gola Plains and Floodplains of the Ghaghra and Rapti rivers) calcretes occur in B2 to C horizon. These units are marked by high water table. Calcrete occurs as micritic groundmass and

coarsely crystalline calcite. Major pedofeatures are sparitic nodules and also a few coarsely crystalline calcite grains with sharp boundaries which force apart the ground mass. Additionally crystic plasmic b-fabric is observed in most of the thin-sections of these calcareous soils. These calcretes are termed as type III.

CHAPTER 5

SUMMARY, SYNTHESIS AND CONCLUSIONS

5.1 INTRODUCTION

The Indogangetic Basin is presently covered by one of the most extensively developed fluvial plains of the world, i.e. the Indogangetic Plains. This basin has been subjected to tectonic processes since its inception (Parkash and Kumar, 1991) and the tectonism must be affecting the development of soils and morphology of these plains presently. Also, the Thar desert in the western part of these plains witnessed a climatic change from cold arid to warmer climate at about 10,000 yrs B.P. (Singh et al., 1972, 1974). The possibility of such a climatic event affecting the rest of the Indogangetic Plains is very high. Though the Indogangetic Plains are apparently monotonous, the application of the technique of soil-landscape mapping and detailed investigations of soils has proved to be very useful in studies of some parts of the Indogangetic Plains (Singhai, 1988; Mohindra, 1989, Kumar, 1991; Mohindra et al., in press). Keeping the above points in view, the central parts of the Gangetic Plains between rivers Ramganga and Rapti in eastern Uttar Pradesh state, has been mapped by remote sensing techniques along with field checks for their soil-geomorphic units and associated tectonic features. Detailed study of soils of the different soil-geomorphic units has been used to develop a soil-chronoassociation. Also the role of tectonism and climatic changes on development of morphology and soils of the area has

been elucidated.

5.2 INVESTIGATION PROCEDURES

Identification of various geomorphic units for the study area was carried out using the studies of topographic maps, Landsat B & W images, and FCC's of Landsat and IRS 1A. A morphological map has been prepared based on these studies. Later on, detailed field work has been carried out to confirm the variability of soil characteristics in these geomorphic units. Field examination followed by laboratory studies, have confirmed that the soils in individual geomorphic units are fairly uniform or show variation in a small range. Therefore, these geomorphic units can be referred as soil-geomorphic units. The field work has been carried out along three main A, B and C traverses so as to cover all the major soil-geomorphic units. In addition to pedons along the three traverses, some pedons were examined separately to record the variation in soil characteristics in different soil-geomorphic units. A total of 55 soil profiles (pedons) were studied in the field. Master horizons as well as sub-horizons were studied in field and various soil properties such as colour, texture, structure, mottling, lime content, consistency etc. were recorded for each horizon/or subhorizon, according to U.S.D.A. Soil Taxonomy (1978). Thickness of each horizon/subhorizon was also recorded in each pedon. Of the 47 soil profiles studied in the field, 32 profiles were chosen for detailed laboratory analyses. A total of 166 samples were analysed for grain size distribution using the method of Galehouse (1971). Finer fraction (<2μm) has been

used to identify the clay minerals by X-ray diffraction method. The clay minerals were identified using the scheme given by Wilson (1987) and their semi-quantitative estimation was carried out using the procedure of Klages and Hopper (1982). Chemical analysis of the nine major elements was done using two solution method given by Shapiro (1975).

In determining the degree of soil profile development , clay accumulation index of Levine and Ciolkosz (1983) was calculated for different pedons from grain size distribution data. Also for this purpose, molar ratio SiO_2/R_2O_3 where $R_2O_3 = Fe_2O_3 + Al_2O_3 + TiO_2$) was determined from chemical analysis data of soils.

Distribution of quartz and feldspar has been investigated using the X-ray diffraction method (see Hashmi and Nair, 1986). Stable isotopes $\delta^{13}C$ and $\delta^{18}O$ of calcretes in soils were determined by reacting calcrete with 100% phosphoric acid. The liberated CO_2 was analysed on a Mass Spectrometer (McCrea, 1950).

Micromorphological investigation for 43 oriented blocks of undisturbed soils was carried out by impregnating them with crystic resin by the method described by Jongerius and Heinztberger (1963) and Miedema et al. (1974). Large thin-sections of 60 x 40 mm size were made from impregnated samples. Thin-sections were described according to the terminology given by Bullock et al. (1985). Also the degree of b-fabric development is described by terms such as weakly, moderately, strongly and very strongly developed. The extent of development is measured by the percentage of area of thin-section by a particular b-fabric. The terms used for this are rare (<10%), common (10-20 %) and

very common (>20%).

5.3 GENERAL FEATURES OF THE STUDY AREA

The study area is a part of the vast Gangetic Plain. The area covers a major part of eastern Uttar Pradesh. This area includes a major part of the eastern Upper Ganga Plain and some part of the Middle Ganga Plain (Singh and Singh, 1971).

The study area is a monotonous plain area with negligible relief. Topographically the most significant feature of the area is a submontane belt, running at the foot of the Siwalik Hills. It strikes roughly E-W and lies in the northern part of the area. The belt consists of two parallel strips, the piedmont zone (called the Bhabhar) and the Tarai belt. The Bhabhar zone is 10-30 km wide and comprised of coarse unsorted alluvial fan sediments. The central part of the Bhabhar in the study area has been severely dissected due to stream erosion. The Tarai belt, 12 to 15 km wide, is a gently sloping zone of groundwater seepage. It consists of fine sand, silt and clays and is a highly fertile alluvial tract.

Major rivers in the study area are a part of well integrated drainage system of the Ganga. Characteristic features of drainage of the area are:

1. The Ghaghra and the Ganga are large extra-basinal, perennial rivers with discharges of 94,400 and 58,980 million m^3 respectively in the area. The Ramganga is an intermediate size extra-basinal river with an annual discharge of about 15,620. It is impounded by a dam and carries significant discharge only

during rainy season.

2. Numerous small streams arise in the Siwalik Hills and are braided in nature over the piedmont zone. These form a sub-parallel drainage pattern. Most of them are lost in the piedmont zone. Only a few of them continue further south into the Gangetic Plains. They may get lost in the plains or ultimately join the master stream especially in the western part of the area. In the middle and eastern parts of the area, most of Siwalik streams leaving the piedmont zone join the longitudinal Sarda and Rapti rivers respectively, flowing along the southern boundary of this zone.

3. Some alluvial streams i.e. Sai and Kalyan arise in the plains or at the base of piedmont zone. During monsoon season these streams carry large discharges supplied by overland flow. During other seasons, these are fed by groundwater and carry small discharge only. These flow in a region of gentle gradient and form a pinnate drainage pattern.

4. Rivers like the Ghaghra and Rapti show a typical and similar change in direction in the study area. First these flow in southeasterly direction, then to ESE and finally in almost easterly direction. This give them a curved path with a convexity in the southwest direction.

The Ramganga, Gomti and Kosi are braided in the upper reaches and change to meandering nature away in south. The river Ghaghra maintains its braided character almost over the whole area. The major morphological feature in study area is stable

upland (Interfluves) between Deoha-Ganga and Rapti rivers and these are 15-20 m above the adjoining floodplains.

The climate, in general, can be described as subhumid for the study area. The climate is mainly controlled by the proximity to Himalayas. The rainfall increases and temperature decreases as one moves nearer to Himalayas from south. The rainy season accounts over 90% of total annual rainfall. The monsoon rainfall and annual rainfall decreases westward as well as southward in study area.

5.4 MAJOR SOIL-GEOMORPHIC UNITS

Using remote sensing techniques and detailed field and laboratory analysis, the following fourteen soil-geomorphic units have been recognized.

Soil-Geomorphic Units	Symbols
i. Kosi - Gola Piedmont	KGPD
ii. Upper Kosi-Gola Plain	UKGP
iii. Lower Kosi-Gola Plain	LKGP
iv. Upper Deoha/Ganga-Ghaghra Interfluve	UDGGHIF
v. Middle Deoha/Ganga-Ghaghra Interfluve	MDGGHIF
vi. Sihali-Mohan-Kandra Piedmont	SMKPD
vii. Old Sihali-Mohan-Kandra Piedmont	OSMKPD
viii. Upper Rapti-Ghaghra Interfluve	URGHIF
ix. Lower Rapti-Ghaghra Interfluve	LRGHIF
x. Ghaghra Floodplain	GFP
xi. Old Ghaghra Plain	OGP
xii. Old Ghaghra Bar	OGB
xiii. Rapti Flood plain	RFP
xiv. Gholia-Dhobania-Bhambhar Piedmont	GDBPD

An additional unit of the Lower Deoha/Ganga-Ghaghra Interfluve, earlier studied by Mohindra (1987) in detail, has been taken into consideration for classifying these units. Based on field soil characters, texture and chemical composition, five

groups of soils were defined in Chapter 3 and this classification was confirmed by micromorphological studies in Chapter 4. Since these groups reflect degrees of soil profile development, these can be classified as members of a soil-chronoassociation (Mohindra et al., in press) (Table 5.1).

TABLE 5.1 : SOIL CHRONOASSOCIATION FOR THE STUDY AREA

Member	Estimated age Yrs. B.P.	Soil of geomorphic surface included.
QGH1	< 500	Floodplains of Ghaghra, and Rapti, Kosi-Gola Piedmont Gholia-Dhobania -Bhambhar Piedmont, Sihali-Mohan-Kandra Piedmont
QGH2	> 500	Upper Kosi-Gola Plain, Old Ghaghra Plain, Sihali-Mohan-Kandra Piedmont
QGH3	> 2500	Lower Kosi-Gola Plain, Upper Rapti Ghaghra Interfluve, upper Deoha/Ganga-Ghaghra Interfluve, Old Ghaghra Bar
QGH4	> 6500	Lower Deoha/Ganga-Ghaghra Interfluve
QGH5	9,000-11,000	Middle Deoha/Ganga-Ghaghra Interfluve, Lower Rapti-Ghaghra Interfluve.

The soil-geomorphic units of the Ghaghra Floodplain, Old Ghaghra Bar and Old Ghaghra Plain are genetically related and are a part of the vast geomorphic unit of the Ghaghra Plains. These plains, as a whole, are incised in the Deoha/Ganga-Rapti structural block (discussed later) and as a result are marked by a series of cliffs of 15- 20 m. height on the bothsides i.e. on

the east and west or north and south sides. These plains are wide (40-45 km) in the central region near Gonda and taper down to 10-15 km in south beyond Faizabad.

A brief description of the morphology and soils of various soil-geomorphic units is given below.

5.4.1 QGH1 Member

5.4.1.a Ghaghra Floodplain

The river Ghaghra, a major river, runs for a stretch of about 330 km in the northeastern part of the study area. It debouches from a deep gorge cut in the Siwalik Hills near Surkhet in Nepal. It enters the Gangetic Plains near Kaurialaghat in Kheri district. Two major tributaries in the plains- the Sarju and the Sarda rivers join the river Ghaghra from east and west respectively. In B&W Landsat images a broad zone of uniform dark gray tone with occasional light gray patches of braid islands/bar are seen along the river course, suggesting a high moisture and shallow groundwater table in this region. This zone marks the floodplain of the river Ghaghra, which shows braided nature all through its course in the study area.

5.4.1.b Rapti Floodplain

The river Rapti enters the Gangetic Plains near Singhaiaghat through a cut in the Siwaliks in Nepal. It is a single thread river, straight to tightly meandering in nature. It flows in southeasterly direction for a stretch of 30-40 km and then in E-W direction. The floodplain of this river is wide 15-20 km in central part and the width decreases both in the upstream and downstream directions.

5.4.1.c Kosi-Gola Piedmont

This unit marks the northwestern boundary of the study area. In north it is bounded by the Siwalik Hills. This unit is 20-25 km wide and extends in an elongated pattern parallel to the foothills. This unit is underlain by coarse and unsorted sediments brought down by subparallel to parallel streams. It is marked by a high drainage density. Most of the streams loose their discharge in the piedmont due to percolation and only the Kosi and Gola rivers continue further south. The streams shift their courses frequently and this unit is marked by high rate of net aggradation.

5.4.1.d Sihali-Mohan-Kandra Piedmont

This geomorphic unit of Sihali-Mohan-Kandra Piedmont is 20-25 km wide extending E-W below the foothills. It is bounded by the Ghaghra and Sarda rivers in the east and west respectively. This region has been extensively affected by tectonic activity due to upliftment, resulting in severe dissection of the piedmont by several small streams running in N-S direction before joining the river Mohana. The Mohana flows from West to East along a fault at the base of this unit and forms its southern boundary. As a result two soil-geomorphic units can be recognised from this geomorphic unit i.e. Young and Old Sihali-Mohan-Kandra Piedmonts. The Young Sihali-Mohan-Kandra Piedmont is marked by active floodplains of braided streams and covered by poorly developed soils. The Old Sohali-Mohan-Kandra Piedmont is remnant, undissected part of the Piedmont and overlain by moderately developed soils. Only soil-geomorphic unit of the Young Sihali -

Mohan - Kandra Piedmont is included in QGH1 member.

5.4.1.e Gholia-Dhobania- Bhambhar Piedmont

This geomorphic unit lies in northeastern part of the study area, bound by Siwalik Hills in the north and Rapti Floodplain in the south. This unit is named after three prominent streams of the area. In B&W Landsat images it shows uniform light gray tone with medium texture. Numerous streams forming subparallel to parallel drainage pattern, flow in the southerly direction. Most streams are braided in nature. These spread their load over an even surface and disappear due to the loss of discharge caused by seepage. A few streams continue southwards and join the Rapti river flowing at the base of the unit. Some of the streams are slightly incised in the lower part of their courses. On the whole, it is an actively aggrading piedmont.

5.4.1.f Soils of the QGH1 Member

Field examination of these soils shows that these are very poorly developed soils, mostly with A/C type horizonation and rarely with thin B2 horizon (15-20 cm) in the distal part of the Kosi-Gola Piedmont. Texturally these are coarse to medium textured. Distribution of sand, silt and clay with depth in many of the profiles suggest primary sedimentary layering. Variation of major oxides and SiO_2/R_2O_3 ratio do not show any significant trend with depth in the soil profiles of this unit. The fine fraction (<2μm) of these soils generally consists of illite, kaolinite, vermiculite and chlorite, in descending order of abundance. Micromorphological investigations show that pedality development has not taken place and the apedal and

massive structures are often noted. Voids are mainly vughs with extremely rough internal surface. Weak to moderate plasma separation is observed. Stipple speckled and cross-striated b-fabrics are common. Also undifferentiated b-fabric observed is due to the presence of fine organic matter. Most of minerals are fresh, except for plagioclase, which is very weakly altered. Lithorelicts of shale/schist are observed.

Irregular shaped calcareous nodules are associated with the lower horizons. Their abundance increases with depth. The complexity in shape and size of nodules suggests their precipitation from shallow groundwater prevailing in these units.

5.4.2 QGH2 Member

5.4.2.a Upper Kosi-Gola Plain

This unit is bounded by the Kosi-Gola Piedmont in the north and by the Lower Kosi-Gola Plain in the south. Major rivers which drain this landsurface are the Kosi and Gola originating in the Siwalik Hills and a few alluvial rivers like Pilakhar. This surface is a typically undulatory in nature. Though the regional slope is 1-2m/km due south, small local variation from this trend as shown by direction of alluvial streams can be explained by dichotomic slopes (Harward, 1967) over the medium sized Kosi and Gola alluvial fans in the area. Some of the alluvial streams occupy old courses of the Kosi and Gola rivers.

5.4.2.b Old Ghaghra Plain and Old Sihali-Mohan-Kandra Piedmont

The Old Ghaghra Plain covers parts of the Ghaghra Plains between the Ghaghra and its tributary Sharda river in the north

and a narrow strip of 10-20 km width all along the eastern side of the Ghaghra Floodplain.

The general morphology of the Old Sihali-Mohan- Kandra Piedmont has been described earlier. It shows dark tone on image due to dense forest vegetation.

5.4.2.c Soils of QGH2 Member

Soils of this member are moderately developed. The solum (A+B) thickness ranges from 58 to 110 cm. The B2 horizon thickness is quite variable from 21 to 48 cm. Color of these soils is 2.5Y hue with chroma 5-6 and 3-6 value. Colours are grayer, where $CaCO_3$ concretions are concentrated. Pedality is weakly to moderately developed. Sesquioxide mottles and concretions increase in frequency and size and become softer with depth. Calcium carbonate nodules occur in many soil profiles of this member. Carbonate concretions are irregular shaped and range from 0.5 mm to 1.5 cm in size. Abundance of these concretions also increases with depth. Texturally the soils are medium grained with silt as a dominant constituent. Clay translocation has occured to some extent and the clay accumulation index varies from 131.67 to 353.43.

Due to leaching environment, silica is depleted in the lower B2 horizons, whereas Al_2O_3, Fe_2O_3 and TiO_2 have shown relative increase. Other elements do not show any significant variation, except CaO which shows an increase when finer calcrete is present. The SiO_2/R_2O_3 ratio shows a relative decrease of 28.60 to 45.00 % in the B horizon with respect to A horiozn.

Major clay minerals occurring in these soils are illite, kaolinite, vermiculite and chlorite.

Micromorphological investigations confirm the weak to moderate development of pedality. Peds are usually subangular and are partially separable. Vughy and vesicular microstructures are common. In A horizon chitonic and gefuric related distribution is noted, whereas in B horizon the C/F related distribution is usually porphyric. Illuviation of clay has taken place, as 20-30 µm thick limpid to dusty clay hypocoatings along channel voids are observed. Plasma separation is moderate to strong, as strongly developed cross- and reticulate striated b-fabrics are observed. Three type of calcrete features associated with these soils were noted : (i) Thick hypocoatings by fine (micritic calcrete) along vesicles and voids, (ii) irregular shaped sparitic nodules, and (iii) dissolution/decalcification of these nodules along voids. Reworked basic soils matter in the form of isotubles in B horizon suggests strong animal activity.

5.4.3 QGH3 Member

5.4.3.a Lower Kosi Gola Plain

This is a triangular shaped unit bounded by the Upper Kosi-Gola Plain in north, in west by the Ramganga river and in east by the Deoha river. This unit is drained by a small incised alluvial stream and is marked by coarse texture in Landsat images.

5.4.3.b Upper Deoha/Ganga-Ghaghra Interfluve

This unit comprises the upper part of the stable land

between the Ghaghra and Deoha/Ganga rivers. This is an even landsurface with very low regional slope of less than 1m/km in south eastern direction. In Landsat images this unit shows uniform gray tone with fine to medium texture. It has been differentiated from the lower part of the Interfluve by its slightly darker gray tone due to the complete absence of salt fflorescence. Rivers draining this unit are the Gomti, Katana and Sukheta Gomti. The last one is a Siwalik river, while others are purely alluvial streams, originating from the Bhabhar and Tarai tracts. These streams have very narrow channels and erosion is prominent on either sides of these rivers creating large tracts of badland.

5.4.3.c Upper Rapti-Ghaghra Interfluve

Similar to the unit discussed above, this unit also makes the Upper part of stable land surface between the Rapti and Ghaghra floodplains. In Landsat images this unit is marked as a bright patch with medium texture due to good drainage. This unit is rectangular in shape. A few small alluvial rivers like the Kuvana and Bisuhi drain this unit.

5.4.3.d Old Ghaghra Bar

The river Ghaghra seems to have left behind certain ancient bars during its movement/migration across its floodplain. These bars have not been affected by recent depositional processes like the active floodplain of the Ghaghra. The unit can be recognised distinctly in B&W Landsat images, as the old bars comprising this unit show slightly brighter tone than the adjacent surfaces within the floodplain.

5.4.3.e Soil of the QGH3 Member

Field investigations of the soils of this member indicate that the thickness of solum varies from 82 cm to 145 cm and thickness of B2 horizon ranges from 52 cm to 85 cm. Subangular blocky to angular blocky soil structure is moderately to strongly developed. Colour of these soils ranges from 2.5Y to 10YR hue. Sesquioxide mottling and Fe-Mn concretions are less prominent in the Upper Deoha/Ganga-Ghaghra Interfluve, as compared to the Lower Kosi-Gola Plain and in Upper Rapti-Ghaghra Interfluve. In later units mottling and concretion increase in size and abundance with depth. Fe-Mn nodules are globular in shape and the largest size is 1-2cm. In some profiles from slightly low-lying areas with shallow water table, $CaCO_3$ concretion formation is taking place in B2 to C horizons. Their size and abundance increase from B to C horizons. Texturally these soils vary from sandy loam to silty loam. Clay content shows appreciable increase from A to B2 horizon. The clay accumulation index calculated for these soils ranges from 501.00 to 840.69. Molar ratio SiO_2/R_2O_3 decrease in B2 horizon with respect to A horizon ranges from 32.6 to 46.6%.

Micromorphological investigations have confirmed the moderate to strong pedality development. Peds are often accommodating and partially separable. Minerals are moderately weathered and biotite flakes are often exofoliated and bleached. Channel and vughy microstructures are often noted. In B2 horizon subangular blocky structures are very well developed. Plasma separation is very strong in B2 horizon, as poro- and

grano-striated reticulate and cross-striated b-fabrics are commonly noted and concentric b-fabric are observed rarely. Illuvial pedofeatures such as ferroargillans are widely developed in B2 horizons. Often these argillans occur as microlaminated hypocoating along channel voids and vesicles. Thickness of these argillans ranges from 50 to 70 μm. Diffused sesquioxide mottles and Fe-Mn concretions are also noted. At least three types of calcareous pedofeatures are associated with these soils: (i) Due to fine calcareous micritic matter in groundmass, crystic plasmic b- fabric is noted, (ii) typic sparitic nodules of $CaCO_3$ with sharp boundaries are observed, and (iii) thick, irregular shaped calcareous nodules which are densely intermixed with basic soil matter and are often masked by ferruginous matter. Animal activity in the form of densely filled reworked soil in crescent shaped isotubles is noted.

5.4.4 QGH4 Member

5.4.4.a Lower Ganga-Ghaghra Interfluve

Description of morphology and soils of this units is based on the work of Mohindra (1989). Soils of this group are exposed east of the Middle Deoha/Ganga-Ghaghra Interfluve. In Landsat images this unit is marked by patchy distribution of salt showing bright tone and associated waterlogged area showing dark tone. The Burhi Sarju and Gomti are the main rivers flowing through the middle of this unit with narrow deeply incised channels.

5.4.4.b Soils of the QGH4 member

Soils of this unit are characterised by the moderately

developed soil profiles. Solum thickness varies from 85 - 115 cm. with 42-70 cm. thick B2t horizons. Color of these soils varies from light olive brown to olive brown in 2.5Y hue with moist value of 4 to 5.5 and chroma 2 to 5. These soils are fine textured and show accumulation of clays in B2 horizons. Clay accumulation indices vary from 730.75 to 1221.70. Variation of major oxides and molar ratio show that these are moderately to strongly developed soils. Among clay minerals, chlorite occurs in minor amount with illite, kaolinite and vermiculite constituting major clay fractions.

Micromorphological studies confirm moderate to strong development of subangular blocky structure. The peds are partially separable and accommodating. The voids are mainly channels and interpedal packing voids. The channel voids are usually smooth due to hypocoatings (50 - 100 µm) by speckled to impure clays.

Moderate to strong plasma separation is observed in the form of commonly occurring cross- and reticulate striated b-fabrics. At places strongly oriented porostriated b-fabric is also noted.

Calcrete pedofeatures are common in these soils and often comprise about 10% of the thin section area. Notable features include typic orthic and strongly impregnated nodules of various shapes and sizes. Thin wire type (500-600 wide and 4-5 mm in length) composed of micritic calcite is noticed. Large (3-5 mm diameter) irregular shaped micritic nodules showing diffused boundaries and development of prismatic calcite in part of the

nodule are observed. At places thick 500-600 μm hypocoatings by the micrite are also observed.

5.4.5 QGH5 Member

5.4.5.a Middle Deoha/Ganga-Ghaghra Interfluve

This is the largest soil-geomorphic unit and lies in southeastern part of the study area. It includes the middle part of the Deoha/Ganga-Ghaghra Interfluve. In Landsat images it is very distinctive, as this unit is highly salt affected, and very broad patches of bright toned salt-affected region alternating with grayer non-salt affected patches are observed. Salt-affect-ed regions are topographically slightly lower than non-salt affected regions. Main rivers draining the landsurface are the Sai, Gomti and Kalyan. Sai and Kalyan are purely alluvial. These streams show deep downcuttings and large tracts of ravine land are associated with them. Also due to improved drainage, salts have been leached out from areas adjoining to these streams. This unit is an even landsurface with regional slope of less than 1 m/km in general.

5.4.5.b Lower Rapti-Ghaghra Interfluve

This is the second major soil-geomorphic unit in the study area and includes the lower part of the stable upland between floodplains of the rivers Rapti and Ghaghra. In tone and texture, this unit is similar to the Middle Deoha/Ganga-Ghaghra Interfluve. However, streams draining this unit are fewer as compared to the later unit. The Bisuhi and Kuvana river are the main alluvial rivers draining this part. Regional slope of this plain landsurface is very low (<1m/km) in south easterly

direction.

5.4.5.c Soils of QGH5 Member

Soils of this member are the most developed. Solum in general is more than 150 cm and B2 horizon thickness is typically more than 93 cm and ranges from 93 to 137 cm. Subangular blocky and angular blocky soil structure is strongly developed. The soils generally show 2.5Y and 10YR hue and are grayer when $CaCO_3$ content is high. Many of the soil profiles in this member contain $CaCO_3$ concretions in B2 to C horizons. The calcite concretions are variable in size and shape. Generally finer disseminated concretions occur in B2 horizons and large, dense complex shaped ones in B3 or C horizons. Some of the profiles close to salt affected areas have calcite concretions occurring throughout the profile. Soil formation has been affected by the calcite concretion accumulation as the pedons free of the $CaCO_3$ accumulation show higher thickness of B2 horizon (108 to 137 cm) than the soils with calcite accumulation (93-94 cm). Sesquioxide mottles and concretions are common feature of these soils. Strong animal activity is observed in B2 horizons. Sometimes globular sand balls are noted from these horizons.

Grain size distribution shows that the clay illuviation has taken place to the maximum extent in these soils. Most of B2 horizons qualify for argillic or Bt horizon (Birkelend, 1983, p. 45). The clay accumulation index ranges from 1010.88 to 1544.07. Similarly chemical analysis of these soils show silica depletion and increase of Al_2O_3 and Fe_2O_3 from A horizon to B2 horizon which are maximum as compared to soils of other members. Molar

ratio SiO_2/R_2O_3 decrease from A to B2 horizon is in the range of 28.49 to 53.70%.

Strong development of pedality is confirmed by the micromorphological studies. Peds are subangular to angular and in some places platy structure is also noted. Voids are few and show smooth boundaries. Often their walls are coated with clays. Illuvial argillic pedofeatures are very common. Thick continuous limpid, clay coatings occur along channels and vesicles and along skeletan grains, forming poro- and grano-argillans. The hypocoatings of illuvial clay are quite thick (100-200μm) and are characteristically microlaminated. Papules of ferruginous clays are also noted in B2 horizon. Plasma separation is very strong. Strongly developed poro- and grano-striated and parallel striated (normal to bedding) b-fabrics are noted in B2 horizon. Various calcareous pedofeatures such as crystic plasmic b-fabric, micritic hypocoatings, sparitic nodules and dissolution of calcite along voids are observed.

5.5 SYSTEMATIC VARIATION OF SOIL CHARACTERISTICS

Systematic changes in soils of QGH1 to QGH5 members of the soil-choronoassociation can be observed in respect of soil-morphology, texture, chemical composition and micromorphology. These changes are discussed below.

5.5.1 Soil Morphology

The soils in the area show systematic variation from the least developed soils in member QGH1 to the most developed soils in QGH5. Thickness of B2 horizon shows gradual increase from member QGH1 to QGH5. In member QGH1 often A/C type soil

horizonation is observed and rarely thin (15-20 cm) B horizon is encountered in the proximal part of the Kosi-Gola Piedmont. In member QGH2 the B2 horizon thickness ranges from 21 to 48 cm and its range is 42 to 85 cm in soils of member QGH3. In member QGH4 the solum thickness is upto 115 cm along with moderately to strongly developed B2 horizon upto 72 cm. In member QGH5 B2 horizon is thicker (108-137 cm) in soils free of calcium carbonate accumulation than those with accumulation of calcium carbonate concretions (93-94 cm).

5.5.2 Textural Variation

Coarse textured (sandy loam) soils occur in QGH1 member soils, and these do not show any significant variation in sand, silt and clay content with depth due to primary fluvial sedimentation. Soils of other members are mainly silty loams and become heavier with higher degree of development, especially in B horizon. Degree of illuvial translocation has also been assessed by calculating clay accumulation index of Levine and Ciolkosz (1983). In QGH2 member this Index typically ranges between 214.0 to 351.0 with an exceptional value of 605.6. QGH3 soils show moderate amount of clay translocation and the index varies from 693.3 to 845.3. QGH4 soils show substantial clay translocation to lower horizon and the index ranges from 560.90 to 1050.00. In member QGH5 the clay translocation is maximum and the index ranges from 1010.9 to 2361.42.

The figures are so large that there may not be any significance of reporting the data upto decimal level

5.5.3 Chemical Composition

Soils are generally rich in silica and poor in Fe_2O_3 indicating acidic nature. In QGH1 soils there is no significant

lacking clarity.

variation in the distribution of oxides with depth. In soils of QGH2 member the silica decreases to a small extent and Fe_2O_3 and Al_2O_3 show small increase with depth. The molar ratio decrease in B horizons with respect to A horizons ranges from 28.60 to 45.00 %. In QGH3 member soils the decrease in the molar ratio is in the range of 32.60 to 46.01. Decrease of the molar ratio in QGH4 is in range from 25.90 to 28.90%. In QGH5 soils the maximum decrease of SiO_2 and maximum increase of AL_2O_3, Fe_2O_3 and TiO_2 is noted and the molar ratio decreases and is in the range of 28.49 to 53.07%.

5.5.4 Clay Mineralogy

Fine fraction (<2 μm) of the soils show that the dominant clay minerals present in the soils are illite, kaolinite, vermiculite and chlorite in decreasing order of abundance. Chlorite is sensitive to degree of pedogenesis and is present in significant amounts in soils of member QGH1 and QGH2 and its content decreases in QGH3 soils. It is present in small amount in QGH4 member soils and is completely absent in QGH5 soils.

5.5.5 Micromorphology

Micromorpholgical investigations show QGH1 member soils lack pedality development. QGH2 soils exhibit weakly developed subangular blocky peds, which are partially separable. In QGH3 soils moderately developed subangular blocky structure is seen and moderately to strongly developed pedality is observed in QGH4 soils. QGH5 soils show strongly to very strongly developed subangular to angular blocky structure with well separable peds. Intergrain and compact grain microstructures are common in

younger soils whereas vughy and channel microstructures are common in the soils of older geomorphic units.

Dominant voids occurring in the soils are channels, vughs and vesicles. In QGH1 soils the surfaces of the voids are extremely rough and sometimes simple packing voids are noted. In QGH2 and QGH3 soils the voids are rough to smooth due to thin coatings along them. In QGH4 the voids in general are smooth and in QGH5 soils the voids are dominantly smooth due to thick argillan coatings.

Plasma separation and the development of b-fabric (Fig. 5.1) show distinct changes with the degree of soil profile development. In QGH1 soils, the upper A horizons exhibit undifferentiated b-fabric due to the presence of opaque organic matter and the lower horizons are marked by strongly developed parallel striated b-fabric (parallel to bedding) due to sedimentary layering. Rarely weaker to moderate development of stipple speckled and cross b-fabric is observed. QGH2 member soils commonly show moderate to strong development of cross- and reticulate striated b-fabric and weak to moderate development of stipple speckled, poro- and grano- striated b-fabric is rarely observed. Soils of QGH3 member exhibit moderate to strong development of cross- and reticulate striated b-fabrics, which are more common than in soils of QGH2 member. Rarely weakly to moderately developed concentric and parallel (normal to bedding) striated b-fabric are also observed at places. QGH4 member soils show common strong development of cross- and reticulate striated b-fabrics and rare strong development of parallel striated b-

fabric (normal to bedding). Soils of QGH5 member are marked by commonly occurring strongly to very strongly developed cross- and reticulate b-fabrics and parallel striated (normal to bedding) is more strongly and commonly developed than soils of QGH4 member.

5.5.6 Micromorphology of Calcrete

Calcretes are observed in soils belonging to the youngest to oldest members of the chronoassociation. Three types - I, II and III, of calcretes are recognised in soils of the study area. Type I and II calcretes occur in soils of QGH4 and QGH5 member. Type I calcrete typically occurs in B2 horizons where as type II calcrete occurs mainly in B1 and C horizons of the soils. Type III calcretes may occur in any soil horizon of soils QGH1-QGH3 members, depending upon depth of ground water. Type I calcretes are fine, hard, dense, and irregular in shape and constitute from 2-15% of soil matter and type II and III calcretes are coarse, less dense, (sometimes spongy and vesicular) and comprise 10 - 40% of the soil mass by volume. Micromorphologically Type I calcretes show crystic plasmic b-fabric due to micritic groundmass and typic, orthic, strongly impregnated micritic nodules. These calcretes show second stage of carbonate morphology development of Gile et al. (1966). Type II and III calcretes show coarsely crystalline sparitic hypocoatings along channel voids and vesicles and sparitic, typic, orthic nodules which are often associated with voids and show dissolution and precipitation features.

5.5.7 δC^{13} and δO^{18} Isotopic Composition of Calcretes

δC^{13} and δO^{18} isotopic determination of all types of

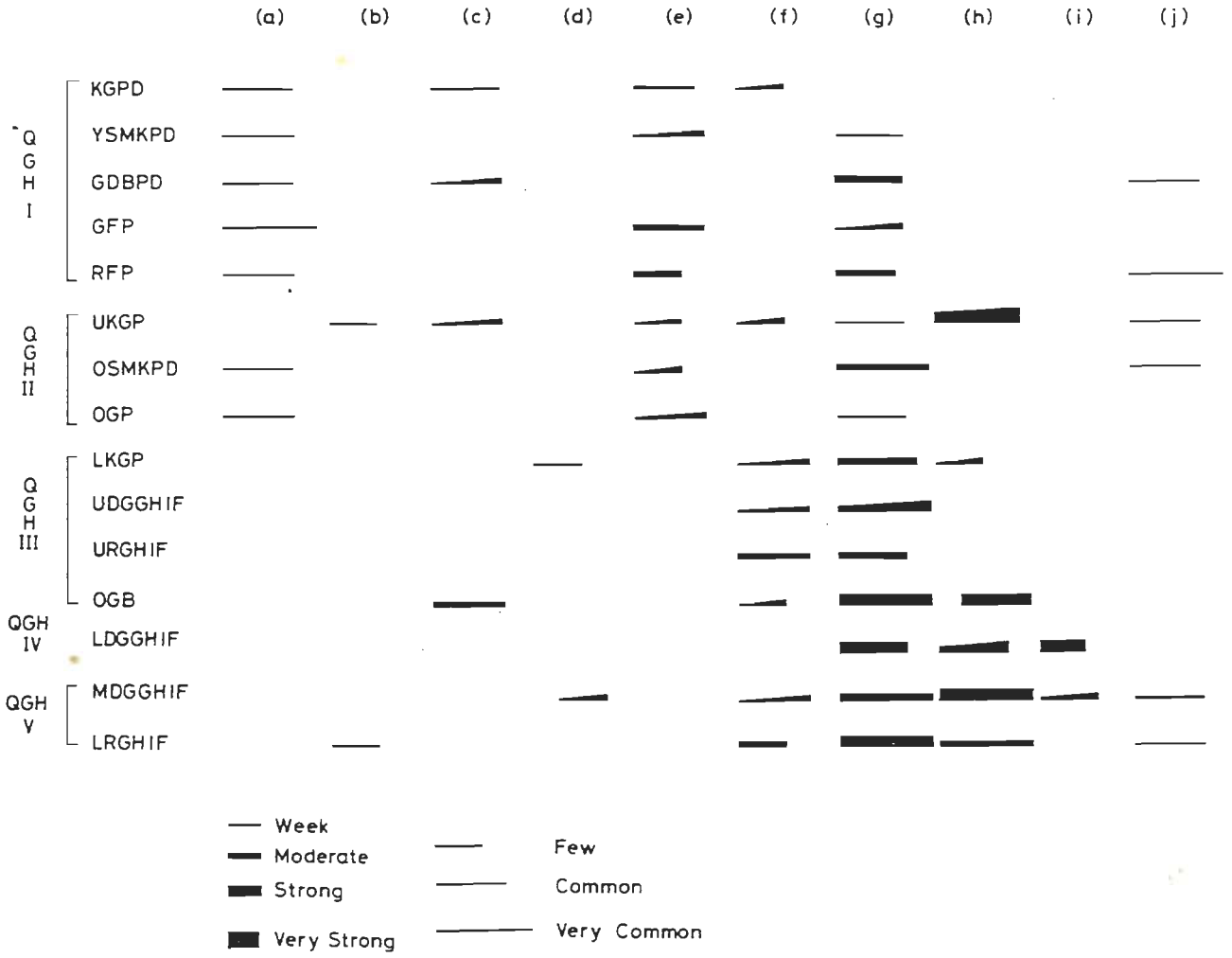

Fig. 5.1 Extent and relative intensities of various b-fabrics. a - Undifferentiated, b - granostriated, c - porostriated, d - cross striated, e - reticulate striated, f - parallel striated (normal to bedding), g - parallel (along the bedding), h - stipple speckled, i - crystic plasmic and j - concentric b-fabric.

calcretes show a small variation of $\delta^{18}O$ in a range of -8.10 to -10.47 $^{o}/_{oo}$ with an average of -8.90 $^{o}/_{oo}$. $\delta^{13}C$ has been relatively depleted in Type I calcretes and show a range of -2.39 to -6.90$^{o}/_{oo}$ in values, whereas Type II and III calcretes show enrichment of $\delta^{13}C$ as the values lies between 0.60 to 1.64$^{o}/_{oo}$.

5.5.8 Variation of Quartz and Felspar Contents in C Horizons

The Thar Desert in the western part of the Indogangetic Plains experienced a climatic change from cold arid to hot humid climate at about 10,000 yrs.B.P. as indicated by study of pollens from core sample of lake sediments in the area (Singh, 1971; Singh et al., 1972, 1974). Similar conclusion was reached by Hashmi and Nair (1986) from the investigation of composition of sediments of the western Indian continental shelf. Felspar content of sediment is a sensitive indicator of climate, especially in the case of first cycle ones (Basu, 1975, 1976; Folk, 1961; Fairbridge, 1976; Girty, 1990). Assuming that source of the sediments brought in by the rivers from the Himalaya and deposited in the Indogangetic Plains remained constant during the short span of the Holocene, felspar content of these sediments could reflect climatic conditions in the source area. Keeping this in view, felspar contents of sand and silt fractions of C horizons from different geomorphic units were determined using a procedure described by Hashmi and Nair (1986). The main aim was to infer the climatic variation for the Holocene Period in the Gangetic Plain.

The counts for peak intensities, of quartz and feldspar for

parent material for older geomorphic surfaces such as the Middle Deoha/Ganga-Ghaghra and Lower Rapti-Ghaghra Interfluve, for quartz range from 5833.3 to 8333.3 and for feldspars from 1209.2 to 2511.5. The counts particularly for total felspars in other geomorphic surfaces such as in floodplains and in piedmonts are low and range between 201.7 to 888.8. Ratio of absolute counts for total felspar and quartz gives better differentiation between different units. For upland areas such as the Upper and Middle Deoha/Ganga-Ghaghra Interfluves, Upper and Lower Rapti-Ghaghra Interfluve and Lower Kosi-Gola Plain, the ratio of felspar and quartz ranges from 0.15 to 0.30. This ratio shows lower values (0.11 to 013) for the Upper Kosi Gola Plain and Old Ghaghra Bar. The lowest values for this ratio (0.04 to 0.1) are recorded for floodplains of the Ghaghra and Rapti and piedmonts.

The higher values of felspars for the older geomorphic surface (Middle Deoha/Ganga-Ghaghra Interfluve Plains and Upper and Lower Ghaghra-Rapti Plains) from the study area are attributed to deposition in such areas during an arid climate. As discussed later, they are assigned an Early Holocene age and it coincides with an arid climatic phase. This climate helped to preserve the feldspars from weathering. Whereas decreasing values of feldspars for the other geomorphic surfaces with decreasing age (which are younger than 10,000 yrs B.P., as discussed later) could be due to a climatic change from arid to present day humid (Monsoonic) climate.

5.6 STRUCTURE AND TECTONIC FEATURES OF THE STUDY AREA

Based on mapping of soil-geomorphic features and drainage

patterns in the area, two major tectonic features i.e faults and tectonic blocks can be identified (Fig. 5.2). Major faults recognised are:

1) Ganga fault
2) Deoha fault
3) Sarda fault
4) Ramganga fault
5) Balrampur - Lucknow fault
6) Utraula - Amethi fault
7) Ghaghra fault
8) Himalayan Frontal Fault

5.6.1 Ganga Fault

This fault was studied by (Kumar, 1991) in region further west of the present area. In his area, it separates the oldest unit of Ganga-Yamuna Interfluve in south from much younger unit of Ramganga-Ganga Interfluve in the north. In the present area the Ganga Floodplain is of incised nature. It has straight course and takes sharp turns at places. On two sides of its floodplain occur the oldest soil geomorphic units with kankar, salt efflorescence and well developed soils.

5.6.2 Deoha Fault

The narrow, straight channel of the Deoha river follows this fault. This fault marks the western boundary of the oldest soil-geomorphic unit i.e. Middle Deoha/Ganga-Ghaghra Interfluve and separates it from younger units of the Kosi-Gola Piedmont and Upper and Lower and Kosi-Gola Plains in the west. This fault has affected the Frontal Fold Belt also and consequently eastern part of Frontal Fold Belt has moved towards south, relative to the western part along this fault.

5.6.3 Sarda Fault

It is a longitudinal fault, marking the boundary of

floodplains of the Ghaghra and Sarda in south from the Sihali-Mohan-Kandra Piedmont in north. The Sarda river after entering the plains should have continued south, following the regional slopes. However, it takes an easterly turn due to uplifting of the Deoha/Ganga-Ghaghra Block along this fault.

5.6.4 Ramganga Fault

The river Ramganga follows short straight segments of 20 to 120 km in length, separated by sharp turns. Near foothills east of the Ramganga the drainage pattern is in SW direction and in west the drainage and paleodrainage are subparallel to the active Ramganga course. The landsurface east of the Ramganga is higher by 3 to 4 m in comparison with that in west. Soil-geomorphic units east of the Ramganga vary in ages from QGH3 to QGH1, whereas that in the west soils are older than the QGH3 member (Sudhir Kumar, pers. comm.).

5.6.5 Ghaghra Faults

Ghaghra I and Ghaghra II faults separates the Ghaghra plains from the adjoining upland areas in the east and west and trend NW-SE and WNW-ESE respectively. These are marked by cliffs of 10 - 15 m. relief. These two faults join at Faizabad and continue as Ghaghra III fault along the Ghaghra floodplain in an easterly direction.

5.6.6 Balrampur - Lucknow and Utraula - Amethi Faults

Balrampur - Lucknow and Utraula - Amethi Faults trend NE-SW direction and coincide approximately with northwestern and southeastern boundaries of the Faizabad ridge. The sinuosity and

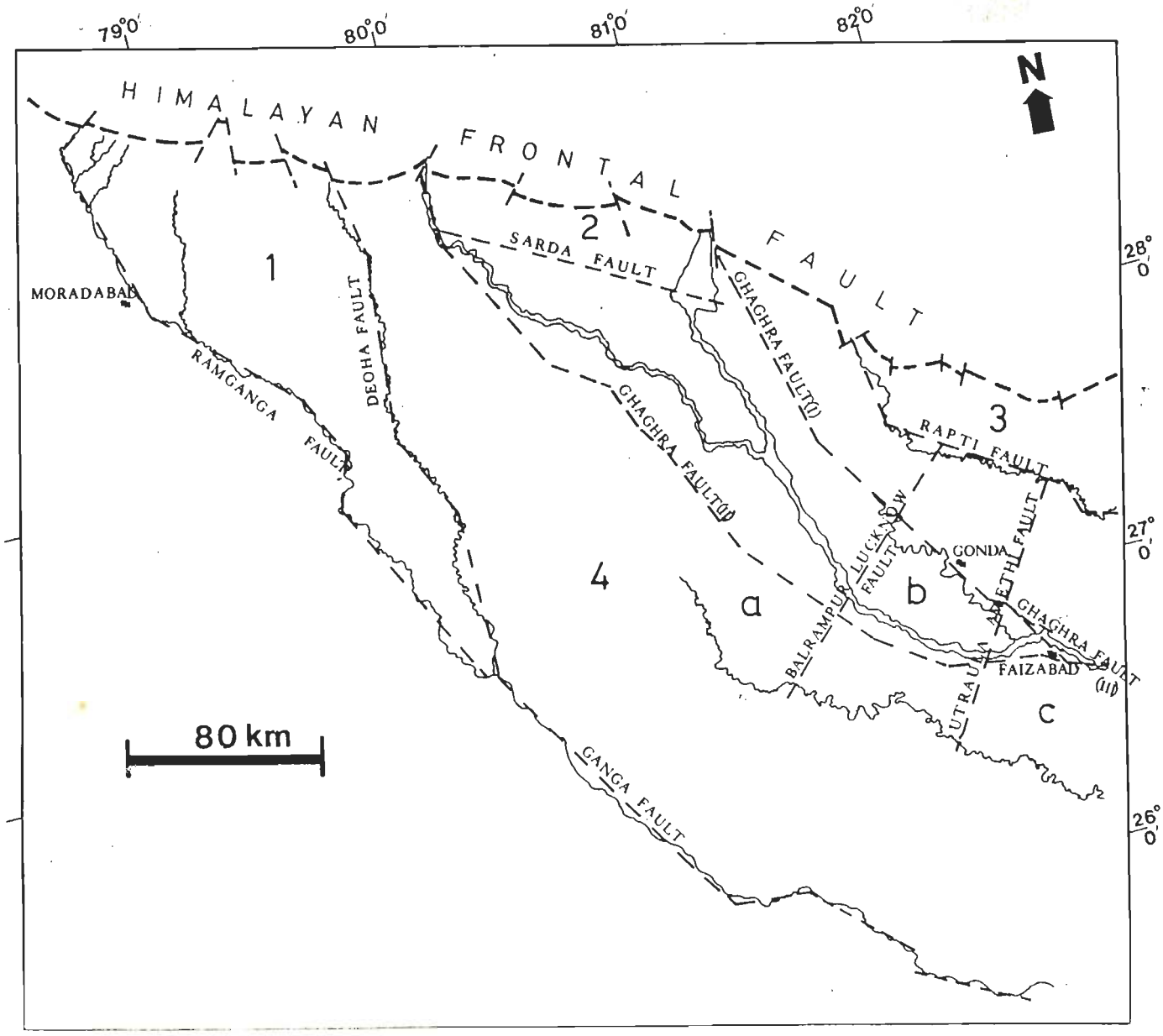

Fig. 5.2 TECTONIC MAP OF THE STUDY AREA. 1- RAMGANGA-DEOHA BLOCK, 2- SARDA BLOCK, 3- RAPTI BLOCK, 4- DEOHA/GANGA-RAPTI BLOCK, a- BHARAICH SUB-BLOCK, b- GONDA SUB-BLOCK, c- FAIZABAD SUB-BLOCK

width of the floodplain rivers like the Gomti, Ghaghra, Rapti etc. changes as these rivers move across these faults.

5.6.7 Rapti Fault

This fault separates Gholia - Dhobania - Bhambhar Piedmont from the Lower Rapti - Ghaghra Interfluve and controls the course of the Rapti river

5.6.8 Himalayan Frontal Fault

This fault system separating the geomorphic systems of the Siwalik Hills and Indogangetic plains was first mapped and named as Himalayan Frontal Fault in eastern Nepal by Nakata (1983). This fault has been mapped earlier in different areas by a number of workers (Nakata, 1983; Singhai 1988; Mohindra 1989; Kumar 1991). In the present area, it is a set of EW running faults, offset by a number of transverse faults trending NW-SE and NS. In the eastern area, the transverse faults are mainly right lateral faults.

5.6.9 Tectonic Blocks

The whole study area can be divided into four major blocks separated by faults and these blocks have behaved independently and have been affected by uplift/subsidence, tilting and sagging at different times. Their existence and behaviour have been inferred from width of floodplains and changes in courses and changes in sinuosity of streams along their course and distributions of soils. The major blocks are Ramganga-Deoha Interfluve Block, Rapti Block, Sarda-Ghaghra Interfluve Block and Deoha/Ganga-Rapti Interfluve Block.

Within Deoha/Ganga-Rapti Block, covered by soils of oldest QGH5 member of soil chronoassociation over most of the area a number of sub-blocks ie. Bahraich, Gonda and Faizabad can be identified. The Bahraich sub-block covers northern part of main block and continues up to Balrampur-Lucknow Fault. This sub-block is marked by exceptional widening of the floodplains of the Rapti and Ghaghra as compared to upstream as well as downstream areas. Also the Gonda sub-block between Balrampur - Lucknow and Ulraula - Amethi Faults coincides with the Faizabad Ridge. Within this sub-block as compared to adjoining areas, a higher tightening of meanders in the course of rivers Gomti, Sai and Rapti and Sarju in the floodplain of the Ghaghra is observed. This is due to the sagging of this sub-block and reactivation of the Faizabad Ridge.

Rapti Block and Sarda-Ghaghra Interfluve blocks are overlain by Gholia-Dhobania-Bhambhar and Sihali-Mohan-Kandra Piedmonts respectively and have been subsiding in the recent past to accommodate high sedimentation in these units. The Ramganga - Deoha block also has subsided to give rise to pedofacies association discussed below.

5.7 DISCUSSION

5.7.1 Soil Chronoassociation

Soil chronoassociation has been defined by Mohindra et al. (in press) as a grouping of soils based on the degree of development of soils in areas with varied climate and parent materials. In the present area, too, climate and probably parent material varied drastically. An integrated approach has been used

to group these soil-geomorphic units into five soil chronoassociation members (Table 5.1) on the basis of thickness of B2 horizon, field characteristics, clay accumulation index, decrease in SiO_2/R_2O_2 ratio from A horizon to most developed B horizon, degree of pedality, thickness and nature of argillans and plasma separation.

Earlier workers (Mohindra, 1989; Kumar, 1991) thought that all the upland areas of the Gangetic Plains, containing calcrete and showing salt fflorescence were of same age in the range of 9000-11,000 yrs.B.P., as these dates are the oldest ones, reported for calcretes from the top soils of the Middle Deoha/Ganga-Ghaghra Interfluve (Rajagopalan, 1988). However, in the present study, the Lower Deoha/Ganga-Ghaghra Interfluve is considered to be younger and has been separated from the Middle Deoha/Ganga-Ghaghra Interfluve, on the basis of detailed soil morphological and micromorphological characters, though both are marked by salt afflorescence and show apparently similar remote sensing characters. The Middle Deoha/Ganga-Ghaghra Interfluve has been grouped into the oldest member QGH5 of the soil chronoassociation and given an age of about 9000-11000 yrs B.P. as suggested by Mohindra et al. (in press) and Kumar (1991), whereas the Lower Deoha/Ganga-Ghaghra Interfluve is included in the younger QGH4 member. The soil description of the Lower Ganga-Yamuna Interfluve by Kumar (1991) suggests that these soils are similar to those of the Lower Deoha/Ganga-Ghaghra Interfluve. Two ages of calcrete, one each from the Lower Deoha/Ganga-Ghaghra Interfluve and Lower Ganga-Yamuna Interfluve are 6500 and 7000 yrs B.P. (Mohindra et al., in press; Kumar,

1991). Thus soil of the QGH4 member and their equivalents can be tentatively assigned an age of more than 6500 yrs.B.P.

Soils of the QGH3 member overlap characters of soils of QGH3 and QGH4 members of soil chronoassociation on the Gandak megafan and adjoining area (Mohindra et al., in press) just east of the present area and thus can be assigned an age of more than 2500 yrs B.P., as suggested by Mohindra et al. (in press).

Ages for other members of the chronoassociation are tentative.

5.7.2 Pedogenic Processes in the Area

About 90% of the study area is covered by QGH4 and QGH5 member soils, which are marked by calcretes and surface efflorescence of salts. Also parts of the area covered by other soils are also characterised by the presence of calcrete. An integration of field and laboratory analysis of data on the soils suggest the following points regarding the origin of calcretes of the area:

i. Micromorphology of type I calcretes, occurring mainly in QGH4 and QGH5 soils and typical positive values of $\delta^{13}C$ for them suggest that they are pedogenic in nature. Conditions for their formation prevailed till about 6500 yrs. B.P. Type II and III calcretes are characterised by precipitation and dissolution pedofeatures on a large scale. Such processes lead to depletion of $\delta^{13}C$ in the precipitated calcrete (Salomons et al., 1978). Indeed the negative values of $\delta^{13}C$ support such a hypothesis. It is suggested that type II calcretes have formed by partial

dissolution of type I calcrete and its reprecipitation in the lower horizons, due to amelioration of climate.

Type III calcrete occurs from surface to C horizon in areas with shallow groundwater table and is found in soils of QGH1-QGH3 member. Frequent occurrence of precipitation and dissolution pedofeatures and negative $\delta^{13}C$ values in this calcrete suggest that these have precipitated from groundwater.

ii. Remote sensing investigations and field studies suggest that in QGH4 and QGH5 member soils, calcretic soils and non-calcrete soils occur in alternate patches. These patches follow general slope of the area as followed by streams draining such regions. Calcretic soils are also marked by salt efflorescence on the surface. Calcretic soils are typically confined to slightly lower areas, (probably representing old floodplains) and are fine grained in C horizons and poor drainage. As compared to these soils, non-calcretic soils are confined to topographically slightly higher area, marked by coarser C horizon, (probab-ly representing former stream channels) and better drainage conditions. Also, non-calcretic soils have better developed soils (B2 horizon 108 - 137 cm thick) than calcretic soils (B2 horizon 93 - 94 cm thick). This may be due to the fact that in addition to the above mentioned differences, the presence of calcrete and illuviation of clays (Birkeland, 1984, p.45). Thus it seems that nature of parent material, microtopography and drainage conditions have acted together and resulted in calcrete development in former floodplains.

iii. Detailed study of morphology and soils of eastern parts of the Lower Rapti-Ghaghra Plain by Mohindra (1989) (not covered in the present study) indicate that the degree of the development of soil in that area, as deduced from morphology and micromorphology of soils, is similar to that of soils of the the Lower Rapti-Ghaghra Interfluve in the study area. However, soils in the eastern part are devoid of calcrete and salt efflorescence, a typical feature of the present area. It is suggested that in the eastern area close to the Rapti river, due to amelioration of climate since last major aridity (9000-11000 yrs. B.P.) and improved drainage, calcrete and salts have been washed out of the soil profile. This is a case of retrograde pedogenesis. Similar case of retrograde pedogenesis has been observed on a large scale on the Lower Ganga- Yamuna Interfluve by Kumar (1991).

As it is observed from the above discussion, formation of pedogenic calcite was significant process during the period of 6500 yrs B.P. to 1100 yrs B.P. Since then dissolution and reprecipitation of calcrete have been significant pedogenic processes in a more humid climate. Ground water precipitation of calcrete is a major process at present. The other pedogenic process is illuviation of clay. Using Birkland's criteria of accumulation of clay in B2 horizon and presence of argillans, B2 horizon of soils of QGH4 to QGH5 can be termed as Argillic Horizon.

Significant weathering of feldspar to sericite and exfoliation and bleaching of biotite and release of iron oxide by breakdown of biotite are observed on a large scale in the soils

of QGH4 and QGH5 members. These minerals are fresh to very weakly altered in soils of QGH1 and QGH2 members. The other soils show intermediate degree of weathering of these minerals.

5.7.3 Role of Tectonics in Development of Soils and Morphology

Tectonics seems to have played a major role in development of soils and morphology of the area. Significant phenomena caused by this process are as follows:

1. The Deoha/Ganga-Rapti Block bears imprint of tectonic activity in a number of ways. The widening of floodplains of the Ghaghra and Rapti in Lucknow sub-block can be explained by tilting of the Rapti-Ghaghra part of the sub-block towards southwest, as a consequence of a compressive force acting from that direction. This force may be caused by northeastern movement of the Indian Plate. Also the Gonda sub-block seems to have reacted to this compressive force differently. This sub-block has sagged slightly giving rise to higher sinuosity of the Gomti, Sai, Rapti and Sarju of the Ghaghra in this sub-block.

Slopes of the Lucknow, Gonda and Faizabad sub-blocks seem to have controlled the changes in the course of the major rivers in the area i.e. Ghaghra, Rapti, Gomti, etc. These sub-blocks have southeasterly, ESE and easterly tectonic slopes respectively and major rivers follow these slopes. This phenomenon gives them an easterly turn from an initially southeasterly course in the plains and a general convexity to the southwest.

Northern- and southern-most parts of the Deoha/Ganga-Ghaghra

Block behaved differently than the rest of the Block in past. The northernmost part (Upper Deoha/Ganga-Ghaghra Unit and Upper Ghaghra-Rapti Unit) received sediments from the Himalayan rivers till the beginning of development of QGH3 soils (2500 yrs B.P.), when Sarda Fault became active and changed the course of rivers in this area. It was accompanied by a slight uplift of the Upper Deoha/Ganga-Ghaghra and the Upper Ghaghra- Rapti Units. Also the Lower Deoha/Ganga-Ghaghra Unit received sedimentation till the beginning of development of the QGH4 member soils (6500 yrs B.P.).

The Deoha/Ganga-Rapti block seems to have been uplifted in at least two stages as suggested by the identification of the Old Ghaghra Bar and Old Ghaghra Plain in addition to active Floodplain of the Ghaghra river.

2. The remaining three blocks mainly include piedmont zone and development of morphological and soil features in these blocks have been controlled by relative motion of the Siwalik Hills and the adjoining areas in the plains. The Ramganga-Deoha Block is an elongated block and trends NW-SE. The other two blocks- Sarda -Ghaghra and Rapti Blocks are narrow, 10-30 km wide, running parallel to the Himalayan trend. All these blocks have been sites of subsidence and have been receiving sediments shed by rise of the adjoining Himalayas, especially the Siwaliks Hills. The Ramganga-Deoha and Rapti Blocks probably had a simple history in the recent past and were marked by mainly aggradation. However Sarda-Ghaghra block had entrenched drainage, due to slight uplift of the Piedmont zone, which permitted formation of QGH2 soils on

this Block. More recently the area has been probably further uplifted, leading to further incision of the area and removal of soils on a larger scale.

The Ramganga-Deoha Block is covered by the Kosi-Gola Piedmont, Upper Kosi-Gola Plain and Lower Kosi-Gola Plain from north to south. The Kosi-Gola Piedmont is 10-25 km wide and is a site of sedimentation by numerous small streams originating in the Siwalik Hills. Further south the Upper Kosi-Gola Plain is 40-50 km wide and is a steep sloped plain and and major features recognised from this unit are two medium sized fans, Kosi fan with about 30 km diameter and Gola fan with a diameter of about 55 km. These fans, especially the Gola fan have been inferred from a few streams originating in plains and forming a dichotomic pattern because their channels are confined to the older courses of master streams. The southernmost unit, Lower Kosi-Gola Plain is marked by only a few streams with entrenched courses.

Systematic changes in the morphology, morphological processes and soils can be inferred from north to south on the Ramganga-Deoha Block. Gradual decrease in drainage density, change from braided to meandering nature of streams, increase in degree of entrenchment of streams, increase in stability of stream courses, decrease in rate of sedimentation and increase in degree of soil profile development are observed from north to south on this block (Fig. 5.3).

Brown and Kraus (1987) introduced the term pedofacies. According to them, the least developed soils form close to the channel, where sediment accumulation is rapid, whereas the most

developed soils forming the distal floodplain, where sediment cumulation rates are significantly lower and these soils constitute a pedofacies relationship. Soils of the Ramganga-Deoha Block constitute a pedofacies associated in the sense of Brown and Kraus (1987), as the degree of development increases with decrease in rate of accumulation from north to south. Comparison of the present pedofacies association with the models of soil development on alluvial fans by Zarza et al. (1992) suggest that the Ramganga-Deoha Block has subsided in the last 2500 years to accomodate sediments shed in the Himalaya; but the rate of rise of the Himalaya has increased with time during this period.

The time at the beginning of formation of QGH3 member soils (2500 yrs B.P.) was of high tectonic activity as that time activity of Sarda Fault and tilting of Lucknow sub-block and start of sedimentation/pedogenesis on the Ramganga-Deoha Block took place.

The major part of the study area is covered by upland tracts overlain by soils of QGH4 and QGH5 members and these have been stable since about 6500 yrs B.P. The Ramganga-Deoha Block, Sarda-Ghaghra Block and Rapti Block have been sites of sedimentation since about 6500 yrs B.P. Sihali-Mohan-Kandra Block has been subjected to erosion during the last 2500 yrs.

5.7.4 Role of Climate in Development of Soils

Climatic aridity during the period 9000-11000 yrs. B.P., coinciding partly with Younger Dryas event, left on imprint in the soils of QGH5 member with pedogenic calcite and saline

Fig. 5.3 Pedofacies diagram observed in study area. a - Schematic profile section from north to south, b - Schematic representation of soil characteristics from north to south in typical soil profiles, c - plot of total clay and pedogenic clay in typical soil profiles of the pedofacies sequence and d - important micromorphological features in soils of the pedofacies sequence.

epipedon. Later amelioration of climate, as discussed above, caused removal/partial dissolution of pedogenic calcite from middle horizons and its reprecipitation in the lower horizons as in soils of QGH5 member in the study area or complete removal of calcrete and salts from some areas as in the eastern part of the Lower Rapti-Ghaghra Interfluve.

The presence of pedogenic calcrete in QGH4 member soils suggest that amelioration of climate since about 10,000 yrs B.P. the conditions favourable for calcrete formation prevailed still later than 9000 yrs. B.P. and probably upto 6500 yrs. B.P.

Girty (1990) reported that along a climatic gradient, amount of felspars reduces drastically below a threshold only. On the basis of limited data on the occurrence of felspars in the C horizons of soils of the present study, it seems this threshold was reached only after start of depostion (> 500 yrs B.P.) of alluvial parent for QGH2 soils only.

5.8 CONCLUSIONS

Major important conclusions from systematic analysis of soils from study area are as follows :

(1) Fourteen soil-geomorphic units have been recognised using remote sensing data, field checks and laboratory analysis. These units are (i) Kosi-Gola Piedmont, (ii) Upper Kosi-Gola Plain, (iii) Lower Kosi-Gola Plain, (iv) Young Sihali-Mohan-Kandra Piedmont, (v) Old Sihali-Mohan-Kandra Piedmont, (vi) Upper Deoha/Ganga-Ghaghra Interfluve, (vii) Middle Deoha/Ganga-Ghaghra Interfluve, (viii) Ghaghra Floodplain, (ix) Old Ghaghra Plain,

(x) Old Ghaghra Bar (xi) Upper Rapti-Ghaghra Interfluve, (xii) Lower Rapti-Ghaghra Interfluve, (xiii) Rapti Floodplain, (xiv) Gholia-Dhobania-Bhambhar Piedmont. In addition another unit of the Lower Deoha/Ganga-Ghaghra Interfluve described by Mohindra (in press) has been taken into consideration for further discussion.

(2) These fifteen soil-geomorphic units have been grouped into five members of a soil chronoassociation (QGH1 to QGH5, with QGH5 being oldest) on basis of degree of soil profile development on these units.

(3) QGH1 member (age <500 yrs. B.P.) includes soils of Kosi-Gola Piedmont, Ghaghra Floodplain, Young Sihali-Mohan-Kandra Piedmont, Gholia-Dhobania - Bhambhar Piedmont. QGH2 member (age >500 yrs. B.P.) includes soils of Upper Kosi-Gola Plain, Old Ghaghra Bar and Old Sihali-Mohan-Kandra Piedmont. QGH3 member (age >2500 yrs. B.P.) comprises soils of the Lower Kosi-Gola Plain, Upper Deoha/Ganga-Ghaghra Interfluve and Upper Rapti-Ghaghra Interfluve. Soils of the Lower Deoha/Ganga - Ghaghra Interfluve are included in the QGH4 member (> 6500 yrs B.P.). QGH5 member (9000 - 11,000 yrs B.P.) includes the Lower Rapti-Ghaghra Interfluve and Middle Deoha/Ganga-Ghaghra Interfluve soils.

(4) Physical and chemical weathering of mineral grains, translocation of sesquioxides and clay sized particles and their deposition in B horizon, and formation of pedogenic and non-pedogenic calcrete are the major soil forming processes in the study area.

(5) Three types of calcrete have been identified from the study area. Type I calcrete occurs in soils of QGH4 and QGH5 members and mainly in B2 horizons. It has formed during an arid period earlier than 6500 yrs BP. Type II calcrete was formed by dissolution of Type I calcrete and its precipitation in the lower horizons due to amelioration of climate. Type III calcrete are forming frequently in areas of high ground water table by precipitation from ground water. Micromorphological and $\delta^{13}C$ data of calcrete support the above conclusions.

(6) Pedogenic calcrete formed selectively in the former topographically slightly lower areas (probably floodplains) and parent material, microtopography and drainage also played significant role in calcrete formation in preferred areas.

(7) Large tracts of the Gangetic Plains marked by salt efflorescence and pedogenic calcite in soil profile are not marked by earlier workers, but they have at least two soil groups characterised by differing degrees of soil profile development.

(8) Tectonic has controlled evolution of morphology and pedogenesis in a significant way. A number of faults and tectonic blocks have been identified. Regional slopes of tectonic blocks control the courses of rivers like the Ghaghra, Gomati and Son and give them a convexity to southwest. Large tracts as Deoha/Ganga-Rapti Block have remained upland areas since about 6500 yrs. B.P. The Rapti, Sarda-Ghaghra and Ramganga-Deoha Blocks have subsided slowly to accommodate sediments shed by the rising

Himalayas. Activity along the Sarda Fault at about more than 2500 yrs. B.P. resulted in drastic change of course of the Sarda river and tilting of the Lucknow sub-block at that time resulted in widening of the Ghaghra and Rapti floodplains. Slight sagging of the Gonda sub-block resulted in increasing sinuosity of the Gomati, Sai, Rapti and a distributary of the Ghaghra. Sagging and tilting of these blocks was due to a compressional force from southwest.

(9) In the case of the Ramganga-Deoha Block, the rate of rise of the Himalayan foothills has increased since about 2500 yrs. B.P. as a result pedofacies association with a systematic decrease in degree of soil profile development from proximal area in the rates to distal area in soils is observed. Also there is a decrease in rate of sedimentation from north to south.

(10) The area experienced a dry climate during the period 9000-11000 yrs. B.P.. Later amelioration of climate especially later than 6500 yrs. B.P. has resulted in dissolution and removal of calcrete from soil profiles over large areas in the Gangetic Plains.

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APPENDIX-1

Particle Size Distribution In Soil Profiles Of Various Soil-Geomorphic Units

Depth (cm)	Horizon	Sand %	Silt %	Clay %	Texture	Clay Accumulation Index
			KOSI-GOLA PIEDMONT			
Pedon PA3						
0-40	Ap	50.81	36.89	12.29	loam	
40-70	C1	43.00	49.19	7.80	loam	
70-103	C2	43.46	47.62	8.90	loam	
103-128	C3	44.10	50.50	5.39	loam	
Pedon PA4						
0-36	Ap	29.90	50.60	19.42	silty loam	
36-50	B1	26.17	49.52	24.30	loam	
50-73	C1	34.49	51.14	14.36	silty loam	
73-110	C2	60.45	31.42	8.12	sandy loam	
			YOUNG SIHALI-MOHAN-KANDRA PIEDMONT			
Pedon PA10						
0-18	Ap	25.17	68.54	6.29	silty loam	
18-75	C1	27.04	62.02	10.93	silty loam	
75-120	C2	22.37	66.94	10.68	silty loam	
			GHAGHRA FLOODPLAIN			
Pedon PB10						
0-36	Ap	40.82	57.35	16.53	silty loam	
36-72	C1	25.41	61.90	12.68	silty loam	
72-118	C2	15.52	80.79	3.68	silty	
			RAPTI FLOODPLAIN			
Pedon PB14						
0-45	Ap	15.13	74.35	10.51	silty loam	
45-74	C1	16.16	74.20	9.64	silty loam	
74-82	C2	18.53	73.26	8.20	silty loam	
82-100	C3	23.60	60.39	16.01	silty loam	
100-132	C4	50.40	38.08	11.51	silty loam	

Pedon PB15

0-40	Ap	28.75	63.48	7.76	silty loam	
40-75	C1	19.93	63.15	17.00	silty loam	
75-115	C2	13.33	71.28	15.38	silty loam	
115-140	C3	14.87	66.80	18.33	silty loam	

GHOLIA DHOBANIA BHAMBHAR PIEDMONT

Pedon PC16

0-34	Ap	28.30	64.82	16.87	silty loam	109.99
34-66	C1	29.40	65.60	14.98	silty loam	
66-99	C2	16.49	74.92	8.58	silty loam	
99-120	C3	18.18	71.83	9.98	silty loam	
120-150	C4	16.98	76.45	6.56	silty loam	

UPPER KOSI-GOLA PLAIN

Pedon PA5

0-25	Ap	53.34	40.46	6.20	sandy loam	
25-40	B11	56.00	33.65	10.35	sandy loam	
40-60	B12	53.20	34.71	12.09	loam	
60-85	B2	34.66	42.05	23.33	silty loam	131.67
85-130	C	34.00	53.17	12.82	silty loam	

Pedon PA1

0-25	Ap	48.20	46.20	5.60	loam	
25-45	B1	46.47	42.23	11.30	loam	
45-85	B21	28.30	58.25	13.45	silty loam	353.00
85-110	B22	30.05	54.55	15.40	silty loam	
110 +	C	44.99	46.67	8.34	loam	

Pedon PA0

0-20	Ap	33.03	60.99	5.97	Silty loam	
20-38	A1	34.24	59.89	5.86	silty loam	
38-81	B12	28.22	59.50	12.27	silty loam	
81-110	B21	28.35	47.62	24.02	loam	648.83
110-128	B22	28.38	51.09	20.53	silty loam	
128-150	C	27.95	65.77	6.27	silty loam	

Pedon PA2

0-18	Ap	33.91	55.09	9.99	silty loam	
18-38	B1	29.07	60.34	10.58	silty loam	
32-63	B2	22.07	62.06	15.86	silty loam	212.97
63-90	C1	37.00	53.05	9.94	silty loam	
90-110	C2	49.64	42.17	8.18	loam	

Pedon PA6

0-30	Ap	51.96	32.86	15.18	sandy loam	
30-70	B1	23.50	59.44	17.00	silty loam	
70-80	B21	26.23	56.42	19.34	silty loam	
80-97	B22	24.16	51.00	24.83	silty loam	186.43
97-123	BC	31.00	52.35	16.64	silty loam	
123-173	C	33.73	50.84	15.42	silty loam	

Pedon PA9 105.68 ?

0-22	Ap	52.84	46.46	6.38	sandy loam	
22-48	B21	43.12	45.80	11.08	loam	
48-73	B22	58.09	31.44	10.47	sandy loam	224.14
73-118	C1	50.49	43.87	5.64	sandy loam	

OLD SIHALI-MOHAN-KANDRA PIEDMONT

Pedon PA15

0-18	Ap	47.76	39.80	12.20	loam	
18-47	B1	30.37	50.70	18.86	silty loam	
47-82	B2	25.96	54.68	19.30	silty loam	248.50
82-107	C1	25.23	69.15	5.60	silty loam	
107-130	C2	28.36	63.30	8.34	silty loam	

Pedon PA13

0-29	Ap	38.50	58.91	12.50	loam	
29-62	B11	18.36	64.80	16.74	silty loam	
62-89	B12	17.89	67.60	14.49	silty loam	
89-110	B2	24.07	48.59	27.21	loam	353.43
110-135	C1	11.60	75.69	12.60	silty loam	
135+	C2	18.12	71.41	10.38	silty loam	

OLD GHAGHRA PLAIN

Pedon PA14

0-25	Ap	37.46	55.86	6.67	silty oam	
25-60	C1	48.30	47.22	4.47	loam	
60-77	C2	69.57	27.38	3.04	sandy loam	
77-103	B2	27.85	59.96	12.18	silty loam	237.64
103-126	B3	27.27	64.50	8.22	silty loam	
126-155	C	33.03	59.32	7.60	silty loam	

Pedon PC10

0-11	Ap	32.67	63.22	4.10	silty loam	
11-21	B1	19.93	71.21	8.85	silty loam	
21-47	B2	25.21	63.55	11.24	silty loam	185.64
47-88	B3	12.12	78.08	9.80	silty loam	
88-157	C	38.26	56.34	5.40	silty loam	

LOWER KOSI-GOLA PLAIN

Pedon PA7

0-26	Ap	30.80	64.12	5.00	silt	
26-42	B1	31.07	62.69	6.23	silt	
42-66	B21	29.55	55.99	14.45	silty loam	
66-94	B22	27.69	56.99	15.31	silty loam	513.76
94-110	B3	27.02	60.45	12.52	silty loam	
110-128	C1	38.45	55.05	6.40	silty loam	
128-160	C2	37.32	55.83	6.80	silty loam	

Pedon PB2

0-30	Ap	33.30	59.21	7.48	silty loam	
30-54	B21	19.65	65.48	14.87	silty loam	501.00
54-90	B22	16.45	72.85	10.69	silty loam	
90-140	C	32.74	62.82	4.43	silty loam	

UPPER DEOHA/GANGA-GHAGHRA INTERFLUVE

Pedon PB4

0-20	Ap	32.02	61.20	6.70	silty loam	
20-60	B21	20.46	68.99	10.54	silty loam	
60-95	B22	20.16	63.15	16.60	silty loam	845.25
95-135	C	28.92	68.94	2.30	silty loam	

Pedon PB5

0-15	Ap	52.80	42.00	5.20	sandy loam	
15-40	B1	46.40	41.40	12.40	loam	
40-70	B21	44.00	38.00	17.80	loam	
70-94	B22	50.40	36.80	16.70	loam	650.7
94-120	B31	32.40	52.25	14.18	silty loam	
120-150	C	27.60	59.70	11.60	silty loam	

OLD GHAGHRA BAR

Pedon PB9

0-35	Ap	28.79	59.51	11.69	silt loam	
35-60	B1	30.86	58.05	11.09	silty loam	
60-118	B22	25.12	55.78	19.09	silty loam	720.80
118-145	B22	27.62	55.43	20.94	silty loam	
145-175	C	28.76	58.43	12.85	silty loam	

UPPER RAPTI-GHAGHRA INTERFLUVE

Pedon PB11

0-12	Ap	43.65	48.12	8.23	silty loam	
12-30	B1	32.50	56.90	10.60	silty loam	
30-62	B21	35.70	50.13	14.45	silty loam	
62-100	B22	23.43	60.12	16.45	silty loam	793.65
100-140	B3	27.63	60.50	11.80	silty loam	
140-172	C	32.80	58.96	8.23	silty loam	

Pedon PB12

0-18	Ap	43.30	47.80	8.80	loam	
18-43	B21	50.70	30.86	18.43	loam	840.64
43-82	B22	55.45	27.30	17.24	sandy loam	
82-130	C	69.90	25.31	4.70	sandy loam	

LOWER DEOHA/GANGA-GHAGHRA INTERFLUVE

Pedon RC-1*

0-10	10.20	82.30	7.50	
10-32	8.70	75.6	15.80	
32-52	5.8	67.1	27.1	1050.00
52-82	4.6	66.5	28.9	
82-100	5.1	74.5	20.4	
100+	17.6	75.7	6.7	

Pedon RC-2*

0-11	29.5	58.7	11.8	
11-23	17.3	68.5	14.2	
23-43	24.3	57.1	10.6	
43-67	23.1	55.3	21.6	
67-90	15.8	69.6	14.6	
90+	16.0	69.0	14.6	

Pedon RC-4*

0-12	9.8	81.0	9.2	
12-28	17.8	72.8	10.2	
28-48	11.1	69.6	19.6	560.90
48-71	12.0	69.5	18.5	
71-101	10.0	76.8	13.2	
101+	11.5	77.8	10.7	

MIDDLE DEOHA/GANGA-GHAGHRA INTERFLUVE

Pedon PB6

0-12	Ap	29.60	60.09	10.29	silty loam	
12-30	B21	17.94	64.17	17.88	silty loam	
30-55	B22	16.68	62.17	21.14	silty loam	
55-85	B23	12.17	65.50	22.32	silty loam	1010.88
85-120	B24	21.37	61.36	17.26	silty loam	
120-150	B3	28.70	59.28	12.00	silty loam	

Pedon PB7

0-18	Ap	28.34	63.03	8.63	silty loam	
18-38	B1	23.24	60.95	15.80	silty loam	
38-84	B21	21.85	50.66	27.40	silty loam	
84-133	B22	22.58	51.31	26.10	silty loam	2361.42
133-175	B23	23.32	52.55	24.10	silty loam	
175-200+	B3	32.32	54.56	13.12	silty loam	

Pedon PC7

0-18	Ap	26.64	59.46	13.90	silty loam	
18-38	B1	20.32	65.58	14.09	silty loam	
38-56	B21	19.76	66.31	22.92	silty loam	1155.46
56-83	B22	19.63	62.51	17.85	silty loam	
83-150	B23	22.48	61.23	16.28	silty loam	
150-200	C	20.22	70.80	8.97	silty loam	

Pedon PC4

0-22	Ap	19.99	70.18	19.82	silty loam	
22-47	B1	11.96	74.42	13.98	silty loam	
47-78	B21	16.89	68.14	14.96	silty loam	
78-116	B22	24.95	57.18	17.86	silty loam	
116-140	B23	21.68	60.57	17.74	silty loam	
140-200	C	28.34	61.80	9.86	silty loam	

Pedon PC1

0-15	Ap	28.96	59.94	11.09	silty loam	
15-29	B21	23.65	58.46	17.88	silty loam	
29-80	B22	15.66	58.65	25.68	silty clay loam	
80-125	B23	21.85	59.67	18.47	silty loam	

LOWER RAPTI-GHAGHRA INTERFLUVE

Pedon PC12

0-18	Ap	31.70	48.09	13.16	loam	
18-40	B21	32.65	48.75	18.59	loam	
40-78	B22	33.40	48.44	17.12	loam	
78-123	B23	28.21	50.70	21.00	silty loam	1075.18
123-149	B3	22.18	62.80	15.60	silty loam	
149-200	C	32.30	57.80	9.87	silty loam	

Pedon PC13

0-22	Ap	29.00	64.27	6.72	silty loam	
22-50	B1	40.34	47.20	12.46	loam	
50-66	B21	42.67	38.69	18.03	loam	
66-100	B22	38.19	52.39	19.41	silty loam	
100-137	B23	33.26	46.46	20.27	loam	1544.07
137-180	B3	35.46	47.86	16.68	loam	
180-222	C1	37.10	50.00	12.85	silty loam	
222-252	C2	42.94	51.08	6.53	silty loam	

Pedon PC14

0-16	Ap	29.64	60.80	9.56	silty loam	
16-30	B21t	22.05	62.32	15.62	silty loam	
30-75	B22t	16.29	64.40	19.30	silty loam	
75-95	B23t	15.44	63.70	20.78	silty loam	1045.62
95-127	B24t	12.97	66.80	20.22	silty loam	
127-155	B3	21.85	60.28	17.86	silty loam	

APPENDIX-II

VARIATION OF MAJOR OXIDES AND MOLAR RATIOS WITH DEPTH IN VARIOUS SOIL-GEOMORPHIC UNITS

DEPTH(CM)	SiO2 W	Al2O3 X	Fe2O3 Y	TiO2 Z	CaO	MgO	MnO	Na2O	K2O	W/X+Y+Z
KOSI-GOLA PIEDMONT										
Pedon PA4										
0-36	67.13	19.56	2.77	0.97	1.85	1.27	0.16	1.58	4.56	2.88
36-50	65.21	20.59	2.97	1.12	2.86	1.44	0.17	1.45	3.22	2.54
50-73	69.02	17.91	2.87	1.62	1.73	1.19	0.15	1.58	3.78	3.08
73-110	72.61	15.68	1.75	0.98	1.94	0.93	0.13	2.03	3.8	3.94
RAPTI FLOODPLAIN										
Pedon PB14										
0-40	66.60	21.80	2.18	1.81	1.91	1.20	0.04	1.15	2.77	2.58
40-74	66.38	21.37	2.29	1.89	1.55	1.25	0.04	1.73	2.81	2.60
74-82	63.55	24.55	2.54	1.85	1.40	1.21	0.06	1.62	2.64	2.20
82-100	62.21	25.10	2.40	1.93	1.28	1.40	0.07	1.85	3.18	2.11
100-132	59.10	27.28	2.73	1.72	1.48	1.97	0.06	1.97	3.29	1.86
Pedon PB15										
0-40	74.36	13.99	2.29	0.41	3.77	0.38	0.08	1.12	3.44	4.46
40-75	65.30	23.24	3.11	0.86	1.03	0.39	0.14	1.15	4.38	2.40
75-115	63.79	23.08	3.58	0.45	2.84	0.57	0.13	0.79	4.56	2.35
115-140	63.73	23.38	4.24	0.37	2.33	0.48	0.12	0.73	4.48	2.28
GHOLIA DHOBANIA BHAMBHAR PIEDMONT										
Pedon PC16										
0-34	71.13	19.84	3.25	0.39	0.80	0.22	0.04	0.49	3.68	3.03
34-66	72.21	18.20	3.05	0.30	0.90	0.25	0.07	0.50	3.69	3.35
66-99	70.50	18.65	1.94	0.88	4.21	0.30	0.04	0.46	2.87	3.28
99-120	66.80	17.67	2.40	0.81	6.85	1.10	0.07	0.58	3.57	3.20
120-150	59.13	22.05	3.25	1.18	8.94	0.45	0.05	0.46	4.36	2.23
Sihali-Mohan-Kandra Piedmont										
Pedon PA10										
0-18	76.16	15.36	2.23	0.34	0.60	0.60	0.05	0.72	3.41	4.24
18-75	74.15	16.37	2.75	0.99	0.69	0.33	0.09	0.48	4.01	3.68
75-120	75.45	14.77	2.34	1.28	0.73	0.24	0.06	0.28	3.76	4.10

Ghaghra Floodplain

Pedon PB10

0-36	63.30	25.55	3.10	0.10	1.01	1.48	0.08	1.27	3.35	2.20
36-72	64.45	24.51	3.18	1.18	0.09	1.33	0.10	1.21	2.54	2.23
72-118	64.70	24.18	3.41	1.15	0.87	1.37	0.10	1.20	2.59	2.25
118-145	63.12	25.12	3.20	1.12	0.93	1.45	0.08	1.15	2.77	2.14

UPPER KOSI-GOLA PLAIN

Pedon PA1

0-25	74.08	14.59	1.56	1.64	1.87	1.97	0.07	1.63	2.14	4.16
25-45	71.50	16.18	1.78	1.62	2.10	2.48	0.08	1.45	2.18	3.65
45-70	69.45	18.34	1.32	1.72	2.40	2.33	0.06	1.81	2.15	3.25
70-85	67.61	18.52	2.52	1.70	2.49	2.51	0.08	1.77	2.37	2.97
85-110	70.59	15.61	2.02	1.61	2.68	2.81	0.05	1.75	2.44	3.67

Pedon PA2

0-18	80.55	12.33	2.53	0.9	0.73	0.14	0.02	0.53	2.07	5.11
18-32	73.43	16.52	3.89	1.8	0.72	0.14	0.02	0.52	2.79	3.31
32-63	73.22	16.99	3.52	1.9	0.63	0.17	0.04	0.53	2.86	3.27
63-90	75.78	15.33	2.66	0.81	0.66	0.18	0.02	0.66	3.12	4.03
90-110	80.29	12.16	2.35	0.74	0.65	0.15	0.01	0.63	2.87	5.26

Pedon PA6

0-30	70.32	16.5	3.06	0.85	1.32	1.86	0.11	0.99	4.94	3.45
30-70	61.26	21.42	5.3	1.21	3.57	1.92	0.17	1.05	3.2	2.19
70-80	59.49	24.79	5.01	0.75	3.2	2.19	0.18	1.04	3.18	1.95
80-97	60.65	25.91	5.05	0.78	1.37	1.27	0.14	0.82	3.84	1.91
97-123	67.92	22.13	2.84	0.27	1.14	0.29	0.11	1.06	3.49	2.69
123-173	71.12	18.48	2.42	0.57	2.00	1.17	0.12	1.05	2.93	3.31

Old Ghaghra Plain

Pedon PA14

0-25	71.22	15.35	2.14	0.94	4.01	0.81	0.09	1.42	3.88	3.86
25-60	72.27	14.68	2.65	0.87	3.55	0.79	0.11	1.42	3.55	3.97
60-77	74.86	11.57	1.50	0.84	6.05	0.79	0.09	1.39	2.77	5.38
77-103	62.12	18.38	3.89	0.78	6.92	1.14	0.11	1.24	4.43	2.70
103-126	61.59	19.07	3.23	0.82	7.83	1.12	0.11	1.25	4.34	2.66
126-155	69.43	14.32	2.19	0.19	7.71	0.86	0.09	1.49	3.57	4.16

Old Ghaghra Bar

Pedon PB9

0-35	77.76	12.44	3.15	0.37	0.88	0.31	0.08	1.08	3.77	4.87
35-60	74.33	16.56	2.25	0.89	0.81	0.38	0.12	0.89	3.64	3.77
60-118	69.19	20.64	2.94	1.40	0.77	0.34	0.10	0.76	3.79	2.77
118-145	71.11	18.72	2.76	1.63	0.63	0.39	0.10	0.75	3.73	3.08
145-175	70.23	16.98	4.93	0.98	0.93	0.53	0.16	1.53	3.58	3.07

LOWER KOSI-GOLA PLAIN

Pedon PA7

0-26	77.60	13.50	2.34	0.80	0.74	0.42	0.10	0.91	3.39	4.66
26-42	72.60	16.98	3.36	1.24	0.51	0.37	0.07	0.75	3.87	3.36
42-66	71.77	17.98	2.96	1.24	0.55	1.06	0.07	0.77	3.46	3.24
66-94	70.74	18.14	4.07	1.43	0.46	0.73	0.13	0.73	3.43	2.99
94-110	68.83	19.13	3.74	1.59	0.81	1.07	0.21	0.79	3.69	2.81
110-128	70.08	17.13	4.68	1.06	0.96	1.34	0.25	0.72	3.63	3.06
128-160	70.08	17.13	4.68	1.06	0.96	1.34	0.25	0.72	3.63	3.06

Pedon PB2

0-30	79.72	11.84	2.35	0.25	0.46	0.25	0.05	1.07	3.02	5.52
30-54	70.60	18.06	4.10	1.50	0.42	0.36	0.06	1.12	3.18	2.98
54-90	66.82	20.67	4.86	1.46	0.54	0.82	0.06	0.57	4.02	2.48
90-140	71.44	17.60	3.76	1.38	0.47	0.67	0.07	0.55	3.12	3.14

UPPER DEOHA/GANGA-GHAGHRA INTERFLUVE

Pedon PB4

0-20	75.16	15.87	2.35	0.83	0.39	0.72	0.05	1.32	2.83	3.95
20-60	71.34	18.30	3.07	1.48	0.62	0.68	0.06	1.09	3.28	3.12
60-95	68.30	20.66	3.58	1.47	1.60	0.72	0.08	0.99	2.43	2.66
95-135	70.09	14.84	3.52	0.79	4.92	1.26	0.06	1.06	3.21	3.66

UPPER RAPTI-GHAGHRA INTERFLUVE

Pedon PB11

0-12	61.12	28.23	2.98	1.00	1.86	1.35	0.06	1.13	3.24	1.89
12-30	56.5	30.14	3.54	1.37	1.93	1.55	0.05	1.14	3.18	1.61
30-62	58.11	28.37	3.17	1.48	1.81	1.72	0.07	1.31	3.39	1.76
62-100	56.39	29.54	3.81	1.55	1.44	1.83	0.08	1.27	3.47	1.62
100-140	57.92	28.81	4.07	1.50	1.23	1.64	0.07	1.18	2.90	1.68
140-172	58.90	27.33	4.24	1.45	1.31	1.60	0.09	1.42	3.13	1.78
172-210	55.68	30.45	3.84	1.53	1.28	1.91	0.06	1.27	3.35	1.55

LOWER DEOHA/GANGA-GHAGHRA INTERFLUVE

Pedon RC-1

0-10	76.14	12.86	2.72	0.15	0.46	1.52	--	1.05	1.86	4.84
10-32	79.11	14.39	1.79	0.23	0.71	1.51	--	1.68	1.75	4.82
32-52	79.11	14.86	2.36	0.16	0.26	1.36	--	1.06	1.86	4.55
52-82	70.69	16.68	3.56	0.30	0.68	1.75	--	0.85	2.13	3.44
82-100	73.03	16.13	4.36	0.29	0.38	1.54	--	0.77	2.34	3.51
100 +	74.65	15.77	4.00	0.26	0.04	1.07	--	0.76	2.02	3.74

Pedon RC-2

0-11	74.11	15.07	3.57	0.35	0.54	0.96	--	0.90	2.18	3.90
11-23	70.48	15.71	4.14	0.34	0.14	2.69	--	0.65	2.45	3.49
23-43	69.03	17.87	5.46	0.38	0.44	1.80	--	1.02	2.72	2.91
43-67	70.12	17.72	3.80	0.38	0.25	2.27	--	1.02	2.34	3.20
67-90	66.19	17.66	4.77	0.31	3.19	1.87	--	1.04	2.62	2.91
90 +	73.11	18.15	5.04	0.35	0.71	1.29	--	0.70	3.37	3.11

MIDDLE DEOHA/GANGA-GHAGHRA INTERFLUVE

Pedon PB6

0-12	73.74	17.55	2.43	0.59	0.86	0.20	0.05	0.91	3.52	3.58
12-30	70.58	19.69	2.69	1.00	0.65	0.21	0.04	0.95	3.73	3.02
30-55	67.63	20.12	4.55	1.78	0.89	0.27	0.03	0.60	3.98	2.56
55-85	69.29	19.90	3.64	1.64	0.72	0.21	0.03	0.69	3.59	2.75
85-120	69.50	19.77	4.06	1.34	0.77	0.28	0.04	0.70	3.39	2.76
120-150	69.31	18.82	2.88	0.87	0.77	0.26	0.10	0.78	3.72	3.07

Pedon PB7

0-18	76.79	14.22	3.07	0.57	0.39	0.50	0.10	1.15	3.04	4.30
18-38	73.76	16.24	3.56	1.20	0.34	0.32	0.12	0.76	3.10	3.51
38-84	70.12	19.67	3.92	1.46	0.32	0.31	0.12	0.73	3.08	2.79
84-133	69.11	20.39	4.16	1.59	0.30	0.34	0.14	0.68	3.09	2.64
133-175	67.35	20.64	4.92	1.37	0.30	0.71	0.07	0.78	3.17	2.50
175-200+	68.98	19.32	4.32	1.28	0.45	0.79	0.13	1.00	3.59	2.77

Pedon PC4

0-22	77.37	13.30	2.75	1.20	0.55	0.78	0.06	1.34	2.48	4.49
22-42	73.61	15.64	4.10	1.63	0.39	0.67	0.07	1.07	2.68	3.44
42-78	66.51	22.50	3.83	1.45	0.78	0.38	0.06	1.16	2.71	2.39
78-116	70.50	17.41	4.43	1.89	0.54	0.38	0.06	1.09	2.59	2.97
116-140	70.51	17.50	3.93	1.89	0.56	0.47	0.06	1.87	2.75	3.02

Pedon PC1

0-15	75.21	12.97	3.23	1.72	1.28	0.26	0.06	1.53	3.58	4.20
15-29	70.18	14.54	5.38	2.38	1.49	0.41	0.09	1.67	3.73	3.15
29-80	65.81	16.63	5.40	2.40	1.81	0.64	0.08	1.66	4.04	2.69
80-125	64.94	17.17	5.76	2.69	2.28	0.53	0.08	1.53	4.20	2.53

LOWER RAPTI-GHAGHRA INTERFLUVE

Pedon PC12

0-18	80.20	10.65	1.83	0.39	1.12	0.27	0.07	1.61	3.70	6.23
18-40	74.49	14.23	3.46	0.82	1.04	0.21	0.09	1.26	4.24	4.02
40-78	69.27	17.76	4.70	1.59	0.88	0.25	0.08	0.88	4.43	2.88
78-123	73.00	13.90	5.48	1.37	0.93	0.25	0.18	0.77	3.88	3.52
123-149	74.23	14.33	3.78	1.47	1.02	0.31	0.15	0.65	3.94	3.79
149-200	77.45	11.06	3.19	1.61	0.91	0.25	0.10	0.80	4.40	4.88

Pedon PC13

0-22	77.32	14.02	2.40	1.38	0.12	0.20	0.07	0.12	3.13	4.34
22-50	70.00	18.81	3.79	1.29	0.85	0.24	0.06	1.04	3.73	2.93
50-66	68.39	19.03	4.22	1.95	1.21	0.84	0.05	0.79	3.36	2.71
66-100	64.41	20.94	4.01	1.80	1.41	2.24	0.08	0.83	4.13	2.41
100-137	64.62	21.82	3.10	1.75	2.09	1.46	0.09	0.97	3.97	2.42
137-180	58.03	20.24	2.86	0.97	7.65	5.40	0.07	0.94	3.59	2.41
180-222	53.97	17.76	3.92	0.93	11.07	7.70	0.05	0.97	3.49	2.39
222-252	60.81	18.24	1.88	0.84	7.92	5.57	0.09	0.83	3.73	2.90
252-272	63.99	20.50	3.26	1.32	5.73	0.54	0.09	0.70	3.72	2.55

Pedon PC15

0-16	73.03	11.37	2.49	0.70	8.33	0.26	0.09	1.08	2.17	5.02
16-30	72.04	12.95	3.86	1.89	4.89	0.24	0.07	0.95	2.97	3.85
30-75	70.96	14.37	4.73	2.35	2.98	0.36	0.04	0.98	3.07	3.31
75-95	72.09	15.24	4.55	1.89	1.61	0.39	0.03	0.96	3.11	3.33
95-127	73.59	15.15	3.73	2.11	0.91	0.24	0.02	0.97	3.13	3.51
127-155	75.21	12.87	4.23	1.15	0.96	0.20	0.03	0.97	3.90	4.12

APPENDIX-III

Clay Mineral Variation With Depth In Various Soil-Geomorphic Units

Depth (cm)	Illite	Kaolinite	Vermiculite	Chlorite
Upper Kosi-Gola Plain				
Pedon PA9				
0-22	74.81	13.13	6.93	5.10
22-48	76.78	13.89	9.32	0.00
48-73	71.66	14.49	10.21	3.62
73-118	66.60	15.23	15.04	3.04
118-160	71.42	16.38	10.08	2.10
Pedon PA6				
0-30	53.76	34.94	1.07	10.21
30-70	46.78	42.10	1.16	9.94
70-80	44.53	46.96	0.81	7.69
80-97	51.66	34.00	7.00	7.33
97-123	62.6-	27.10	2.20	7.85
Lower Kosi-Gola Plain				
Pedon PA7				
0-26	78.90	11.05	9.95	00.00
26-42	83.94	8.02	8.02	00.00
42-66	88.78	6.50	4.60	00.00
66-94	89.18	6.90	3.89	00.00
94-110	86.02	7.10	5.10	1.60
110-128	77.70	12.16	2.70	7.40
128-160	80.08	10.70	5.06	3.30
Pedon PB2				
0-30	93.30	4.00	2.63	00.00
30-54	87.60	8.20	4.10	00.00
54-90	86.80	7.30	5.70	00.00
90-140	91.68	5.17	3.13	00.00

Old Sihali-Mohan-Kandra Piedmont

Pedon PA8

0-29	71.42	14.12	14.44	00.00
29-62	70.43	17.55	10.27	1.73
62-89	64.51	17.70	15.86	1.88
89-110	65.44	16.23	18.32	00.00
110-135	58.20	22.30	19.40	00.00
135+	69.50	16.14	14.34	00.00

Upper Deoha/Ganga-Ghaghra Interfluve

Pedon PB4

0-20	87.40	7.19	5.39	00.00
20-60	85.85	9.85	4.29	00.00
60-95	80.64	12.47	6.88	00.00
95-135	72.32	10.90	16.77	00.00

Lower Deoha/Ganga-Ghaghra Interfluve

Pedon PC4

0-22	91.89	4.66	3.42	00.00
22-47	89.81	5.01	5.16	00.00
47-78	89.06	3.44	7.48	00.00
78-116	88.85	3.55	7.59	00.00
116-140	85.73	4.40	9.80	00.00
140+	81.86	6.80	11.33	00.00

Upper Rapti-Ghaghra Interfluve

Pedon PB11

0-30	93.75	4.46	1.78	00.00
30-62	93.60	4.80	1.46	00.00
62-100	87.50	8.57	3.92	00.00
100-140	91.60	5.40	2.94	00.00
140-172	89.86	5.06	5.06	00.00
172-210	91.79	3.20	4.96	00.00

Lower Rapti- Ghaghra Interfluve

Pedon PC12

0-18	87.86	7.87	4.20	00.00
18-40	90.03	8.03	1.92	00.00
40-78	90.63	7.85	1.51	00.00
78-123	89.9	8.10	1.91	00.00
123-149	85.3	12.30	2.30	00.00

Rapti Floodplain

Pedon PB14

0-45	80.18	11.79	4.70	3.30
45-74	81.36	12.44	2.93	3.20
74-82	73.69	15.32	4.16	6.81
82-100	75.50	10.90	11.15	2.30
100-132	76.04	14.44	10.64	0.00

Lower Deoha/Ganga-Ghaghra Interfluve

Pedon RC-1

0-10	78.00	12.40	6.80	2.80
10-32	85.20	7.60	5.10	2.10
32-52	87.20	8.40	2.70	1.80
52-82	85.70	7.70	2.40	2.50
82-100	83.40	3.60	4.30	1.90
100 +	72.10	10.20	9.50	2.60

Pedon RC-2

0-11	81.30	9.70	4.40	00.00
11-23	82.70	11.00	4.90	00.00
23-43	83.20	12.00	4.80	00.00
43-67	81.80	13.50	4.70	00.00
67-90	68.40	24.40	7.20	00.00
90 +	71.40	22.80	5.80	00.00

APPENDIX IV

DESCRIPTION OF TYPICAL THINSECTION

Thin section No. PA3-4 Kosi-Gola Piedmont

General Morphology

C horizon, 103 - 128 cm, Olive gray, sandy loam, structureless, hard (dry) friable (moist) slightly sticky and slightly plastic (wet), no roots, non-calcareous

Microstructure

The soil under thin section shows that no peds have developed, mostly it consist of massive structure with few elongate arched channels and vughs which show extremely rough surface. Microstructures observed include intergrain channel microstructure (Fig. 4.1, 4.2). Total void space estimated is about 15%. The voids are usually normal to bedding and show basic random distribution.

Basic Mineral Components C/F limit at 20 µm C/F ratio 80/20

Coarse fraction

Single coarse grain quartz about 70%, subangular to angular, 300 - 400 µm in size, Micas are about 5 -10%, usually fresh to slightly altered flakes of 400 µm . Feldspars up to 10%, mainly include orthoclase and a few weakly altered microcline and plagioclase. a few litorelicts of shale and schist of 500-600 µm size are upto 2%. Other coarse minerals observed include a few heavy minerals and opeques.

Fine Fraction/groundmass

Yellowish to brownish, mainly minearlic mixed with fine organic matter, consists of unsorted impure clay and fine silt. The finer fraction usually occurring in the interstices of coarser grains. Plasma separation is weak.Undifferenciated b-fabric is noticed commonly.c/f related distribution is mainly gefuric and chitonic (Fig. 4.3).

Pedofeatures

Illuvial clay pedofeatures are absent. One long bow shaped ferruginous micropan is observed. strongly impregnated FeMn concretions of >400 µm size are observed.

Thin Section No. PA4-2 Kosi- Gola Piedmont

General Morphology

B horizon, 36-50 cm, olive gray to olive, sandy loam, weakly developed subangular blocky structure, slightly hard (dry) friable (moist) slightly plastic and slightly sticky (wet), common fine medium fibrous roots, non-calcareous.

Microstructure

The soil under thin section shows apedal and massive structure. voids are mainly channels and vughs and a few vesicles which show extremely rough surfaces. Microstructures observed include compact grain microstructure intergrain channel and sometimes vughy microstructure is also noted. The soil shows extremely high content of organic matter in form of desecrate fine to medium sized mixed and scattered in groundmass also partially decaying fibrous roots

Basic Mineral components C/F limit at 20 µm C/F ratio 60:40

Coarse fraction

Quartz grains upto 70% are usually coarse >400 µm (range 200-500 µm), angular to subangular in shape and are are randomly distributed. Other mineral grains of the size of the size of quartz include K-felspar, mainly orthoclase upto 10-15%, Plagioclase grains are less than 2% and are slightly altere. micas are upto 5%, heavy and fresh to weakly altered litorelicts of shale and schist are about 2-3%.

Fine fraction/groundmass

Mainly organominearlic in nature, shows colourless to dark yellowish brown colour. Mostly it occur as groundmass. The fine fraction is mainly of impure fine silty clay. Plasma separation is weak as undifferentiated b-fabric is commonly and rarely weakly developed speckled and b-fabric is noted. c/f related distribution, mainly enulic and sometimes double spaced porphyric related distribution is also noted.

Pedofeatures

Illuvial clay features are absent. Impure calcareous groundmass producing crystillitic b fabric. Hypo coatings and dissolution features by micritic calcite. Finely distributed discrete organic mass shows undifferentiated b-fabric. Partially decaying fibrous roots (Fig. 4.4).

Thin Section No. PA4-3 Kosi-Gola Piedmont

General Morphology

C horizon, 50-73 cm, olive gray to olive, sandy loam, structureless, slightly hard (dry) friable (moist) slightly plastic and slightly sticky (wet), very few fene fibrous roots, non-calcareous.

Microstructure

Thin section of the soil shows apedal massive soil in most of the part. Voids are mainly elongate arched rough walled channels, vesicles and vughs. This shows compact grain microstructure with intergrain channel and vesicular microstruc- ture. The voids do not show any orientation and are randomly disributed.

Basic Mineral Components C/F limit at 20 µm C/P ratio 60 : 40

Coarse Mineral Fraction

Single grain, poorly sorted subangular, quartz upto 60% most ofthe grains in 400µm (range 100-400 µm) are noted. Other minerals of the quartz size include K- felspars, orthoclase and few microcline grains are angular to subangular in shape and are up to 15%. These are fresh to slightly altered, few very large orthoclase grains (>600µm) show well developed cleavages and microclines with cross hatched twinning are noted. Rock fragments of shale and schist are less than 2%, mica are upto to 5-10%.

Fine Fraction/Groundmass

Colourless to yellowish brown of unsorted fine silt and impure clays occurring as groundmass. Plasma separation is weak. Undifferenciated b-fabric is commonly observed, and also weakly to moderately developed poro, cross and parellel striated b-fabrics are noted at few places. Also undifferentiated b-fabric due to fine opaque and organic matter is noted. c/f rellated distribution is usually open porphyric distributions, at places they show enulic and chitonic distribution also.

Pedofeatures

A few channel infillings by impure clay and fine silt are noted. Moderately impregnated diffused mottles of sesquioxides. Illuvial clay pedofeatures are absent.

Thinsection no PC16-2 Gholia-Dhobania-Bhambhar Piedmont

General Morphology

C horizon, 34-66 cm, light olive brown to olive brown silt loam, massive,y) firm (moist) plastic and sticky (wet), very few fine fibrous roots, common fine medium pores, non calcareous.

Microstructure

The soil in section show apedal and massive nature, no ped has developed. Voids are mainly irregular shaped vughs and elongate arched channels. This show vughy to spongy microstructure. Voids do not show any orientation, and are randomly oriented.

Basic Mineral Component C/F limit at 20 µm C/F ratio 40:70

Coarse Fraction

Subangular, single grain, quartz upto 60%, ranging in size upto 150 µm, most of the grains of 100 - 150 µm, and a few >150 µm all showing basic random distribution in groundmass. K-felspars are upto 10-15%, mostly orthoclase few grains of microcline also present micas are upto 5%, both muscovite and biotite show slighty altered flakes (>150 µm). Other coarse minerals include a few heavy mineral grains of hornblende and rutile, and a few lithorelicts of shale and schist etc. are present in minor amount less than 1%.

Fine Fraction/Groundmass

Mainly mineralic also some very fine organic matter is present, occuring descretely mixed with other groundmass. The fine mass is yellowish to reddish brown due to ferruginous masking. Plasma seperation is moderate as moderately developed cross striated, grano striated and poro striated fabric also porostraited b-fabric are commonly observed.C/F related distribution is mainly open porphyric and at places enulic distribution is noted.

Pedofeatures

Illuvial clay pedofeatures are absent. Typic orthic strongly impregnated manganese nodules are observed.

Thinsection no PC16-3 Gholia- Dhobania -Bhambhar Piedmont

General Morphology

C horizon, 66-99 cm light olive brown silty loam, few medium distinct dark grayish brown, structureless, hard (dry) firm (moist) plastic and sticky (wet), strongly calcareous with Kankars upto 10% 1-2 cm dia.

Microstructure

Apedal and massive soil. The soil shows vesicular channel microstructure. The voids are upto 20%, mainly vesicles and a few irregular shaped vughs and channels. Voids are unoriented and show basic random distribution.

Basic Mineral Components C/F limit at 20 µm C/F ratio 40:60

Coarse Fraction

About 70% quartz it is single grain monocrystalline, subangular and range in size 100 - 150 µm. Micas are upto 10-15%. Muscovithe laths 100 -1 50 µm are more in abundace than biotite, both of them show weak alteration. K-feldspars are about 10-15%, showing subhedral and anhedral shape, a few microcline grains are also present. Other minerals include few grains of hornblende and rock fragments.

Fine Fraction/Groundmass

Whitish to yellowish, mainly of fine silt and impure clay, generally anisotopic in cross polarised light. Occurring as groudmass. Plasma seperation is moderate as weakly to moderately developed commonly observed b-fabric including crystic, cross and poro striated b-fabric (Fig. 4.5). C/F related distribution is mainly porphyric.

Pedofeatures

Loose incomplete infilling of a channel void by fine silt mixed with micrite. Crystic plasmic b-fabric due to calcareous groundmass. Calcite impregnation features are very prominent constituting upto 40% of thinsection area. They occur in form of typic orthic, rounded to subrounded sparatic nodules, also few very much irregular shaped (digitate) sparatic calcite concretions are observed (Fig. 4.6, 4.7). Geodic, septaric micro spartic calcarous nodule masked by ferriginous matter.

Thinsection no PB10-2 Ghaghra Floodplain

General Morphology

C1 36-72 cm, light olive brown to olive brown (2.5Y4.5/4), very few medium distinct mottles of dark yellowish brown (10YR4/6), silty loam, structureless, friable (moist) slightly plastic and slightly sticky (wet), few fine roots, common fine medium pores, strongly calcareous, gradual smooth boundary

Microstructure

Thin section of the soil shows that no peds have developed, the soil is usually apedal and massive with compact grain microstructure. Voids are mainly rough surfaced elongate arched channels, other voids are a few simple packing type one due to dense packing of coarse fraction. Total pore space is about 10%. The voids are unoriented and show basic random distribution. Microstructures observed include compact grain and bridged grain microstructures.

Basic Mineral Components C/F limit at 20 µm, C/F ratio 80:20

Coarse Fraction

Usually it consists of moderately sorted densely packed fine sand of (100-200 µm) size. Most of the coarser fraction consists of single grain (150 - 200 µm) quartz, which is about 70-80% of the coarse fraction. Feldspars are about 5-6%, mostly K felspar, a few plagioclase grains are also present. Micas are usually fresh to weakly altered and are about 5-10%. Other minerals occuring in minor amount include hornblende grains and other heavy minerals and a few lithorelicts.

Fine Fraction/Groundmass

Mainly mineralic in nature showing anisotropism, also some fine calcareous matter is sparsely distributed and mixed with other groundmass. Plasma seperation is weak. Undifferenciated b-fabric and weakly developed poro and grano striated b-fabric are noted. C/F related distribution is mainly monic and gefuric.

Pedofeatures

Illuvial clay pedofeatures are absent. Calcareous pedofeatures are common. They occur in form of crystillitic plasmic b-fabric due to micrtic groundmass. Undifferentiated b-fabric (Isotic plasmic) b-fabric due to humus associated with ferruginous matter.

Thinsection no PB10-3 Ghaghra Floodplain

General Morphology

C2 72-118 cm, grayish brown to dark grayish brown (2.5Y 4.5/2), very few medium distinct mottles of dark yellowish brown (10YR 4/6), silty, structureless, firm (moist) slightly plastic and slightly sticky (wet), no roots, common fine medium pores, strongly calcareous (kankars).

Microstructure

In thin section the soil shows apedal to weakly developed subangular blocky structure continuity this apedal soil is broken by many small irregular shaped vughs and vesicles, producing vughy and vesicular micro structure. Total void space is about 10-15%. The voids do not show any orientation and are randomly distributed. The voids generally show rough surface.

Basic Mineral Components C/F limit at 20 µm, C/F ratio 40:60

Coarse fraction

Mostly of coarse silt and fine sand ranging in size 50-200 µm, poorly sorted to moderately sorted. Quartz is monocrystalline and subangular in shape and 100-200 µm in size, it is about 70-80% of the coarse fraction. Micas are about 5-10%, usually 100 - 200 µm, a few large >400 µm flakes of muscovites are also seen, which show slight alteration. Other minerals of quartz size are k-feldspars and a few grains of rock fragments and a few heavy minerals.

Fine Fraction/Groundmass

Mainly mineralic in nature, also some discretely mixed organic matter is seen. It consist of impure clays and fine silt of micaceous, siliceous and calcareous matter. Plasma seperation not very strong, as weakly developed stipple speckled and porostriated b-fabrics are noted. C/F related distribution, usually porphyric, at places enulic and chitonic related distributions are also noted.

Pedofeatures

Illuviation features are not present. Calcareous pedofeatures are common, they occur in form of, (i) crystic plasmic b-fabric occuring widely in thinsection due to calcareous matter in groundmass, (ii) typic, orthic and strongly impregnated, coarsely crystalline (sparatic) nodules (2-3%) of thin section is observed. Coarsely crystalline calcite in groundmass, showing prominet boundaries and cleaveges (Fig. 4.8, 4.9).

Thinsection no PB14-2 Rapti Floodplain

General Morphology

C horizon, 45-74 cm, light olive brown to olive brown silty loam, common medium distrinct mottles of yellowish brown to dark yellowish brown colour, structureless, firm (moist) slightly plastic and slightly sticky (wet), common fine fibrous roots, strongly calcareous with kankars upto to 3 cm dia., upto 10%.

Microstructure

In thin-section the soil shows apedal soil mass, continuity of the massive apedal soil mass is broken by many vesicles and a few elongate slightly arched channels, producing vesicular channel microstructure, total void space is about 10%. The voids are unoriented and show basic random distribution.

Basic Mineral components C/F limit at 20 µm C/F ratio 20:80

Coarse Fraction

Mostly fine grained (100-150 µm), densely packed in groundmass. Quartz constitutes most of the coarser fraction, others are micas and feldspars.

Fine Fraction/Groundmass

Mostly mineralic in nature, consisting of fine silt to clays of micas, calcareous and siliceous matter. Sometimes it is mixed with ferruginous matter. Plasma sepration moderate, as moderate to strong development of parallel and porostriated b-fabrics are commonly noted alongwith crystic plastic b-fabric at few places. C/F related distribution, is porphyric for very coarse grains and for rest of the fraction it is gefuric and enulic.

Pedofeatures

Illuvial clay pedofeatures are absent. Calcareous features are dominant. Sparatic hypocoatings (thick 100 µm to 150 µm) along voids (Fig. 4.12). Cystic plasmic b-fabric due to dense micrtic groundmass. Coarsely crystalline, very well developed calcrte impregnation of prismatic calcite inside a large ferruginous dissolution pedofeature.

Thinsection no PB14-3, Rapti Floodplain

General Morphology

C horizon, 74-82 cm, Dark grayish brown silty loam, common medium distinct yellowish brown to dark yellowish brown mottles, structureless, very few fine medium fibrous roots, moderately calcareous.

Microstructure

In thin section most of the soil shows apedal massive soil. voids are mainly elongate rough walled channels and other are vesicles and few vughs. Total void space is about 20%.

Basic Mineral Components C/F limit at 20 μm C/F ratio 50:50

Coarse fraction

Mostly of fine sand (100 - 200 μm) size, densely packed, at places showing compact grain microstructure (PN vii 34). It consists of mainly quartz, micas and feldspars.

Fine Fraction/Groundmass

Whitish to yellowish brown, mainly of clay and fine silt of micas, calcareous and siliceous matter, often mixed with ferruginous matter. Moderately developed cross striated and poro striated b-fabric are commonly observed and rarely strongly developed parallel striated b-fabric at a few places (Fig. 4.10) related distribution is porphyric, monic and gefuric related distribution is also noted (Fig. 4.11).

Pedofeatures

Illuvial clay pedofeatures are not present. Calcareous impregnation pedofeatures comprises about 5% of thin section area. They occur in form of typic, strongly impregnative sparatic elongated nodules of 3 mm size. Hypo- and quasi-coatings by ferrgious matter are rarely observed.

Thin section No. PA5-4, Upper Kosi-Gola Plain

General Morphology

B21 horizon, 60-85 cm, Light olive brown, silty loam, weakly developed subangular blocky structure, hard (dry) firm (moist) sticky and plastic (wet), common fine medium tabular pores, weakly calcareous.

Microstructure

The soil under thin section shows weakly developed subangular blocky structure (Fig. 4.13) in most of the part, in parts apedal and massive soil is also seen. Voids are mainly vughs and channels with rough surface. Total pore space is about 20%. Channel and vughy microstructure is noted.

Basic Mineral Components C/F limit at 20 μm C/F ratio 40 : 60

Coarse Fraction

Mainly single grain quartz (150 - 400 μm) upto 80%, it is subangular and fractured. Other mineral grains of the size of quartz include feldspar grains constitute upto 5%, mainly of orthoclase, micas are upto 5%, heavy minerals and others are less than 1%. The coarse grains are unoriented and show basic random distribution.

Fine Fraction/Groundmass

Colourless to yellowish, mainly of micaceous and fine silt and clays. In some part ferruginous and calcareous fine mass mixed with groundmass also occur. Plasma separation is very strong, as very strongly developed reticulate fabric is very commonly observedalong with moderately developed porosstriated and crystic b-fabric at a few places (Fig. 4.18). c/f related distribution is mainly porphyric and at places enulic related distribution is also noted.

Pedofeatures

Illuvial pedofeatures are very few. Hypocoatings of micritic calcareous matter around voids. Fine (300 - 400 µm) moderately impregnated micritic nodules are about 2-3% of thin section. Weakly to moderately impregnated diffused iron oxide mottle are upto 5-6%

Thin Section No PA5-5 Upper Kosi-Gola Plain

General Morphology

B34 horizon, 85-130 cm, Olive brown silty loam, weakly developed subangular blocky structure, hard (dry) firm (moist), slightly plastic and sticky (wet) very few fine fibrous roots, strongly calcareous with kankars upto 10%.

Microstructure

The soil under thin section shows weakly developed subangular blocky structure, peds not very well separated and only sometimes accommodating faces are seen. Voids are mainly elongated arched rough to smooth walled channels, producing channel microstructure. Total void space estimated is around 15%. The voids are unoriented and show basic random distribution.

Basic Mineral components C/F limit 20 µm C/F ratio 30 : 70

Coarse fraction

Single grain, monocrystalline, quartz upto 60%, ranging in size from 100µm to 200µm , randomly distributed in groundmass. Micas are upto 10%, other minerals including K-felspars, hornblende, rock fragments etc. constitute rest of the coarse fraction.

Fine Fraction/groundmass

Whitish to yellowish fine silty and clay matter, occurs as widely distributed as groundmass. Plasma separation very strong as shown by the reticulate and cross striated b-fabrics which are widely noted. Also moderately developed grano and poro striated b-fabrics are noted.

Pedofeatures

Calcareous pedofeatures are dominant and occupy about 10% of the thin section. They occur in form of coatings, crystillitic b-fabric and typic orthic nodules. The nodules show dissolution along the voids (Fig. 4.23). Moderately to strongly impregnated typic to digitate, orthic, microspartic to sparitic nodules. Hypocoatings by micrtic calcite along voids. Coarsely, well crystallised calcite in dense calcareous groundmass, also showing dissolution and crystallization. Channel infilling by impure clay in a small part of soil is also observed. Strongly developed cross and reticulate striated b-fabric (Fig. 4.19). Moderately impregnated ferruginous diffused mottles of sesquioxides.

Thin section no PAO-4 Upper Kosi-Gola Plain

General Morphology

B22 horizon, 81-110 cm, light olive brown loam, few fine distinct dark yellowish brown mottles, weakly developed subangular blocky structure, hard (dry) firm (moist) slightly sticky and slightly plastic (wet), few clay cutans along pores, few medium fibrous roots, non calcareous.

Microstructure

In thinsection the soil shows mostly weakly developed subangular blocky structure at places apedal soil is also seen. The peds are not well separable. Numerous irregular shaped rough to smooth surfaced vughs and vesicles occur in and in between peds. Total void space estimated is about 25 to 30%. The voids are not oriented and show random basic distribution Microstructure observed include bridged grain and pellicular grain microstructure and vughy microstructure.

Basic Mineral Components C/F limit at 20 μm, C/F ratio 60/40

Coarse Fraction

Poorly sorted, densely packed single grain quartz upto 60% of coarse fraction mostly of 400 μm size, and 20% are of 100 - 200 μm size. Other minerals of quartz size are feldspar mostly of K- felspar upto 10-15%, Micas upto 10-15%, biotite laths upto 200μm in length are slightly altered, muscovite laths are fresh to unaltered, hornblende grains 50-60 μm are less than 1%, heavy minerals include Rutile, Anatase and others are less than 1%, a few slightly altered schistose and shaly lithorelicts are present.

Fine Fraction/Groundmass

Colourless to yellowish, mainly micaceous and other finer mineral, in form of clays and very fine silt. Occurring widely as groundmass and coatings along voids and grains and also as infilling of channels voids. Plasma separation is moderate, as moderately developed poro and stipple speckled b-fabrics are commonly noted. C/F related distribution mainly is chitonic and enulic.

Pedofeatures

Illuvial clay pedofeatures are widely distributed as argillans. limpid clay to dotted clay hypocoatings along voids and channels (upto 30-40μm) and grains (Fig. 4.15). Ferruginous micropan which consists of microlaminated limpid to speckled clay, (2 mm in length and 100 -150 μm is thickness) (Fig. 4.20). Depletion of iron oxide and diffused mottles.

Thinsection No. PAO-5 Upper Kosi-Gola Plain

General Morphology

C horizon, 128 cm, Olive yellow, silty loam, common medium coarse distinct dark grayish brown mottles with Fe Mn concretions, very weakly developed subangular blocky structure, hard (dry), firm (moist), slightly plastic and sticky (wet), no roots, non calcareous.

Microstructure

In thin-section the soil shows apedal structure in most of the part, at places weakly developed peds are present, continuity of the apedal soil is broken by numerous interconnected vughs, producing vughy microstructure. Total void space estimated is about 30%. The voids are unoriented and show basic random distribution. Other microstructures observed include compact grain microstructure, bridged grain and pellicular grain microstructure.

Basic Mineral Components C/F limit at 20 μm, C/F ratio 80:20

Coarse Fraction

Poorly sorted grains of quartz upto 70%, ranging in size from 100 to 400 µm , mostly they are subangular, and monocrystalline. Most of the grains are of 300 - 400 µm size, rest 20% are of 100-200 µm . Other minerals of quartz size include fresh to weakly altered micas upto 5-10%, k-feldspars are upto 10% and a few hornblende and heavy minerals together with some lithorelicts constitute the rest.

Fine Fraction/groundmass

Colourless to yellowish brown, mainly of micaceous and siliceous fine silt and clay, anisotropic in cross polarized light. Plasma seperation is weak as stipple speckled and cross striated b-fabrics are weakly developed and are commonly observed. C/F related distribution is mainly chitonic and enulic, at places gefuric related distribution also occur (Fig. 4.16).

Pedofeatures

Illuvial pedofeatures are absent. Weakly impregnated ferruginous mottles and strongly impregnated typiic orthic nodules of sesquioxides. Calcerous pedofeatures are common in form of nodules and crystic plasmic b-fabric (Fig. 4.21).

Thinsection no PA6-2 Upper Kosi-Gola Plain

General Morphology

B1 horizon, 30-70 cm, Pale olive silty loam, common medium distinct dark yellowish brown mottles, weakly developed subangular blocky structure, hard (dry) friable (moist) slightly plastic and slightly sticky (wet) common fine medium fibrous roots, strongly calcareous.

Microstructure

The soil in thinsection shows weakly to moderately developed subangular bloky peds. The voids are mainly elongate arched channels and irregular shaped surfaced vughs. The voids generally have rough surface sometimes smooth surface is also noted. Total, void space is about 25%. The voids show basic random distribution pattern. The microstructures observed include intergrain channel and vughy microstructure.

Basic Mineral components C/F limit at 20 µm C/F ratio 60:40

Coarse fraction

Moderately sorted quartz is upto 70% of coarser fraction, it is usually subhedral in shape and most of the grains are of 200 - 300 µm in size, few fine 50-60 µm size grains also occur. K-felspars are upto 10%, mainly orhoclase, few microcline grains are also seen (Fig. 4.17), a few plagioclase feldspar grains showing characteristic twinning and weak alteration are also seen. Micas are upto 10%, biotites are usually altered showing bleaching and exofoliation. Other minerals include a few lithorelicts and heavy minerals. form of diffused mottles, is amorphous and isotropic, some amount (2%) of discrete isotropic organic matter is also present.Fine

Fine Fraction/groundmass

Dirty white to yellowish sometimes micro contrasted dark due to organic matter. It occurs as groundmass, and as thin coatings along grains and voids. Plasma separation is weak as cross striated, reticulate b-fabric are weakly developed and are commonly noted. Stipple speckled b-fabric, crystic plasmic fabrics are moderately developed. C/F related distribution is mainly chitonic and gefuric, also at places close porphyric related distribution is noted (Fig. 4.17).

Pedofeatures

Illuvial clay pedofeatures are few and they occur in form of thin (20-30 µm) hypocoatings along voids by impure clays. Thick (100 - 150 µm) micritic to microsparatic hypocoatings (PN.iv 38). Typic, strongly impregnated extremely irregular shaped micritic to microsparitic nodules. Calcrete dissolution along boundaries and voids in nodules. Crystic plasmic b-fabric due fine micritic groundmass at places.

Thinsection no. PA6-3, Upper Kosi-Gola Plain

General Morphology

B22 horizon, 70-80 cm, Olive gray to olive, silty loam, common medium distinct dark yellowish brown mottle, weakly developed subangular blocky structure, hard (dry), firm (Moist), slightly plastic to sticky (wet), common fine fibrous roots, strongly calcareous with Kankars upto 2% of 5 mm in size.

Microstructure

The thin section of the soil shows weak to moderately developed subangular blocky structure, the peds are weakly separable and partially seperable. Voids are mainly elongate, arched smooth walled channels and a few vughs and vesicles are also present producing intergrain vughy and vesicular channel microstructure. animal activity very prominent, as seen by large isotubles filled with.

Basic Mineral Components C/F limit 20 µm C/F ratio 30 : 70

Coarse Fraction

The coarser fraction is moderately sorted, mostly of quartz grains of 60-100 µm in size, most of the coarse grains are subhedral in shape. Other identifiable coarse mineral grains include micas, both muscovite and biotite show weak to moderate degree of alteration. The coarse fraction is usually showing open porphyric related distribution.

Fine Fraction/Groundmass

Whitish to yellowish, mostly of very fine silt and clays of micaceous and calcareous matter, anisotropic in cross polarised light. Plasma separation is moderate to strong, as strongly developed poro-striated b-fabric is commonly developed along with moderately developed cross striated b-fabric at places. C/F related distribution, generally is open porphyric.

Pedofeatures

Few illuvial clay pedofeatures of argillans occur, in form of 30-40 µm thin ferruginous clay hypocoatings along voids. Calcareous impregnation pedofeatures are dominant. They occur in form of nodules, coatings and crystic plasmic b fabric, strongly impregnated, typic, micrtic to micro sparatic nodules of (>600 µm) constitute about 5% of the thin section area. Crystic plasmic b-fabric is noted due to densely packed calcareous groundmass. Hypocoatings by micrtic calcrete along channel and voids. Strong animal activity, as large isotubles are filled with reworked basic soil in crescent manner.

Thinsection no PA6-6, Upper Kosi-Gola Plain

General Morphology

C2 horizon, 127 cm, Olive silty loam, many medium distinct dark yellowish brown mottles, structureless, hard (dry) firm (moist), slightly sticky slightly plastic (wet), no roots, strongly calcareous with Kankars upto 2 cm in size about 5%.

Microstructure

In thin section the soil shows apedal massive soil structure the continuity of apedal soil mass is broken by vesicles and channels, producing intergrain channel and vesicular micro- structure. Total void space is around 10%. The voids are not oriented and show basic random distribution.

Basic Mineral components C/F limit at 20 µm , C/F ratio 60:40

Coarse Fraction

Usually the coarse grains of quartz and micas and other grains are densely packed. Quartz are around 60%, mostly of 300 µm and a few quartz are upto 100 µm in size, Micas, biotites are of 100 -150 µm size laths, which are slightly altered. A few rutile grains and other heavy minerals are also seen

Fine Fraction/Groundmass

Whitish to yellowish brown, of fine silty and impure clays of micaceous, siliceous, calcareous and ferruginous matter. Plasma separation is as weak as undifferenciated b-fabric is commonly observed with weakly developed stipple speckled and cross striated b-fabric at a few places.

Pedofeatures

Illuvial clay pedofeatures are absent. Calcareous impregnation has widely developed in the soil in form of nodules coatings and groundmass. Typic, orthic, strongly impregnated, semirounded to rounded micrtic nodules. Elongated, convolute shaped sparitic nodule showing calcification and decalcification. Few thin calcareous hypocoatings along voids Diffused mottles of sesquioxides.

Thinsection no. PA9-3 Upper Kosi-Gola Plain

General Morphology

B2 horizon, 48-73 cm, Light brown, silty loam, common fine distinct mottles of strong brown colour, weakly developed subangular blocky structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), common fine fibrous roots, common fine medium pores, non-calcareous.

Microstructure

Under thin section the soil shows weakly to moderately developed subangular blocky structure. The peds are partially accomodating and separable, The voids mainly are compound packing voids, which are often interconnected, other voids include elongate arched channels, and a few vughs and vesicles also occur. The soil shows channel microstructure. Total pore space is around 15% . The voids do not show any definite orientation and are randomly distributed.

Basic Mineral Components C/F limit 20 µm C/F ratio 30/70

Coarse Fraction

The coarse consists of mainly quartz, feldspars and micas, which are densely packed in finer groundmass. Quartz is up to 70%, ranging in size upto 150-200 µm , usually fractured single grains, few very large (>400 µm) polycrystalline quartz are also seen. Feldspar grains are upto 10%, they are mainly orthoclase and a few grains of slightly altered microcline are also seen. Micas are upto 5-10% generally 100 - 150 µm in length, few large (>400 µm) moderately altered biotite grains are noted.

Fine Fraction/Groundmass

Colourless to yellowish, mainly micaceous and siliceous in nature and consists of very fine silt and impure clays. Occurring as groundmass and coatings along grains and voids. Plasma separation is moderate as commonly noticed by weakly to moderately developed stipple speckled and cross striated b-fabric. C/F related distribution, most part of coarse fraction is show porphyric related distribution patterns at places gefuric and chitonic distribution is also noted.

Pedofeatures

Few illuvial clay pedofeatures are present in form of thin (30-40 μm) hypocoatings of impure clay along (voids), these coatings are not microlaminated. Infilling of an arched bed channel by impure clays.

Thinsection no PA15-2 Old Sihali-Mohan-Kandra Piedmont

General Morphology

B1 horizon, 18-47 cm, dark gray to dark grayish brown (2.5Y 4/1), few fine medium distinct mottles of strong bvrown (7.5YR 5/7) colar, silty loam, weakly to moderately sable,hard (dry) fragile (moist) slighlly plastic and slightly sticky (wet), common fine medium fibrous roots, common fine medium pores, non calcareous, clear smooth boundary.

Microstructure

Thin section of the soil shows, weak to moderate development of sable structure (Fig. 4.30), continuity of compact massive soil is broken by a few irregular shaped vughs and and few irregular planar interconnected voids, producing intergrain vughy microstructure. Total pore space is about 10%. The voids do not show any orientation are randomly distributed.

Basic Mineral Components

C/F limit at 20 μm C/F ratio 60:40

Coarse fraction

Quartz about 60-70%, upto 100-150 μm in size, subangular to subrounded in shape, showing enulic and porphyric distribution. Micas are upto to 15% laths of both muscovite and biotites, upto 150 μm in length, are generally fresh. Feldspar are upto to 10%, it mainly include orthoclase and a few microcline and plagioclase grains are also seen. Other coarse grains occuring in minor amount include rock fragments and heavy minerals and opaques.

Fine Fraction groundmass

Dirty white to yellowish brown, mainly it consists of impure clay and fine silt also some fine discretely mixed organic matter is associated with it. Plasma separation is strong. At places moderate to strong development of parallel striated b-fabric occurs (Fig. 4.31) also moderately developed poro and cross striated b-fabrics are commonly noted (Fig 4.32). Also commonly undifferentiated b-fabric is noted due to fine organic matter. C/F related distribution is usually single spaced open porphyric, at places enulic related distribution is also noted.

Pedofeatures

Illuvial clay pedofeatures though present are not very conspicuous, as very thin (30-40 μm) strongly oriented speckled clay hypo-coating along channel voids (PN.viii 8.51). Diffused mottles of ferruginous matter

Thinsection no PA15-4 Old Sibali Mohan Kandra Piedmont

General Morphology

C1 horizon, 82-107 cm, light olive brown (2.5Y 5.5/6), silty loam, massive,structureless hard (dry) friable (moist) slightly plastic and slightly sticky (wet), no roots, common fine medium pores, strongly calcareous calcareous, gradual smooth boundary

Microstructure

Under thin section the soil shows, massive apedal structure. The continuity massive compact soil mass is broken by few irregular vughs and vesicles. Compact grain and vughy microstructure is noted. Total pore space is around 10%. The voids show basic random distribution.

Basic Mineral Components C/F limit at 20 µm C/F ratio 60:40

Coarse fraction

Mostly of fine sand and silt size quartz about 70% of the coarse fraction. They are subangular and subhedral and are densely packed in ground mass. with enulic, chitonic related distribution pattern. Other coarse mineral grains include micas 10-15%, k-feldspars about 10% and a few rock fragment grains and a few slightly altered hornblende grains and other heavy minerals.

Fine Fraction/groundmass

Dirty white and yellowish brown impure clay and fine silt. It is intricately mixed with calcareous and ferruginous matter. Plasma separation is moderate. As at places undifferenciated b-fabric is noted and moderately development of cross-striated, also at places crystic, plasmic fabric is noted due to fine calcareous ground mass. grano- and poro-striated b-fabrics are seen (Fig. 4.22). C/F related distribution mainly is gefuric and chitonic and at places enulic related distribution is noted.

Pedofeatures

Calcareous pedofeatures account for 10% of thin section area in form of sparatic, typic, orthic, elongate to semirounded nodules. Crystic plasmic b-fabric has widely developed due to dense to loose calcareous groundmass.

Thinsection no. PC10-2 and PC10-3 Old Ghaghra Plain

Microstructure

In thin section, the soil shows weakly developed subangular blocky structure. Voids are mainly elongate smooth to irregular surfaced channels and vesicles. Showing compact grain channel microstructure. Total void space is about 10%. The voids are randomly distributed.

Basic Mineral Components C/F limit at 20 µm, C/F ratio 60:40

Coarse Fraction

Moderately sorted coarse sand (upto 500 µm), densly packed in finer groundmass. Quartz is >70% of the coarse fraction, it is mainly single grain, 300 - 500 µm in size, angular to subangular in shape. Micas are about 10%, they are about 500 µm long flakes, showing slight alteration. Feldspars are about 6-7%, mainly orthoclase and a few microcline and plagioclase grains are also seen. Other coarse grain minerals occuring in minor amount include a few lithorelicts of slightly altered schist/shale, hornblende and other heavy minerals.

Fine Fraction/Groundmass

Colourless to yellowish brown, mainly mineralic in nature, and consists of very fine silt and impure clays of mica and silica it is anisotriopic. It occurs as groundmass and as coatings. Plasma separation is strong, as commonly occuring well developed b-fabric include porostriated (Fig. 4.26) and parallel striated b-fabric (Fig. 4.25). C/F related distribution, mainly is chitonic, at places enulic and porphyric and related distribution is also noted.

Pedofeatures

Illuvial pedofeatures are few, they occur in form of thin (20 -30 µm) grano- and poro-argillans of ferruginous impure clays. Quasi ferruginous coating along voids (Fig. 4.26). Weakly developed crystic plasmic b-fabric due to calcareous groundmass. Strongly developed poro striated b- fabric (Fig. 4.26) and parallel striated b-fabrics. Strong animal activity in form of large isotubles densly filled by reworked basic soil in crescent shaped manner.

Thinsection no PA14-2, Old Ghaghra Plain

General Morphology

C Horizon, 25-60 cm, very dark grayish brown loam, massive, friable (moist), few fine fibrous roots, weakly calcareous without Kankars.

Microstructure

In thinsection the soil shows apedal massive soil structure, Voids are mainly simple packing voids. Densely packed medium sized sand producing compact grain microstructure. A few vughs and elongated channels are also seen in the massive soil. Total void space is about 10%.

Basic Mineral Components C/F limit at 20 µm, C/F ratio 70:30

Coarse Fraction

Generally single grain medium sand is densely packed together. Quartz is about 80% of the coarse fraction, 200-300 µm in size, showing monic and chitonic distribution. Micas are about 10%, both biotite and muscovite are fresh to slightly altered, feldspars are about 5%, they are mainly orthoclase and a few plagioclase grains showing characteristic twinning and weak alteration are also noted. Hornblende grains 100-150 µm in size and other heavy minerals occur in minor amount.

Fine Fraction/Groundmass

Mainly mineralic and partly organic in nature, mostly of unsorted impure clay and fine silty. Usually anisotropic and also some part of fine fraction is istropic due to fine discrete organic and ferruginous matter. Generally occurring as groundmass and in the interstices of coarse grains. Plasma separation is weak as commonly observed b-fabric include stipple speckled b-fabric, cross striated and at places weakly developed parellel striated b-fabric is also observed. C/F related distribution is mainly gefuric and enulic.

Pedofeatures

Illuvial clay pedofeatures are not very prominent, impure clay coatings along grains and voids are observed. Micrtic to microsparatic hypocoatings along voids are noted. Isotic plasmic/undifferentiated b-fabric due to excess of fine discrete organic matter. Moderately developed crystic plasmic b-fabric due to moderately impregnated micritic calcite in the groundmass.

Thinsection no PA14-4 Old Ghaghra Plain

General Morphology

B Horizon, 77 - 103 cm, dark grayish brown silty loam friable (moist) slightly sticky and slightly plastic (wet) few fine fibrous roots, strongly calcareous with Kankars upto 5% with Gastropod shells.

Microstructure

The soil shows moderately developed subangular blocky soil structure. The peds are partially accommodating. Voids are mainly compound packing voids. The apedal soil mass inside the peds contains few vesicles and channels. Total void space is about 10%. The voids are unoriented and show basic random distribution.

Basic Mineral components C/F limit at 20 µm C/F ratio 30:70

Coarse Fractions

Medium grained sand, which show dense packing. Mainly of quartz 80% of the coarse fraction, micas are about 10%, k-feldspars about 5-6%. Other minerals occuring in minor amount are a few hornblende grains and other heavy minerals.

Fine Fraction/Groundmass

Mainly mineralic and some part organic in nature. It consits of impure clays and fine silt, generally anisotropic in cross polarised light also in some part it is istropic. Plasma seperation is weakly developed as cross-striated and stipple speckled b-fabrics are comonly observed along with undifferenciated b-fabric at a few places.

Pedofeatures

Calcareous impregnation features are common. Micritic hypocoatings along channel voids. Moderately impregnated micritic calcite in groundmass producing cystllitic b-fabric. Weakly developed irregular shaped calcareous nodules. Gastopod shells in calcareous groundmass. Rounded and alternately layered, reworked basic soil matter due to animal activity.

Thinsection no. PA7-3 Lower Kosi-Gola Plain

General Morphology

B21 horizon, 42-66 cm, grayish brown to light olive brown silty loam, moderately developed subangular blocky structure, very few medium distinct strong brown mottles, hard (dry), firm (moist), slightly sticky and slightly plastic (wet), a few fine fibrous roots, non calcareous.

Microstructure

Under thinsection the soil shows moderately to strongly developed subangular blocky structure (Fig. 4.33). The peds are partially accommodating and separable. some part of the thinsection also shows apedal and massive soil. Voids are mainly compound packing interconnected planar voids, elongate arched smooth walled channel voids and a few irregular shaped vughs and vesicles. Total void space is about 20%. The voids are unoriented and randomly distributed. The channel voids and packing voids are generally coated with very fine silt to impure clays.

Basic Mineral Components C/F limit at 20 µm, C/F ratio 40/60

Coarse Fraction

Generally poorly sorted. Mainly it consists of quartz upto 70%, size upto 300 µm, but most of the grains range in size 100 - 150 µm, they are subangular to angular in shape. showing open porphyric distribution, Other minerals of

quartz size include micas upto 10-15%, both biotite and muscovite laths (100 - 200 µm) are slightly altered. Feldspar 5-10%, orthoclase and few grains of microcline and and a few grains of slightly altered plagioclase feldspar are also noted. Amphiboles, heavy minerals and lithorelicts constitute the rest of the coarse fraction.

Fine Fraction/Groundmass

Yellow to yellowish brown, mainly minearlic in nature, of clays and very fine silt. Generally it is anisotropic in cross polarised light. The finer fraction occur widely as groundmass and coating along voids and skeltan grains. Plasma separation is moderate, an stipple speckled oriented b-fabric, poro and cross-striated b-fabrics are moderately developedand commonly seen along with weakly developed reticulate b-fabric at a few places. C/F related distribution, generally is open porphyric, at places enulic related distribution is also noted.

Pedofeatures

Illuvial clay pedofeatures are widely present, hypo clay coatings (50- 60µm) along channel voids and along ped faces (Fig. 4.35, 4.36). Depletion/ferruginous hypocoating along (60 µm) along void. Weakly to moderately impregnated diffused iron oxide mottles upto >500 µm size. Strongly impregnated, typic orthic iron oxide nodules of >500 µm size.

Thinsection no. PA7-6 Lower Kosi-Gola Plain

General Morphology

C Horizon, 110 - 128 cm, Light olive brown, silty loam, common medium distinct strong brown mottles, with densely packed Fe-Mn concretions (PN.iv 19), firm (moist) slightly plastic and slightly sticky (wet), not roots, strongly calcareous with Kankars up to 2%, of <1 cm in size.

Microstructure

In thin section the soil shows apedal massive soil structure, voids are mainly vughs and vesicles and also a few channel voids are seen. Total void space estimated is around 20%. Microstructures observed include compact ggrain and bridged grain microstructure. Large (1-2 mm) strongly impregnated Fe Mn concretions also seen in apedal soil mass.

Basic Mineral Components C/F limit at 20 µm C/F ratio 60:40

Coarse Fraction

Mostly fine sand to silt sized material densely packed together. Quartz about 50 -60% it is of 100 - 150 µm in size, subangular micas upto 15-20% muscovites and biotites slightly altered. Other minerals of the size of quarz include feldspars 5-10 % and a few hornblende grains, heavy minerals and opeques constitute the rest.

Fine Fraction/Groundmass

Yellow to yellowish brown due to ferruginous matter. and whitish to colourless due to calcareous groundmass. The finer fraction generally occur as groundmass. Plasma separation moderate, as seen by moderately developed parallel striated b-fabric (Fig. 4.39) is commonly along with weakly developed cross striated b-fabric at a few places. C/F related distribution mainly is gefuric at places enulic and monic related distribution is also noted.

Pedofeatures

No illuvial clay pedofeatures. Calcareous impregnation pedofeatures are abundant, strongly impregnated, thick, sparitic rounded to subrounded nodules are notable feature of this soil. Often these are masked by ferruginous matter. In side the sparitic nodules some basic soil mater is mixed. Sparitic nodules showing calcification and decalcification along voids (Fig. 4.40). Moderately to strongly developed parallel striated b-fabric (Fig. 4.39). Loose incomplete micritic infilling of channels voids. Typic, orthic and strongly impregnated FeMn concretions (Fig. 4.41).

Thinsection no PB2-2, Lower Kosi Gola Plain

General Morphology

B2 horizon 34-54 cm, brown silty loam, mdeately developed subangular blocky soil structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), few clay cutans, few fine fibrous roots, common fine medium roots, non calcareous.

Microstructure

The thin section moderately to strongly developed subangular blocky structure (Fig. 4.34). The peds (average 5 mm in size) are partially accomodating and separable. The peds are bounded by interconnected channel voids. Total void space is around 20%. The voids do not show any definite orientation, and are randomly distributed.Channel and vughy microstructure is observed.

Basic Mineral Components C/F limit at 20 μm C/F ratio 40:60

Coarse Fraction

Mostly of 200-250 μm size quartz constituting upto 60-70% of coarse fraction. Other minerals of the size of quartz include feldspars upto 10-15%, Micas 10-15%, biotites are slightly to highly altered showing iron release and exofoliation. A few fresh to slightly altered hornblende grains of 50-60 μm size and a few lithorelicts of shale/schist also occur. Heavy minerals occur in less than 1%.

Fine Fraction/Groundmass

Yellowish to dark brown due to some amount of very fine organic matter, generally anisotropic except the dark organic matter, it consists of fine silt and dusty to impure clay. It occurs as groundmass and coatings along grains and voids. Plasma separation is moderate, as poro, and cross striated b-fabric are moderately developed and commonly observed along with reticulate and grano striated b-fabric at a few places. C/F related distribution mainly porphyric and enulic, also chitonic related distribution is noted.

Pedofeatures

Illuvial clay pedofeatures, very thin (20-30μm) hypocoatings along grains and voids, not microlaminated (PM.vi 25). Weakly to moderately impregnated diffused iron oxide mottles. Release of iron due to biotite alteration and other mafic minerals.

Thinsection no. PB2-3, Lower Kosi-Gola Plain

General Morphology

B2 Horizon 54-90 cm, brown silty loam, common mottles of medium distinct strong brown colour, moderately developed subangular blocky soil structure, hard (dry) firm (moist) slightly plastic and slightly sticky (wet), common clay cutans, non calcareous.

Microstructure

Thinsection of the soil shows moderately developed subangular blocky structure, the peds are partially accommodating and partially separable. The voids are mainly compound packing interconnected voids. The voids have smooth surface due to coatings along them. Other voids include channels and a few vughs and vesicles. Total voids space is about 20%. Voids are unoriented and show basic random distribution. Channel and vughy microstructures are observed.

Basic Mineral Components C/F limit at 20 μm C/F ratio 40:60

Coarse fraction

Quartz about 70-80%, (100-300 μm) in size, most of the grains are of 100μm or less and are poorly sorted, single grain monocrystalline in nature. Micas are upto 10%, biotites flakes are upto 150 μm in length and are altered, muscovites are slightly altered producing insitu pedogenic clay, felspars are upto 5-10% mostly k-felspar, a few rock fragment of shale/schist are also seen.

Fine Fraction/Groundmass

Yellow to yellowish brown mainly micaceous and consists of fine silt and impure clays, occurring as groundmass and as hypocoatings along voids and grains. Plasma separation is strong as stipple speckled, reticulate striated and poro striated b-fabric are moderately to strongly developed and are commonly observed along with weakly developed concentric b-fabric at a few places. C/f related distribution is mainly open porphyric and sometimes gefuric and chitonic distribution is also noted.

Pedofeatures

Illuvial clay pedofeatures are many, in form of thick (50-60 μm) microlaminated coatings by limpid to speckled clay along voids (Fig. 4.37, 4.38). Loose incomplete infilling of channels by impure clay is noted. Typic, orthic, strongly impregnated, semi rounded to oval shaped ferruginous nodules with sharp boundaries are noted.

Thinsection no. PB4-3 Upper Deoha/Ganga-Ghaghra Interfluve

General Morphology

B22 horizon, 60-95 cm, dark grayish brown to olive brown (2.5Y 4/2); few medium coarse mottles of red (2.5YR 4/6) color; silty loam, moderately developed subangular blocky structure; few clay coatings, firm (moist)very plastic (wet); few fine fibrous roots; weakly calcareous.

Microstructure

The soil shows moderately to strongly developed subangular blocky structure (Fig. 4.42, 4.43). Peds are partially acomodating and separable. Dominant voids are are elongate arched smooth surfaced channel voids and irregular shaped vughs and a few vesicles. Total void space is about 20%. voids are not oriented and have a basic random distribution. Channel and vughy microstructures are observed (Fig. 4.44).

Basic Mineral Components C/F limit at 20 μm C/F ratio 30:70

Coarse Fraction

Single grain, monocrystalline, subangular to anhedral shaped quartz constitute about 60-70% of the coarse fraction. Most quartz grains are of size of 100 - 150 μm few large grains (400 μm) are also present. They show basic random distribution, Other coarse mineral grains are mica about 10-15%, biotite flakes show alteration in form of exofoliation and bleaching. Muscovite flakes are slightly altered. Feldspars are 5-10%, they are weakly to moderately altered and generally consists of k-feldspars. A few grains of hornblende (<1%) and other heavy minerals noted are zircon and tourmaline.

Fine Fraction/Groundmass

Colourless to yellow, micaceous in nature, consists of fine silt and clay. It occurs as groundmass and as coatings along the voids and grains. C/F related distribution is mainly open porphyric (Fig. 4.45). strong plasma separation has given rise to various types of striated b-fabric, strongly developed cross striated b-fabric is very commonly observed along with moderately developed poro- , parallel striated b-fabric at a few places.

Pedofeatures

Illuvial clay pedofeatures are common in form of (50-60 μm) thick hypocoatings along voids and grains by dotted and impure clays (Fig. 4.46). Exofoliation alteration of biotite, also bleaching of biotite is observed. Weakly impregnated, diffused mottles of iron oxide cover about 5% of slide area. Strong animal activity is shown by subrounded interconnected excrement feature.

Thinsection no. PB4-4 Upper Deoha/Ganga-Ghaghra Interfluve

General Morphology

C1 95-135 cm, dark grayish brown to olive brown (2.5Y 4/3); few medium coarse distinct mottles of red (2.5YR 4/6) color also few gray mottles due to carbonate concretions; silty loam, structureless; firm (moist) plastic(wet); no roots ; very strongly calcareous with carbonate concretions up to 25% of 1-2cm dia.

Microstructure

Soil material shows apedal and massive soil mas in most part of the section. Voids are mainly irregular shaped vughs and elongate arch shaped rough surfaced channel voids. Apedal soil matter shows channels microstructure. Total void space is about 25%. Voids are unoriented and show basic random pattern.

Basic mineral components C/F limit at 20 μm C/F ratio 40:60

Coarse Fraction

Single grain, monocrystalline quartz most of them are of 200 μm in size and constitutes upto 70-80% of coarse fraction. Other minerals include micas 10-15%, K-feldspars, heavy minerals and lithorelicts constitute rest of the coarse fraction.

Fine Fraction/Groundmass

Colourless to yellow, micaceous in nature, sometimes it is ferruginous and calcareous. It consists of clay and fine silt. C/F related distribution is mainly open porphyric. Weak to moderate plasma separation has given rise to stipple speckled b-fabric and weakly developed cross- and poro- striated b-fabrics.

Pedofeatures

Typic, orthic, strongly impregnated, irregular to circular shaped nodules of sparite. A few sparatic nodules also show dissolution feature (removal of calcareous matter) along voids (Fig. 4.47). Quasi and hypocoatings of calcitic material and impure clay along pores and channels. Weakly impregnated, microcrystalline calcareous ground mass in part of slide shows crystillitic b-fabric.

Thinsection no. PB12-2 Upper Rapti-Ghaghra Interfluve

General Morphology

B21 horizon, 18-41 cm, light Oolive sandy loam, weakly developed subangular blocky soil structurwe, friable (moist), very few clay cutans along pores, common fine medium fibrous roots, non calcareous.

Microstructure

In thinsecton the soil shows weakly developed peds, the peds are not separable. Dominant voids are vughs vesicles and channels. Internal surface of the voids is generally rough and sometimes it is smooth. Total void space is about 10-15%. the microstructures observed include cmpact grain and pellicular grain microstructures.

Basic mineralCompnents c/f limit at 20 µm c/f ratio 60:40

Coarse Fraction

Sinle grain, subhedral quarrtz about 80% of the coarse fraction of 200 µm size (range 150-300 µm). Other coarse minerals of the quartz size include slightly altered micas about 10%, k-feldspars 5-6% and a few grains of hornblende and heavy minerals. All the coarse grain minerals are moderately sorted and are of the size of the quartz.

Fine fraction/Groundmass

Dirty white tom yellowish brown in colour, mainly of micaacious fine silt and clay. It occurs ad braces in betwwen the coarse grains and as coatings along the grains and the voids. Plasma separation is moderate as stipple speckled and cross-striated b-fabrics are commonly noted. C/F related distribution is mainly gefuric and chitonic.

Pedofeatures

Illuvial pedofeaturs are not prminant. A few 50-60 µm thick strongly oriented clay cutans are noted along the channelvoids. Depletion coatings by iron oxide. A few ferruginous micropan (1-2mm in length) ae noted.

Thinsection no. PB12-4 Upper Rapti-Ghaghra Interfluve

General Morphhology

C horizon, 82-130 cm, grayish brown sandy loam, structureless, friable, (moist), no roots, common fine medium pores, non calcareous,

Microstructure

The soil thinsection shows apedal and massive soil structure. alao at places bridged grain bicrostructue is seen. total void space is about 10-15%. Dominant voids are rough surfaced vughs and channels and simple packing voids. the voids are unoriented and show random distribution.

Basic mineral coomponents c/f limit at 20 µm c/f ratio 80/20

Coarse Fraction

Mainly single grain quartz about 80% of the coarse fraction. It is of size of 100-200 µm and it is moderately sorted. Other minerals of quartz size are micas, feldspars and heavy minerals Most of these are unaltered but some of the mica grains show weak alteration.

Fine Fraction/Groundmass

Yellow to yellowish brown, micaceous fine silt and clays , Plasma separation weak or nil as undifferentiated b-fabric is commonly observed along with weakly developed stipple speckled b-fabric at a few places is noted. c/f related distribuution is mainly gefuric and sometimes it is monic.

Pedofeatures

Illuvial clay pedofeatures are absent. Sesquiorides motteles and concretions are common and occupy about 10-15% of the thin section. Large magnan (manganese concretions) is noted whiich shows sharp and prominant boundaries.

Thinsection no PB9-3 Old Ghaghra Bar

General Morphology

B21 Horizon, 60 - 118 cm, dark yellowish brown silty loam, few medium coarse faint mottles, weakly developed subangular blocky structure, hard (dry) firm (moist) slightly sticky and plastic, few clay cutans along pores, few fine fibrous roots, non calcareous.

Microstructure

The soil under thin section shows weakly developed to moderately developed peds. At places apedal and massive soil is also seen. Void are mainly elongate channels and vesicles showing intergrain channel/vesicular microstructure. The voids generally show smooth surface due to thin coatings along them.

Basic Mineral Components C/F limit at 20 µm C/F ratio at 50:50

Coarse Fraction

Moderately sorted, fine to medium sand. Mainly quartz (80%), it is subangular to subrounded in shape and (150 - 200 µm) in size, and it is randomly distributed, showing chitonic and enulic related distribution. Micas are about 5 to 10%, biotite and muscovite flakes are slightly to moderately altered producing insitu clays. Feldspars are mainly orthoclase 5-6%, a few slightly plagioclase grains are also seen. Other minerals of coarse fraction occur in minor amount, include a few grains of hornblende and other heavy minerals and a few opeques.

Fine Fraction/Groundmass

Colourles to yellow, mainly micaceous matter of pure to impure clays and fine silt. It is anisotropic in cross polarised light. Plasma separation is strong as strongly developed (Fig. 4.48) cross and reticulate striated b-fabrics are commonly observed along with moderately developed poro striated and stipple speckled b-fabric at a few places. C/F related distribution, chitonic, gefuric are the main C/F related distribution is mainly chitonic and gefuric at places enulic and porphyric related distribution is also seen.

Pedofeatures

Illuvial clay pedofeatures are common. They occur in form of, (i) limpid to speckled clay hypocoatings (60-80 µm) along channel voids (Fig. 4.49), (ii) strongly oriented ferruginous limpid clay infilling in a channel (Fig. 4.50), (iii) grano argillans of few microns around coarse grains. Release of iron from biotite and other mafic minerals. Weakly to moderately impregnated ferruginous mottles.

Thinsection no PB9-4 Old Ghaghra Bar

General Morphology

B22 horizon, 72-118 cm, dark grayish brown silty loam, few medium coarse faint mottles, moderately developed subangular blocky soil structure, hard (dry) firm (moist) slightly plastic and sticky (wet) few fine fibrous roots, non calcareous.

Microstructure

Under thin section the soil shows weakly developed subangular blocky structure (PM i 15), the peds are partially accommodating and separable. Voids, packing voids are usually compound and irregular shaped, a few inped vesicles and vughs are also seen. Vughy microstructure is noted. Total void space is about 15%. The voids are randoumly distributed.

Basic Mineral Components C/F limit at 20 µm C/F ratio 50:50

Coarse Fraction

Generally moderately sorted fine sand. Mostly quartz >70% of the coarse fraction. They are 100 - 150 μm in size and subangular to subrounded in shape. micas are about 10-15%, both biotite and muscovites show some alteration. Feldspars are about 10%, mainly orthoclase with few grains of plagioclase. Other coarse grain minerals include a few rock fragments, a few hornblende grains and other heavy minerals.

Fine Fration/Groundmass

Colourless to yellowish, mainly micaceous impure clays and fine silt. Occuring as groundmass and as thin argillans along voids and grains. Plasma separation is moderate to strrong as cross striated, poro striated and stipple speckled b-farbics are commonly observed along with moderately developed parallel striated and monostriaated b-fabrics at a few places. C/F related distributionis mainly chitonic and enulic and at place porphyric related distributionis also noted (Fig. 4.48).

Pedofeatures

Illuvial clay pedofeatures are common, they ocur in form of thin (50-60 μm) hypocoatings along voids by limpid and speckled clays. (Fig. 4.49, 4.50). Very thin grano argillans. Large ferruginous impure clay micropan. Diffused iron oxide mottles occur scatterdly constituting 2-3% of thin-section.

Thinsection no PC1-3 Middle Deoha/Ganga-Ghaghra Interfluve

General Morphology

B2 horizon, 29-80 cm, Light olive brown silt loam, moderately developed subangular blocky structure, hard (dry) friable (moist) plastic and sticky (wet), clay cutans common as pores. strongly calcareous with fine carbonate concretions up to 2%.

Microstructure

The soil shows moderately developed subangular blocky structure. The peds have irregular surfaces and are accommodating. Dominant voids are interconnected planar packing voids, irregular shaped vughs, elongate arch smooth surface channels. In part of slide planar voids are closely spaced subparallel, producing platy microstructure. Total void space is about 15-20%.

Basic Mineral Components C/F limit at 20 μm C/F ratio 40:60

Coarse fraction

Monocrystalline, quartz upto 60-70% of the coarse fraction. It is subhedral to subrounded, moderately sorted and range in size 100-150 μm . Micas are about 10-15%, biotite and muscovite flakes of 200 μm in length show random distribution pattern, at places platy microstructure due to preferred orientation is noted. Biotite alteration in form of release of iron is noted. K-feldspars about 10-15% of 100-200 μm size, most of them are subhedral to anhedral in shape and show weak alteration. Other identifiable minerals of the size of the quartz include a few grains of hornblende 50-60 μm size, which show slight alteration.

Fine Fraction/Groundmass

Finer fraction of the soil mainly of micaceous fine silt and clay. It is coiourless to yellowish brown and shows higher order of interference colours in cross polarised light. It is limpid to speckled. C/F related distribution, mainly open porphyric, also in parts it shows enulic related distribution pattern. Plasma separation is strong, reticulate and parallel striated b-fabrics are very well developed and are commonly observed, also strongly developed crystic plasmic b-fabric is noted.

Pedofeatures

Thick (100-120 µm) hypo coatings along voids by limpid to dotted clay (Fig. 4.58). Calcareous pedofeatures are dominant constitute about 10% slide area. They occur in form of typic, orthic and strongly impregnated micritic and sparatic nodules of irregular to subrounded in shape. A set of elongated parallel strongly impregnated micritic nodules (Fig. 4.62, 4.63). Thick hypocoating by sparatic calcite along subrounded void (PN. v 23). Depletion feature by release of iron from biotite and other mafic minerals is observed. Animal activity in part of slide is noted by subrounded coalsceased reworked basic soil material also an isotuble of 1 cm in length is observed, which is filled with crescent shaped reworked basic soil matter.

Thinsection no. PC1-4 Middle Deoha/Ganga - Ghaghra Interfluve

General Morphology

B22 horizon, 80-125 cm, light olive brown silty loam, moderately developed subangular blocky structure, very few medium faint dark grayish mottles. Slightly hard (dry), friable (moist) slightly sticky and slightly plastic (wet) few fine fibrous roots, strongly calcareous, fine concretions (upto 1 cm) about 10%.

Microstructure

The soil shown moderately developed subangular blocky structure in most of the part of the thin section. Dominant voids are elongate arched smooth walled channels and a few irregular shaped vughs and vesicles. Total void space estimated is 10-15%. The microstructures observed include compact grain microstructure, Pellicular grain microstructure (PN. v 30) and bridged grain microstructure. micro microstructure. Voids are less, 10-15%, few vughs other voids are simple packing voids and also bridged grain microstructure is seen.

Basic Mineral components C/F limit at 20 µm C/F ratio 60/40

Coarse fraction

Single grain quartz about 70% of the coarse fraction most of the grains are of the size of 200 µm . Thin mica flakes of biotites and muscovite range are upto 10% and these are weakly altered. K-feldspars are about 10%. Other minerals of the size of quartz include a few hornblende grains and other heavy minerals and a few lithorelicts.

Fine Fraction

Yellow to yellowish brown coloured, mainly micaceous matter of fine silt and clay. It occurs as groundmass and coatings. Plasma separation is weak as weakly developed cross striated is commonly observed along with weakly developed stipple speckled b-fabric at a few places. C/F related distribution, gefuric and chitonic related distribution (Fig. 4.53).

Pedofeatures

Few thick hypocoatings (Fig. 4.58) of limpid and dotted clay along void and grains are noted. Amorphous pedofeatures, include weak to moderately impregnated ferruginous diffused mottles and FeMn concretions. Impregnation of micritic calcareous matter in groundmass producing crystillitic b-fabric. Rounded and elongated micritic nodules (Fig. 4.62, 4.63, 4.64) are also seen.

PC4-2 Middle Deoha/Ganga-Ghaghra Interfluve:

General Morphology

B1 horizon, 22-47 cm, grayish brown to light olive brown silty loam, few fine distinct grayish brown mottles,

weakly developed subangular blocky structure, hard (dry), firm (moist), slightly sticky and plastic (wet) many fine tubular pores, few fine medium fibrous roots, noncalcareous.

Microstructure

The soil has weakly developed subangular blocky structure, voids are mainly vughs and vesicles, packing voids are few generally simple packing voids. The equigranular coarse fraction is higher and is densely packed producing compact grain micro structure. Total void space estimated is around 15%. Voids are unoriented and show basic random distribution.

Basic Mineral components C/F limit at 20μm C/F ratio 60:40

Coarse Fraction

Single grain, monocrystalline angular to subangular quartz constitute up 60-70% of the coarse fraction, most of quartz grains are 100 -150μm in size. Micas are about 10-15% and it includes fresh to slightly altered muscovite, biotite flakes are generally altered and show exofoliation and bleaching. K-feldspar is about 10%. Other identifiable coarse grains include a few rock fragments of shale and schist and a few grains of hornblende and other heavy minerals.

Fine Fraction/Groundmass

Yellow to yellowish brown mainly of micaceous nature sometimes ferruginous and organic in nature. It consists of fine silt and clays, occuring mainly as groundmass. Plasma separation not very strong as weakly to moderately developed poro-, grano- and cross and parallel striated b-fabrics are commonly noted (Fig. 4.61). C/F related distribution is mainly chitonic and gefuric.

Pedofeatures

A Few subrounded discrete mass of reworked basic soul due to animal activity. Thin (20 -30 μm) dusty clay hypocoatings along voids and grains (PN. v 16). Ferroargillic elongated arched (>400 μm long 60 μm wide) papule. Depletion coating by ferruginous and matter mixed with organic matter along void. Moderately impregnative diffused mottles of iron oxide.

Thinsection no. PC4-4 Middle Deoha/Ganga - Ghaghra Interfluve

General Morphology

B23 horizon, 78-116 cm, light olive brown to olive brown silty loam, many medium coarse distinct grayish brown mottles with 5% Fe Mn concretions, moderately developed subangular blocky structure, few clay coatings on pores, hard (dry) firm (moist) plastic and sticky (wet).

Microstructure

Under thin section soil shows moderately developed subangular blocky structure the peds (2 mm to 10 mm) are well separated and accommodating. The peds are bounded by interconnected planar voids, other voids are mainly elongate arched smooth walled channels and subrounded smooth walled vesicles. Total void space is about 15%. The voids are unoriented and show basic random distribution.

Basic Mineral Components C/F limit at 20 μm C/F ratio 4060

Coarse fraction

Mostly quartz (80%) single grain, subrounded and monocrystalline, most of the quartz grain are of 100 μmin size and a few are of 300 and 400 μm size. Micas are upto 10%, biotite show bleaching wehereas muscovites are fresh to to weakly altered. K felspars and few grains of plagioclase are about 5-6%. Other minerals of quartz size are horneblende

grains and other heavy mineral identified includes rutile and tourmaline in traces.

Fine Fraction/Groundmass

The finer fraction is colourless, yellowish to yellowish brown, mostly micaceous (>80%) in nature. consists of fine silt and clays. Sometimes ferruginous and organic matter mixed with this. Plasma separation is strong, silt and clays are strongly oriented and commonly show grano-, poro-, and reticulate striated b-fabrics along with moderately developed monostriated and parallel striated b fabrics are observed at a few places.

Pedofeatures

Thick (100 μm) hypocoatings by dusty and speckled clays along voids and grains. Release of iron from biotite and formation of depletion coatings along voids. Typic, orthic and , strongly impregnated subrounded Fe Mn nodule with sharp boundaries is observed. Diffused mottles of sesquioxides.

Thinsection no PB7-3 Middle Deoha/Ganga - Ghaghra Interfluve

General Morphology

B2 horizon, 50-100 cm, light yellowish brown to light olive brown silty loam. Moderately to strongly developed subangular structure, common medium distinct dark grayish mottles common clay cutans along pores common fine fibrous roots non calcareous.

Microstructure

The soil has strongly developed subangular blocky peds (Fig. 4.51). The peds are well separatble and accommodating each other, ped size range 2 mm to 1 cm. Voids are mainly compound packing voids and smooth surfaced channels and vughs. Total void space is about 15%. The voids are unoriented and show basic random distribution. the microstructures observed include channel and vughy microstructure.

Basic Mineral Components C/F limit at 20 μm C/F ratio 40:60

Coarse fraction

Single grain, subrounded quartz (150 - 200 μm) constitutes upto 60-70% of coarse fraction. Micas constitute upto 10-15%, biotite laths (150-200 μm) show preferred orientation. These are generally weakly to moderately altered and show bleaching and exofoliation. Muscovite laths (150 μm) are wekly altered. K-felspars 10% includes mostly orthoclase and a few grains of microcline. A few hornblende grains slightly altered and othe heavy minerals are upto 2%.

Fine Fraction/Groundmass

The fine fraction of soil consists of fine silt and clay. Most part of it is anisotropic. Generally the fine mass is colourless to yellowish brown and brownish black when organic matter is dominant. The fine fraction of clay and fine silly clay which occurs as limpid clay coatings and speckled impure clay as in ground mass. Plasma separation is very strong, strongly developed cross striated, reticulate striated b-fabrics are very commonly observed along with commonly occuring moderately developed poro and parallel striated b-fabrics also finer fraction is strongly oriented along Fe Mn concretions at a few places.

Pedofeatures

Illuvial clay pedofeatures are dominant as thick (200 μm) limpid and dotted clay crescent shaped microlaminated hypocoatings along voids are widely observed (Fig. 4.54, 4.56, 4.57). Impure clay intercalations are noted in groundmass (Fig. 4.55). Depletion pedofeature include iron release from biotite and depletion coating along voids. Amorphous pedofeatures of typic orthic strongly impregnated Fe Mn nodules with prominent boundaries are observed. Diffused mottles are also seen.

Thinsection no PB6-4 Middle Deoha/Ganga - Ghaghra Interfluve

General Morphology

B23 horizon, 55-85 cm, yellowish brown silt loams; common medium coarse faint yellowish red mottles, moderately developed subangular blocky structure, hard (dry) firm (moist) slightly sticky and plastic (wet) few clay cutans on pores, few fine fibrous roots, non calcareous.

Microstructure

The soil shows moderately to strongly developed subangular blocky structure over most part of the section. The peds are partially separated and accommodating (Fig. 4.52). Dominant voids are elongated channels and vughs, which are often coated with clays. The soil shows channel and vughy microstructure.

Basic Mineral components C/F limit at 20 μm C/F ratio 40:60

Coarse fraction

Mainly single grain quartz 50-60% of the coarse fraction, mostly of 100 μm size, subrounded to subangular in shape. and they generally show double spaced open porphyric related distribution. Micas are upto 15%, muscovite laths (150 μm) are slightly altered producing insitu clays, biotite laths show bleaching and iron release. K-feldspars are about 10-15%. Other minerals observed include hornblende and other heavy minerals and a few lithorelicts of wekly altered shale and schist constitute rest of the coarse fraction.

Fine Fraction/Groundmass

Finer faction mainly consists of impure fine silt and clay, showing yellow to yellowish brown when ferruginous matter is dominant. It occurs as coatings and as groundmass. Plasma separation is strong as strong development of reticulate and cross striated b-fabric are observed very commonly along with moderately developed commonly occuring porostriated and parallel striated and strong orientation along FeMn concretion is noticed at a few places.

Pedofeatures

Illuvial clays are the dominant pedofeature observed in these soils. They occur in form of channel argillan (Fig. 4.60). These are thick (upto 100 μm) microlaminated pure limpid clay hypocoatings. Grano argillan, though not well developed as void argillan, also occur. Limpid to dotted clay papule >1000 μm in length and >200 μm in width (Fig. 4.59). Typic orthic strongly impregnative Fe Mn nodules with sharp boundaries (Fig. 4.65). Fe Mn mottles and nodules constitute upto 10% of thin-section.

Thinsection no. PB6-5 Middle Deoha/Ganga-Ghaghra Interfluve

General Morphology

B24 horizon, 85-120 cm, yellowish brown silty loam, common medium coarse faint yellowish red and black mottles, moderately developed subangular blocky structure, hard (dry), firm (moist), slightly plastic and slightly sticky, few clay cutans along pores, few fine fibrous roots, non calcareous.

Microstructure

The soil under thin section shows moderately developed subangular blocky structure (PN. iv 24). Many arched, elongated channels often coated with thin clay and a few vesicles and vughs are also seen. Total pore space is around 20%. The soil shows channel and vughy microstructure. The voids are not oriented and show basic random distribution.

Basic Mineral Components C/F limit at 20 μm C/F ratio 50:50

Coarse Fraction

Single grain, quartz upto 60-70%, subrounded to subangular monocrystalline, size upto 100 µm show open porphyric related distribution. Micas are upto 15%. Muscovites laths are fresh to altered producing some amount of clays, biotite shows exofoliation and bleaching. K-feldspars are upto 10% Other minerals include a few amphiboles and a few grains of lithorelicts.

Fine Fraction/Groundmass

Colourless to yellowish fine mass, consists of limpid to dusty clay also some fine discrete organic matter is also present. Plasma separation is moderate to strong, as strongly developed reticulate striated b-fabric is very commonly observed along with moderately porostriated and parallel striated b-fabric is commonly observed. At places isotic plasmic b-fabric is also observed due to some amount of fine organic matter.

Pedofeatures

Illuvial clay pedofeatures are dominant, in form of limpid pure clay, strongly oriented, microlaminated, convolute shaped channel argillan (150 µm) thick. Also microlaminated 80 µm thick speckled clay hypocoatings along channels. Scattered, diffused and discrete fine ferruginous in groundmass matter producing distinct fabric. Diffused iron and manganese mottles. Isotuble (2 cm) filled with crescent shaped reworked basic soil material.

Thinsection no PC14-3 Lower Rapti Ghaghra Interfluve

General Morphology

B3 horizon, 30-75 cm, light olive brown silty loam, few medium distinct motteles of of very dark grayish brown colour, moderately developed subangular blocky structure, hard (dry) firm (moist), slightlly hard and slightly plastic (wet), few clay cutans along the pores, few fine fibrous roots, strongly calcarous (kankars 10% of 1 cm size).

Microstructure

Soil material shows moderately to strongly developed subangular structure, voids are mainly compound packing voids with a few elongate smooth channels and vesicles. Voids are partially filled with micro-aggregates and other basic soil material. Total void space is about 15%. Voids have a basic random distribution. Microstructure observed include channel and vesicular microstructure

Basic Mineral Components C/F limit at 20 µm C/F ratio 50:50

Coarse Fraction

Mainly single grain quartz upto 70%, it is subhedral to anhedral in shape, poorly sorted, upto 200 µm in size. Slightly to moderately altered micas are about 10-15%. K-feldspars are about 10%. Other coarse grain minerals occuring in minor amount include amphibole, heavy minerals and a few lithorelicts.

Fine Fraction/Groundmass

Dirty white to Yellowish micaceous and calcareous matter of fine silt and clays, which is anisotropic is cross polarised light. It occurs as groundmass and as coatings. Plasma separation is moderate to strong as cross striated b-fabric is very commonly observed and moderately developed parallel striated b-fabric is is seen at few places along with commonly occuring crystic plasmic b-fabric. C/F related distribution is mainly double spaced to single spaced open porphyric, sometimes enulic related distribution is also noted.

Pedofeatures

Thick hypocoatings along voids by limpid to ferruginous clays, and ferrargillic clay papules of 300 µm in length are noted, also loose incomplete infilling of channel voids by fine soil material is observed. Calcite pedofeatures acount for 20% of thinsection area. They occur in form of weakly impregnated calcareous groundmass producing crystillitic b-fabric, strongly impregnated irregular shaped, thick microcrystalline nodules of calcite (Fig. 4.72, 4.73). A cone shaped pedotuble of 4 cm length is observed. The pedotuble is densely filled with basic soil material, which shows distinct fabric (Fig. 4.74). Voids along the walls of the pedotubles show loose incomplete infilling of basic soil and calcarous matter. Bow shaped micropan of finer fraction of basic soil material and ironoxide (PN. iii 3). Animal activity is noted in form of rounded to subrounded excrement features and a few isotubles composed of basic soil material (Fig. 4.75).

Thinsection no. PC12-2 Lower Rapti-Ghaghra Interfluve

General Morphology

B21 horizon, 18-40 cm, yellowish brown to dark yellowish brown (10YR 4.5/4), loam, moderately developed subangular blocky structure, friable (moist) slightly plastic and slightly plastic, common fine fibrous roots, clay cutans along pores common fine medium pores, non calcareous

Microstructure

Soil thinsection shows moderately to strongly developed subangular blocky structure (Fig. 4.66, 4.67). Partially accomodating peds are bund ed by thin planar interconncted voids. Ped walls are irregular shaped and measure up to 5 mm. Thin, bow shaped, planar micropans composed of fine soil matter and ferruginous matter are also present (12-15 mm in length). Voids are mainly of small equidimentional vughs, other voids are elongate smooth walled channels. Total pore space is about 20-25%. Voids are unoriented and show a basic random distribution. Vughy and channel micrstructure are dominant.

Basic Mineral Component C/F limit at 20 µm C/F ratio 30/70

Coarse Fraction

Mainly single grain quartz about 60-70% of the coarse fraction, it is subangular to anhedral in shape, their size range upto 400 µm, but most of the grains are of 100-150 µm in size. he larger (300-400 µm) grains are not oriented and show open porphyric and enulic distribution and close single spaced and double spaced porphyric distribution by smaller (100 µm) grains. Other minerals of quartz size are of micas about 10%, muscovite show wekly altered to unaltered large flakes (400 µm). Biotite flakes show more alteration. K-felsdspars are about 10%. Other coarse grain minerals occuring in minor amount include a few rock fragments, weakly altered hornblende grains, heavy mineral and opaques constitute the rest of the coarse fraction.

Fine Fraction/Groundmass

Mainly mineralic matter of fine micaceous nature. It consists of very fine silt and limpid to specked clay. It occurs as coatings and as groundmass. C/F related distribution is mainly enulic, also close and open porphyric related distribution is noted. Plasma separation is strong, cross striated and reticulate striated b-fabrics are commonly observed along with poro striated b-fabric at a few places.

Pedofeatures

Hypocoatings by dotted and speckled clay along voids are thick as (100 -150 µm). Strongly oriented microlaminated thick (200 µm) limpid clay coatings in a channel void (Fig. 4.68, 4.69). Long straight isotuble (2cm) filled with reworked basic soil in crescentls shaped pattern due to animal activity.

Thinsection no. PC12-4 Lower Rapti-Ghaghra Interfluve

General Morphology

B23 horizon, 78-123 cm, light olive brown silty loam, moderately to strongly developed subangular blocky structure, firm (moist), slightly sticky and plastic (wet), few cutans on pores, non calcareous, medium sized Fe Mn concretions and mottles about 10%.

Microstructure

The soil material shows moderately to strongly developed subangular blocky structure, the peds have irregular accommodating boundaries and range in size from 2 mm to 1 cm. Voids are mainly elongate arched smooth walled channels and irregular vughs. channel vughy microstructure are widely observed. Total pore space is about 20%. The voids show basic random distribution. Few large subrounded mottles of iron oxide and other opaque constitute 5% of slide.

Basic mineral components C/F limit at 20 μm C/F ratio 50:50

Coarse fraction

Mainly single grain monocrystalline quartz is about 60-70% of coarse fraction. The quartz grains are subangular to anhedral in shape. Other coarse grain minerals include micas about 10-15%, few large (400 μm) flakes of unaltered to slightly altered muscovites. K-felspars are about 10-15%. Other minerals occuring in minor amount include amphiboles about 1% and few grains of heavy mineral and rock fragments.

Fine Fracture/Groundmass

Dirty white to yellow coloured, micaous fine silt and ferruginous and speckled clays. Occurring as groundmass and coatings. Strong developed cross striated b-fabric is very commonly observed along with commonly occuring reticulate striated and moderately developed poro and grano b-fabric are noted at a few places. C/F related distribution is mainly porphyric and enulic, also chitonic related distribution is noted at a few places.

Pedofeatures

Thick (100-120 μm) hypocoatings by microlaminated limpid clay along void and channels (Fig. 4.70, 4.71). moderately impregnated subrounded diffused mottles of iron oxide.

APPENDIX- V

ABSOLUTE COUNTS OF QUARTZ AND FELSPARS IN VARIOUS GEOMORPHIC UNITS

Sample No.	Unit	Depth (cm)	Absolute Counts				Felspar/Quartz Ratio
			Quartz	Na Felspar	K Felspar	Total Felspar	
PA11-6	DSP	160	3063.8	201.7	-	201.7	0.06
PA10-3	DSP	120	4915.9	190.4	142.85	333.2	0.06
PA15-5	RDSP	130	3541.6	238.0	142.85	380.8	0.10
PC10-6	OGP	135	8085.1	139.5	232.5	372	0.04
PB10-4	GPP	145	4000.0	409	-	409.0	0.10
PB9-5	OGB	175	6875.0	511.6	325.5	837.1	0.12
PB14-5	RPP	132	8333.3	533.3	355.5	888.8	0.10 0.10
PA9-5	UKGP	160	13333.3	1000	556.5	1556.5	0.11
PA6-5	UKGP	123	5319.14	476.2	238.0	714.29	0.13
PA7-7	LKGP	160	4810.12	794.4	429.9	1224.3	0.25
PB5-7	UDGGHIF	200	5833.3	1069	418.6	1487.6	0.25
PC7-5	MDGGHIF	260	5833.3	930.23	604.6	1534.8	0.26
PB7-5	MDGGHIF	300	7916.6	837.2	372.0	1209.2	0.15
PC4-5	MDGGHIF	140	5106.3	651.16	558.1	1209.26	0.23
PB11-6	URGHIF	210	4388.2	594.3	415.0	1009.3	0.23
PC12-6	LRGHIF	200	6808.5	558.13	1023.2	1581.33	0.23
PC14-6	LRGHIF	155	8250.0	1136.36	590.9	1727.26	0.209 0.21
PC8-5	MDDGHIF	200	8333.3	1906.9	604.6	2511.55	0.30

I do not think mal-
ke reporting of data
upto decimal stons
much significant in this case.

APPENDIX-VI

CARBON AND OXYGEN ISOTOPE COMPOSITION OF CALCRETE FROM DIFFERENT SOIL-GEOMORPHIC UNITS

Sample No.	Soil-geomorphic unit	Horizon	Type of calcrete	δC^{13} (‰)	δO^{18} (‰)
PC14/2	LRGHIF	B1	Type II	0.70	-8.10
PC6/3	MDGGHIF	B2	Type I	-6.90	-16.10
PC6/2	MDGGHIF	B1	Type II	0.76	-8.16
PC13/5	LRGHIF	B2	Type I	-5.62	-8.55
PB7/2	MDGGHIF	B2	Type I	-2.39	-8.51
PA7/7	LKGP	C	Type III	0.69	-9.20
PA6/5	UKGP	C	Type III	1.64	-8.90
PA14/4	GFP	C	Type III	0.28	-10.47
PB10/3	GFP	C	Type III	0.97	-9.64
PB4/4	UDGGHIF	C	Type III	1.80	-8.60
PA15/5	OSMKPD	C	Type III	0.60	-8.00

Abbriviations for soil-geomorphic units are same as in Fig. 2.1.

As to how the composition is coming to negative value.