GEOMORPHOLOGICAL AND PEDOLOGICAL EVOLUTION OF PARTS OF BANGLADESH PLAINS

A THESIS

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in
APPLIED GEOLOGY

By

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Gratis

CANDIDATE'S DECLARATION

I hereby certify that the work, which is being presented in this thesis entitled "**GEOMORPHOLOGICAL AND PEDOLOGICAL EVOLUTION OF PARTS OF BANGLADESH PLAINS**" 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 the period from September, 1991 to November, 1994 under the supervision of Dr. B. Parkash.

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

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ABSTRACT

The Lower-Ganges-Brahmaputra-Meghna river system occupies most of Bangladesh and forms one of the world's largest fluvio-deltaic plains. Neotectonism and Worldwise Quaternary palaeoclimatic and sea level changes have influenced significantly the development of landforms and soils on these plains. Based on the remote sensing techniques, field checks, soil morphology and laboratory investigations of soils from parts of Bangladesh plains, twelve soil-geomorphic units have been recognized.

Studies of field and laboratory characters of soils helped to determine the varying degree of soil development on the different soil-geomorphic units which has been used to group and rank the soils of the different soil- geomorphic units into five members of a soil chronoassociation. These members are **(i)** QGB1 (<1500 Yrs. B.P.) comprising the soils of the Brahmaputra Floodplain and Young Ganges Deltaic Plain, **(ii)** QGB2 (2500 - 3000 Yrs. B.P.) comprising the soils of the Tista Fan, Old Tista Plain and Moribund Ganges Deltaic Plain, **(iii)** QGB3 (3000-4000 Yrs. B.P.) which includes the soils of the Old Brahmaputra Plain, Sylhet Depression and Old Meghna Deltaic Plain, **(iv)** QGB4 (5000-6000 Yrs. B.P.) which includes the soils of the Lower Atrai Depression and **(v)** QGB5 (>15000 Yrs. B.P.) comprising the soils of the Barind Tract, Madhupur Tract and Lalmai Hills.

The soil-forming processes are found to be different on the three major landforms, namely (i) the fluvio-deltaic plains, (ii) the palaefluvio deltaic uplands and (iii) the low-lying depressions. The

fluvio- deltaic plain soils are marked by moderately thick argillans (40-100μm), hydromorphism and ferrolysis of soils and partial decalcification of the upper horizons and reprecipitation of calcite in the lower horizons. The palaeofluvio-deltaic upland soils are marked by sesquioxide-rich (relict red) and polygenetic soils as evidenced from three major phases of pedogenesis such as (i) alternating wet and dry phase of the Late Pleistocene time promoting widespread translocation of fine clay (<.2 μm) and formation of many thick argillans (50-250μm), (ii) dry phase at 7000-8000 Yrs.B.P. promoting the development of calcrete of stage III and (iii) wet and humid phase since the Mid-Holocene period leading to the hydromorphism/ferrolysis of soils both on the upland and lowland areas. Also, these upland soils have reached the fersiallitic and ferruginatic stages of pedogenesis of Duchaufour (1977) on the level areas and margins of the uplands respectively. The depression soils are marked by the general segregations of iron oxides throughout the solum, thick ferriargillans (~80 μm) and flood coatings.

The clay minerals such as illite, kaolinite, chlorite, vermiculite, montmorillonite and mixed layered minerals vary with increasing degree of pedogenesis and profile sites. Chlorite amount decreases with increasing degree of pedogenesis and it becomes totally absent in the oldest soil chronoassociation member (QGB5). Kaolinite shows an increasing trend with increasing degree of pedogenesis. The poorly drained profile sites are marked by the formation of montmorillonite and it is generally preceded by the formation of vermiculite.

Neotectonism has influenced significantly the development of landforms and soils in the study area in the following manners: (i) If a tectonic block is uplifted/tilted gently, the rivers flowing over it shift away and the zone of sedimentation becomes a site of pedogenesis, (ii) If a certain block subsides slightly it becomes a waterlogged depression allowing hydromorphism of soils but higher subsidence allows sedimentation over the block and (iii) Rapid uplift of the tectonic block promotes partial erosion but slow rate of uplift facilitates good profile development. The shiftings of most of the rivers such as the Ganges and the Tista river systems towards the east and the southeasterly subsidence of the Barind and the Madhupur Tracts are attributed to the overall subduction of the Indian plate beneath the Burmese plate.

The observed three cases of gradual changes in the degree of soil development are: **(i)** Rate of sedimentation/subsidence decreases from the proximal to distal part of the Tista Fan. This is accompanied by an increase in the degree of soil development, **(ii)** The Ganges Delta is prograding southward with contemporaneous increase in rate of sedimentation in the direction of progradation. However, there is a decrease in the degree of soil development towards the south and **(iii)** The tilting of the Ganges Deltaic Plain Block towards the east/southeast has caused easterly/southeasterly shifting of the the Ganges river. This has also resulted in the decrease of soil development from the northwest to southeast.

The above soil development relationship can be called as pedofacies after Brown and Kraus (1987). The last one is related to active tectonics and may be called as tecto-pedofacies after Kumar et al. (in press).

Also, the palaeoclimatic and sea level changes have affected significantly the development of landforms and soils in the study area. The monsoon climate passed through (i) a very arid phase at about 22000-18000 yrs. B.P. when the sea level fell down to -130m in the Bay of Bengal allowing the coastline to move over 100 km south than at present and (ii) a very humid phase at about 12500-10500 yrs. B.P. which led to the increase rainfall and run-off in the region (Cullen, 1981). At 6000-7000 yrs. B.P. the transgression of sea swept over many parts of the study area. Except the upland areas, the soil formation started with regression of sea since 6000 yrs. B.P. in the region. Corresponding to the climatic and sea level changes three major phases (e.g. alternating wet and dry, dry, and wet phases) of pedogenic processes have been recognized as discussed earlier.

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INTRODUCTION

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INTRODUCTION

1.1 RATIONALE

Bangladesh plains occupy about 85% of the total area of the country. The country comprises mainly alluvial and deltaic plains of the Lower Ganges-Brahmaputra-Meghna river system. This system carries annually 1.5 million cusecs of water and 2.2 billion tons of sediments to the Bay of Bengal (Coleman, 1969) and forms one of the world's largest delta systems covering an area of 106,000 km^2 (Coleman, 1990). The latter is mostly a flat plain of Late Quaternary age with an average slope of 3-5 cm/km. Also, the Bengal Basin covering most of Bangladesh is considered a part of the Indogangetic Foredeep, created as a result of rise of the Himalayas (Sengupta, 1964; Mathur and Eavns, 1964; Desikachar, 1974 and Singh, 1971). In terms of Plate Tectonic theory, the Basin is considered as a rifted passive marginal basin of the Indian plate and it characterizes a remnant ocean type which acquired its present configuration during the Neogene period as a sequential development of the Himalayas on the north and the Indoburman ranges on the east due to collision between the Indian, Chinese and Burmese plates. The oblique subduction of the Indian plate beneath the Chinese plate on the north and Burmese plate on the east caused the gradual closure of the Bay of Bengal and this neotectonic activity has been continuing till today and affecting the geomorphology of the Basin (Johnson et al., 1976; Luyendyk and Rennick, 1977; Curray et al., 1979; Dickinson, 1982 and Dhoundial, 1987).

In the history of Mankind rivers have played important roles from the dawn of civilization. The great rivers, namely the Ganges, the Brahmaputra and the Meghna have flowed across Bangladesh into the Bay of Bengal and built up an extensive alluvial landscape which needs to be studied in depth for the following reasons:

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

(ii) Soil stratigraphy i.e. soil-chronoassociation has not been prepared for this area.

(iii) Neotectonics has been controlling the evolution of the landforms and soils significantly in the study area. This is to be evaluated and

(iv) Since the study area witnessed the impacts of climatic and sea-level changes during the Quaternary period, the effects of these changes on the evolution of the landforms and soils need to be understood thoroughly.

Keeping all these points in view, detailed investigations of the soils and geomorphology of parts of Bangladesh plains (Fig.1.1) have been carried out. A regional mapping of soil-geomorphic units (Fig. 2.1) was undertaken using remote sensing techniques and field checks. The degree of soil profile development was determined on the basis of field morphology and laboratory analyses of soils. Using these data, a soil chronoassociation was developed for the study area. This has helped to work out the roles of climatic changes, neotectonic activity and sea-level changes on the development of the landforms and soils since the Late Pleistocene period.

1.2 LOCATION AND EXTENT

The area under investigation comprises major parts of the Lower Ganges-Brahmaputra-Meghna river system and lies between latitudes 22^{o} 30′ to 26^{o} 30′, and longitudes 87^{o} 30′ to 92^{o} (Fig.1.1). The study area covers about three-fourths of Bangladesh plains.

1.3 FLUVIAL GEOMORPHOLOGY

The study area is monotonous showing no topographic prominence except some upland areas of the Barind Tract, Madhupur Tract and Lalmai Hills and some low-lying areas of the Lower Atrai and Sylhet Depressions. A knowledge of fluvial geomorphology is essential to a proper understanding of the soils of the study area. The area is situated at the confluence of the three mighty rivers, namely the Ganges, the Brahmaputra and the Meghna. These rivers drain one of the heaviest rainfall areas in the world and their total catchment area together is approximately 17,75000 km^{2} of which only 6% lies in the study area (Fig.1.2). The drainage system of the study area is ill-defined and atleast 20% of the area is normally inundated every year. Lengths and catchment areas of the three major rivers are given in Table 1.1 and the main characteristics of the river systems are discussed below.

The Ganges flows eastward across the plains of West Bengal (India) and continues its course into Bangladesh as Padma and flows into the Bay of Bengal after confluencing with the Brahmaputra near Goalundo

(Fig.1.3.b). This is a meandering river down to the confluence with the Brahmaputra. The channel width varies from 2 km to 8 km. Maximum rate of erosion may be around 400 m per year and its banks migrate generally in a southeast direction. The Brahmaputra flows southward through Bangladesh after crossing the plains of Assam (India). In the northern part of Bangladesh the river divides into two channels, one is known as the Old Brahmaputra and the other (now the main channel) is called the Jamuna. The Jamuna receives four major right bank tributaries viz., the Dud Kumar, Dharla, Tista and Hurasagar. It has one left bank distributary, the Dhaleswari. For most of its course the Brahmaputra maintains only a very low gradient to the sea. At the confluence with the Ganges it is only 8m above M.S.L. The Brahmaputra is a typical braided river. The width of the active river bed varies considerably along the length of the river between 5 and 15km. The lateral bank shifting is erratic and the maximum rate of erosion may be 800m per year. The Meghna river originates in the hills of Manipur (India) and on reaching the border with Bangladesh it bifurcates to form the Surma and Kushiyara rivers which rejoin at Markali and flows as Meghna to join the Padma at Chandpur.

Table 1.1: Lengths and catchment areas of the three major rivers.

Rivers	Lengths (km)	Total catchment area (km^2)	Catchment area within Bangladesh (km^2)	(%)
Ganges	2600	1087300	46300	4.26
Brahmaputra	2900	607464	39100	6.44
Meghna	950	80355	36289	45.16

Source: Annual Flood Report, 1991.

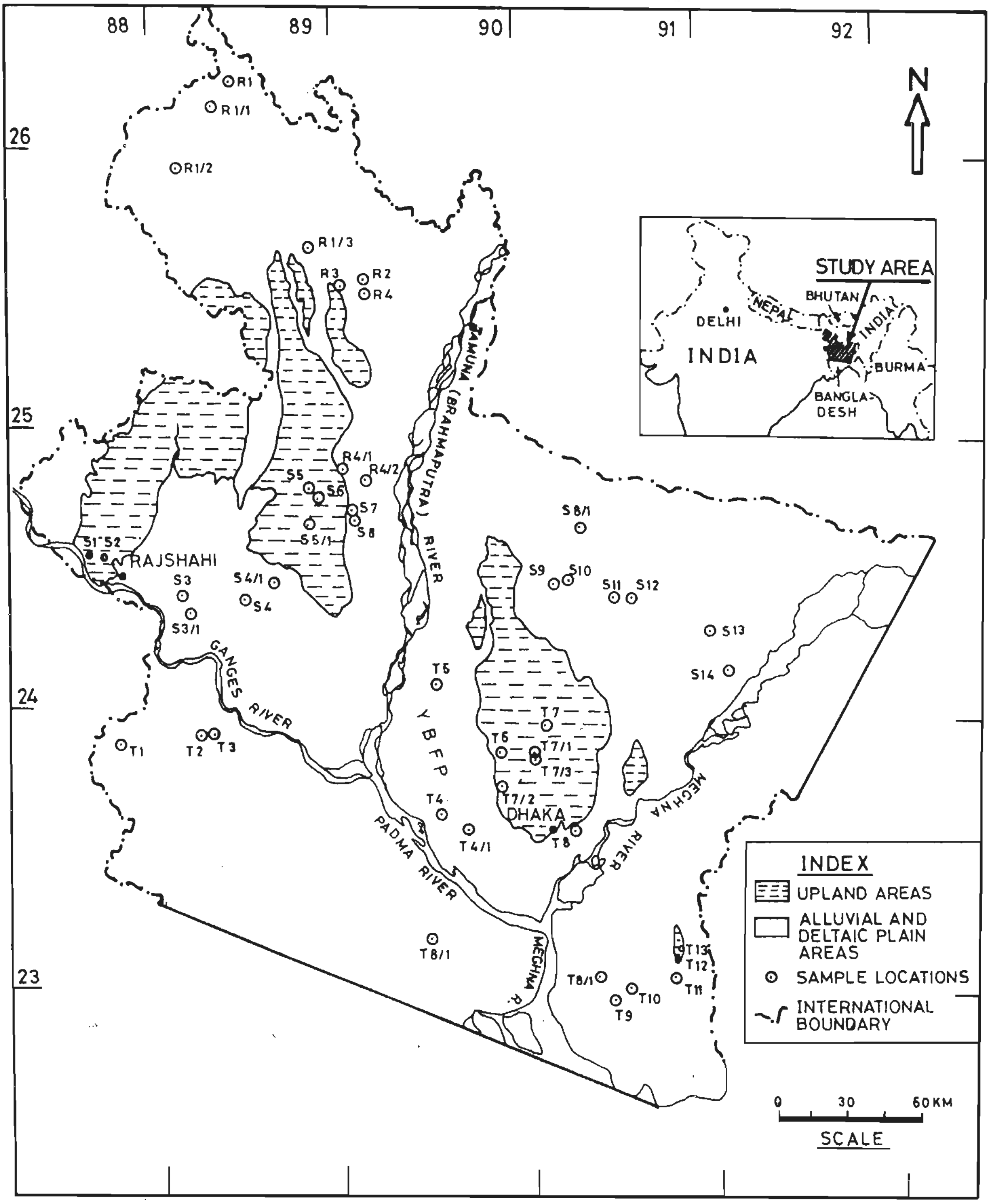


FIG. 1·1. LOCATION MAP OF THE STUDY AREA WITH PROFILE SITES ALONG TRAVERSES 'R', 'S' AND 'T'.

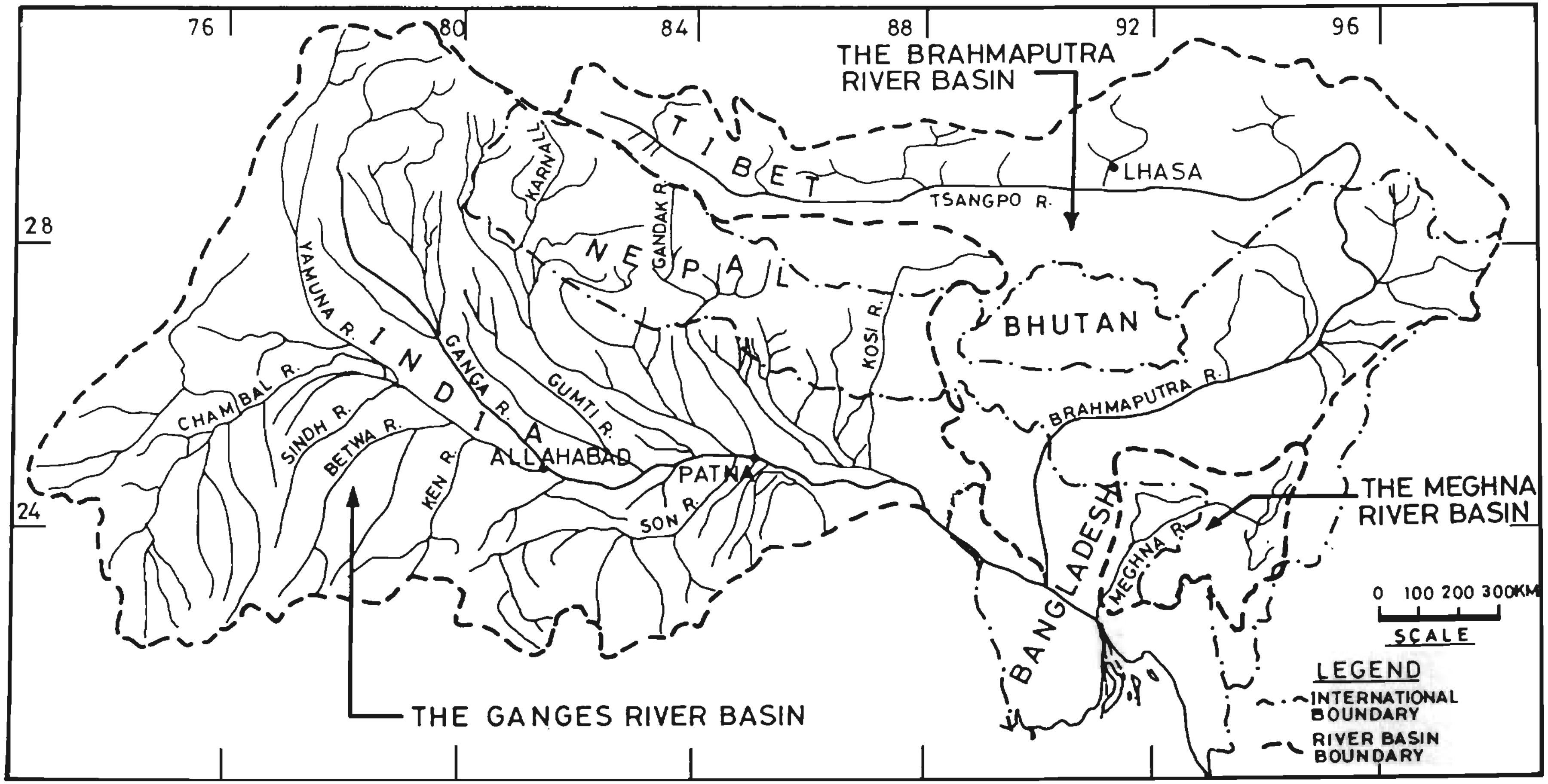


FIG.1·2. THE GANGES, THE BRAHMAPUTRA AND THE MEGHNA RIVER BASINS.
(MODIFIED AFTER ANNUAL FLOOD REPORT, 1991)

With minor exceptions, the Lower Ganges-Brahmaputra-Meghna river system as a whole can be described as braided, a function of large sedimentary load and of greater seasonal variations in discharge. The Ganges Deltaic plain lying to the south of the Ganges- Padma river, is characterized by a maze of interconnecting abandoned distributary channels of the Ganges and it has an elevation of 15-20m in the northwest, 1-2m in the southeast and a 654 km long coastline facing the Bay of Bengal. In the coastal area, a high tidal range of more than 3 m has fashioned a network of channels which reach as far as 130km inland. The combined Old Brahmaputra and the Meghna river system has constructed a broad expanse of low-lying floodplain between the Madhupur and the Tripura hills. The Mahananda, Purnabhaba, Tista and Karatoya rivers together formed the northern plains between the Mahananda and the Jamuna.

The Lower Ganges-Brahmaputra-Meghna river system displays some similarities with the Mississippi (USA) in terms of river regime and climatic factors but differs markedly in tectonic control and tidal dominated coastal processes (Morgan, 1970). Tectonic control of the system is relatable to the presence of numerous faults which have been intermittently active during the Late Quaternary period. A notable subsidence in the Sylhet Depression and the Ganges delta area, uplift of the Barind Tract, Madhupur Tract, Lalmai Hills and Tippera surface and two zones of weakness following approximately the trends of the Jamuna-Padma-Meghna river and the Meghna river are believed to be controlled by neotectonic activity (Fergusson, 1863; Hirst, 1916; Coates et al., 1992; Morgan and McIntire, 1959 and Sesoren, 1984).

1.4 CLIMATIC CONDITIONS

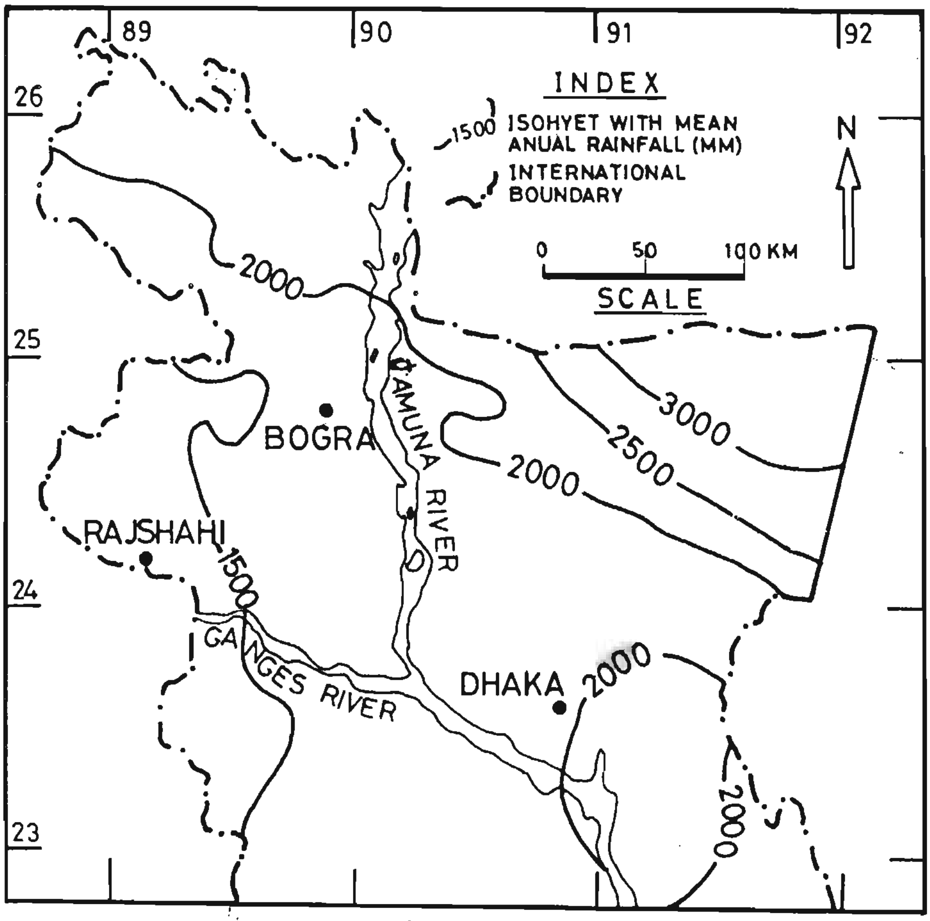
The whole of Bangladesh has a tropical monsoon climate. The seasonal distribution of climatic element is more or less similar throughout the country. Everywhere in Bangladesh there is an excess of rainfall over evaporation both in the rainy season and throughout the year as a whole. Naqvi (1964) has calculated the water balance in different meteorological stations in Bangladesh on the basis of potential evapotranspiration and rainfall.

Evapotranspiration rates range from about 50-75mm per month in December to February to 100 - 177 mm per month in April to May and are generally about 100 - 127 mm per month during the monsoon season. Data available for a small number of years suggest that annual evaporation is about 1000 - 1270 mm in all areas.

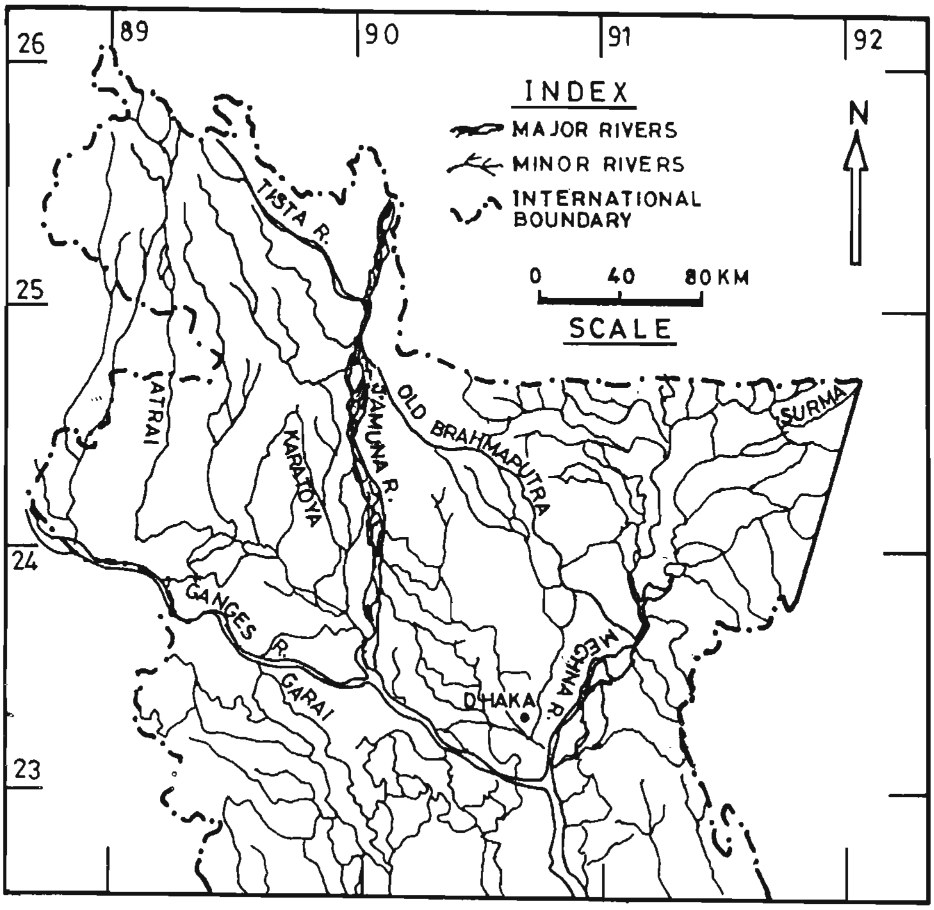
There are 4 main seasons in Bangladesh which vary in length and intensity from year to year.

The Premonsoon season extends from April to May. Temperature and evaporation rates are the highest during this time. Devastating cyclones like Nor'wester occur in almost all areas of Bangladesh during this season.

The monsoon season extends from June to September. This is the period of highest rainfall, humidity and cloudiness. 80-90% of the annual rainfall is normally received and floods occur locally in different areas during this period.



(a)



(b)

FIG.1·3. (a) ISOHYET MAP AND (b) DRAINAGE MAP OF THE STUDY AREA.

The post - monsoon season extends from October to November, is hot and humid but sunny. Cyclones from the Bay of Bengal sometimes hit the coastal areas during this period.

The dry season extends from December to March. It is cool, dry and sunny.

The mean annual temperature throughout Bangladesh is about 25.5^{o}C. Temperature regime is therefore hyperthermic. Mean winter (Dec. to Feb.) and summer (April to July) temperatures are 19.5 and 28.6^{o}C respectively. Extreme temperatures range from about 5^{o}C to 43^{o}C.

The mean annual rainfall is lowest in the central west (1270 - 1524 mm). It increases northward, eastward and southward to more than 2540 mm in the extreme north-west near the northern and eastern hills and also near the coast (Fig.1.3.a). It is highest in the extreme northeast, where it reaches 5080 mm. In all cases, about 90% of the total annual rainfall occurs between mid-April and early October.

1.5 GROUND WATER

In the study area the maximum depths of water tables vary from 2-18 metres. According to the depths of water tables the area has been divided into the following four zones.

(i) Sylhet, Rangpur, part of Jamalpur and southern part of the study area (2-4 m)

(ii) Bogra, Kushtia, Jessore, Faridpur, Mymensingh, Pabna, Dinajpur and part of Comilla (4-6 m) (iii)Rajshahi, Tangail, Jamalpur, Dhaka, Kushtia and part of Bogra (6-8m) and

(iv) Western Rajshahi, part of Tangail, Dhaka city and western Mymensingh (8-18 m). One of the lowest water tables (15 m) is in the Dhaka city, the capital of the country.

The ground water elevation contour map of the study area (Fig.1.4) indicates that that ground water movement is generally from northwest to south direction and the ground water elevation ranges from 85 metres in the north to 1 metre in the south. Average hydraulic gradient is about 53 cm/km in the north and 3 cm/km in the south. These low hydraulic gradients hinder the rapid movement of ground water and probably it is due to low average ground slope of the country (3-5 cm/km).

1.6 TECTONIC FRAMEWOK AND STRATIGRAPHY

i) Tectonic Framework

Tectonic Framework of Bangladesh has been drawn up on the basis of available geological, geomorphological, aeromagnetic, gravity, seismic and drilling data. Bakhtine (1966) gave an outline of the tectonic classification of Bangladesh. Guha (1978) divided the country into four tectonic zones viz. the Indian platform, Bengal Foredeep, Chittagong - Tripura folded zone and Arakan Yoma Geoanticline. A brief account of the tectonic zones is given below.

(a) The Indian platform

It is bounded by the Calcutta-Pabna-Mymensingh Hinge zone to the southeast, the Indian shield to the west, and the Himalayan Foredeep to the northwest (Figs.1.5 and 1.6). This zone is divided into 4 sub-units,

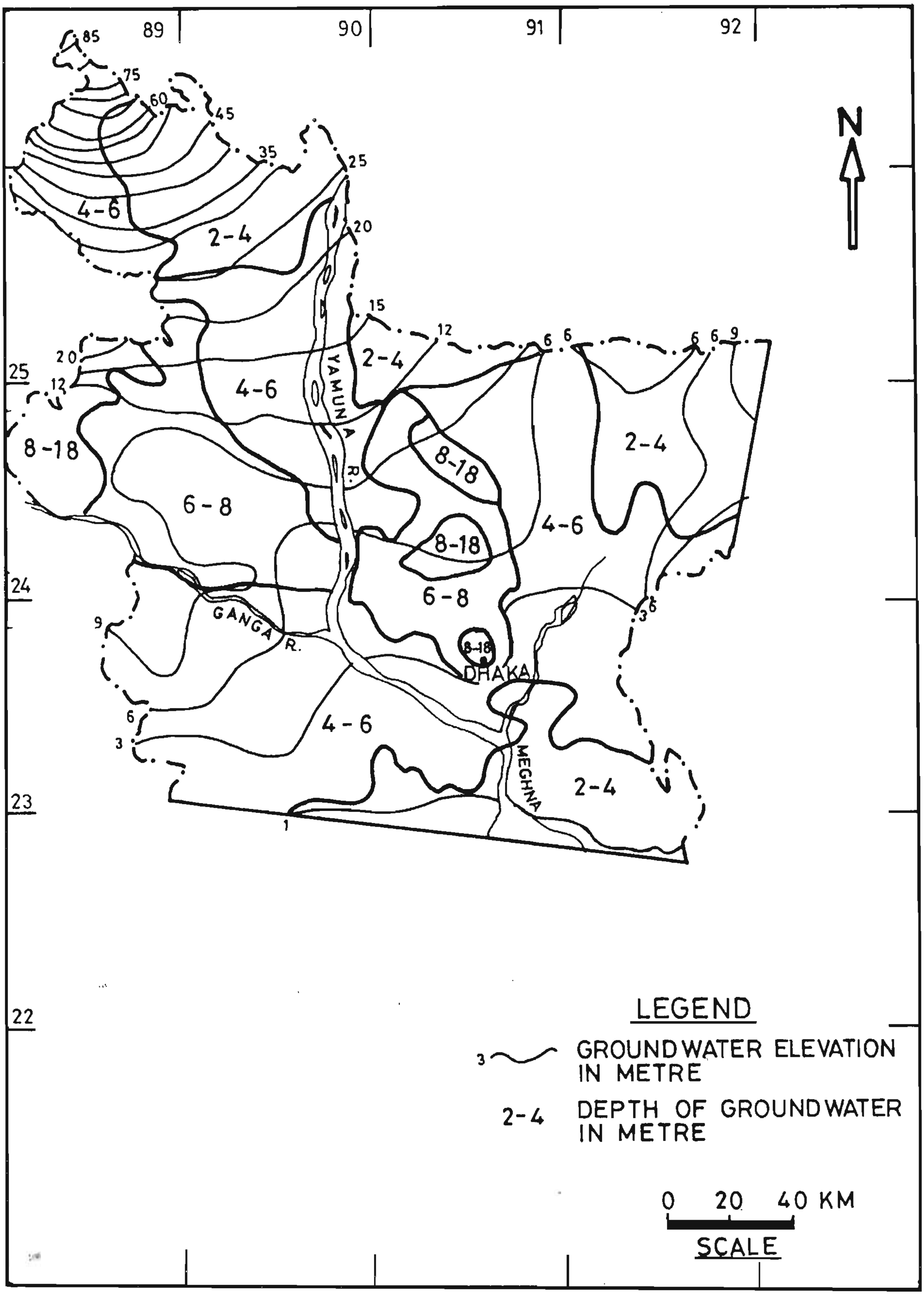


FIG. 1·4. MAP SHOWING LOWEST GROUND WATER TABLE AND MINIMUM GROUND WATER ELEVATION CONTOUR MAP OF THE STUDY AREA. (MODIFIED AND SIMPLIFIED AFTER HUSSAIN AND HASSAN, 1985) e.g., Rangpur saddle, Northern slope of Rangpur saddle, Southern slope of Rangpur saddle and Hinge zone. Rangpur saddle represents the Garo-Rajmahal gap by means of a buried Precambrian ridge which connects the Indian shield and the Shillong Plateau (Ghosh, 1959; Krishnan, 1982 and Auden, 1949). The width of Rangpur saddle is about 100 km and a series of sub-meridional trending faults pass across it. The Northern slope of Rangpur saddle has a width of 60km and it is underlain by 1-2 km of molassic sediments, whereas the Southern slope of Rangpur saddle has a width of 60-125 km and it is underlain by 2.3 - 2.9 km of sediments. The Hinge zone is a 25 km wide zone of Sylhet Limestone and it trends N30^{o}E through Calcutta-Pabna-Myemensingh and demarcates the boundary of the Bengal Foredeep in the west and north.

(b) The Bengal Foredeep

The Bengal Foredeep (Fig.1.6) is a deeply subsided basin developed as a consequence of the uplift of the Himalayan-Burmese mountain chain since the Oligocene period and is connected with the Himalayan Foredeep through the Upper Assam. It is 200 km wide in the northeast and over 500 km wide in the Bay of Bengal. The thickness of Neogene sediments is 12 - 15 kms in this zone. It is mainly characterized by three Troughs (gravity lows) e.g. the Faridpur Trough, Hatiya Trough and Sylhet Trough and one High (gravity high) e.g. the Chandpur - Barisal High (Fig.1.5).

(c) The Chittagong - Tripura Folded Zone

Here the Neogene molasse sediments are compressed into linearly elongated folds parallel to the Himalayan-Burmese mountain chain (Fig.1.5). The lengths and widths of the folds vary from 20 - 70 kms and 8 - 12 kms respectively.

(d) **The Arakan-Yoma Folded System**

This is an intensively folded and thrusted zone of Palaeogene flysch sediments and a regional fault separates it from molasse sediments of Neogene age.

ii) **Stratigraphy**

Bangladesh has a thick stratigraphic succession of mostly Tertiary sediments. The succession varies a good deal in different areas and it has broadly been divided into shelf sediments (mainly continental) and geosynclinal sediments. The thickness of practically all units increase in a southerly direction and the strata that are deltaic or shallow marine in the north become progressively more marine to the south. The thickness of the Miocene and the Pliocene units of the mobile belt also increase towards the Foredeep and becomes progressively more marine. The stratigraphic sequences of Bangladesh and the adjoining State of West Bengal (India) are given in Table 1.2.

Table 1.2: Stratigraphic sequences of Bangladesh and adjoining State of West Bengal (India)

	Bangladesh (Khan and Muminullah, 1980)				West Bengal (Biswas, 1963)	
Age	Shelf sediments		Geosynclinal sediments		Shelf sediments	Lithology
	Group	Formation	Group	Formation	Formation	
Holocene		Alluvium (82m)		Alluvium	Alluvium	sand, silt clay and Gravels
Unconformity						

Table 1.2 contd.

Age	Bangladesh (Khan and Muminullah, 1980) Shelf sediments		Geosynclinal sediments		West Bengal (Biswas, 1963) Shelf sediments	Lithology
Late Pliocene -Pleistocene	Madhupur clay(16m)			Madhupur clay	Debagram (900m)	Clay, Pebbly sandstone
----------Unconformity----------						
Late Miocene -Mid.Pliocene	Dupi Tila (275m)			Dupi Tila (1830m)	Pandua (695)	Clystone, siltstone & gravels, sandstone
----------Unconformity----------						
Middle Miocene	Jamalganj (415 m)		Tipam (2175m)	Girujan (970m) Tipam sand stone (1200m)		Claystone, siltstone,
----------Unconformity----------						
Early Miocene			Surma (5800m)	Bokabil (19830m) Bhuban (4000m)		Siltstone, shale sandy shale & sand stone
----------Unconformity----------						
Oligocene	Bogra (165m)		Barail	Jenam (646m)	Memri (60m)	Siltstone, carb.shale and sandstone
----------Unconformity----------						
Late Eocene	Jaintia (333m)	Kopili (43)			Kopili (21m)	Shale, sand-stone
Mid.Eocene		Sylhet Lst. (197m)			Sylhet-Lst. (316 m)	Fossiliferous sst.
E.Palaeocence -E.Eocene		Tura sst. (104m)			Jalangi (688m)	sst. shale, coal
----------Unconformity----------						
Late-Mid Cretaceolus	Upper Gond-wana	Sibganj Trapwash (135m)			Ghatal (114m) Bolpur (160 m)	Shale, carb. sst. Ferru-ginous shale, clay, sst.
----------Unconformity----------						
Late Jur. -E.Eocene	Rani-ganj	Rajmahal Trap(545)			Rajmahal (287 m)	Basalt
----------Unconformity----------						
Late Perm -ian	Rani-ganj	Paharpur (440m)				Feldspathic sst.with coal seams
----------Unconformity----------						

Table 1.2 contd.

	Bangladesh (Khan and Muminullah, 1980)		West Bengal (Biswas, 1963)	
Age	Shelf sediments	Geosynclinal sediments	Shelf sediments	Lithology
E. Permian	Barakar Kutchma (490m)			Coarse grained sst with coal seams
--------	--------	Unconformity	--------	--------
Archaean	Basement complex			Gneiss

1.7 THE EVOLUTIONARY HISTORY OF THE GANGES -BRAHMAPUTRA-MEGHNA DELTA COMPLEX

The Ganges-Brahmaputra-Meghna river system has constructed a huge subaerial delta with a total sediment column of 22 km beneath the Bangladesh shelf (Curray, 1991). This delta progrades southward and grades into a more extensive subaqueous delta called the Deep-Sea Bengal Fan and they together forms one of the world's major depositional system covering more than 3 million km^2 (Coleman, 1969; Fisher et al., 1969; Curray and Moore, 1971, 1974). Sedimentation in the area took place in two phases. The first major phase of sedimentation started with the Cretaceous marine transgression and continued till the Oligocene period. During this phase sediments were deposited in fluvial, tidal flats, deltaic and lagoonal environments on the stable shelf area of the Bengal Basin, whereas sedimentation took place in a marine environment in the Bengal Foredeep (Sengupta, 1966; Banerjee, 1984; Zaher and Rahman, 1980 and Graham et al., 1975). The second major phase of sedimentation was associated with the Mid-Miocene marine transgression when huge amounts of sediments were funnelled into the Bengal Basin due to major uplift in the Himalayas. During the Pliocene a marine regression occurred followed

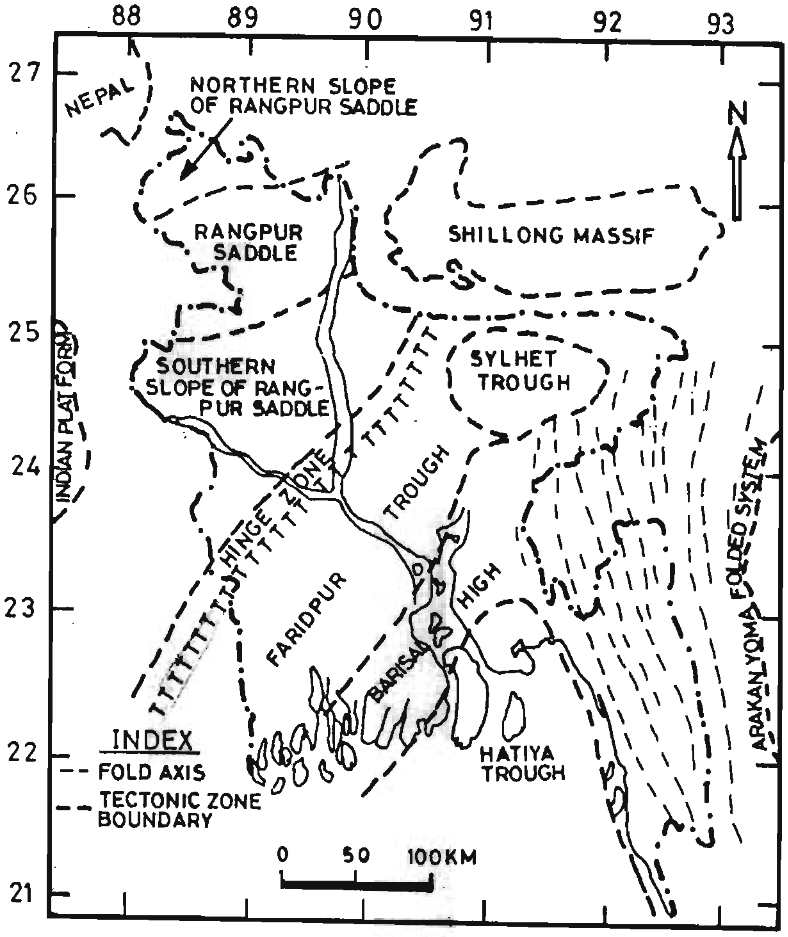


FIG.1-5. TECTONIC FRAME-WORK OF BANGLADESH WITH VARIOUS TECTONIC ZONES (AFTER GUHA,1978)

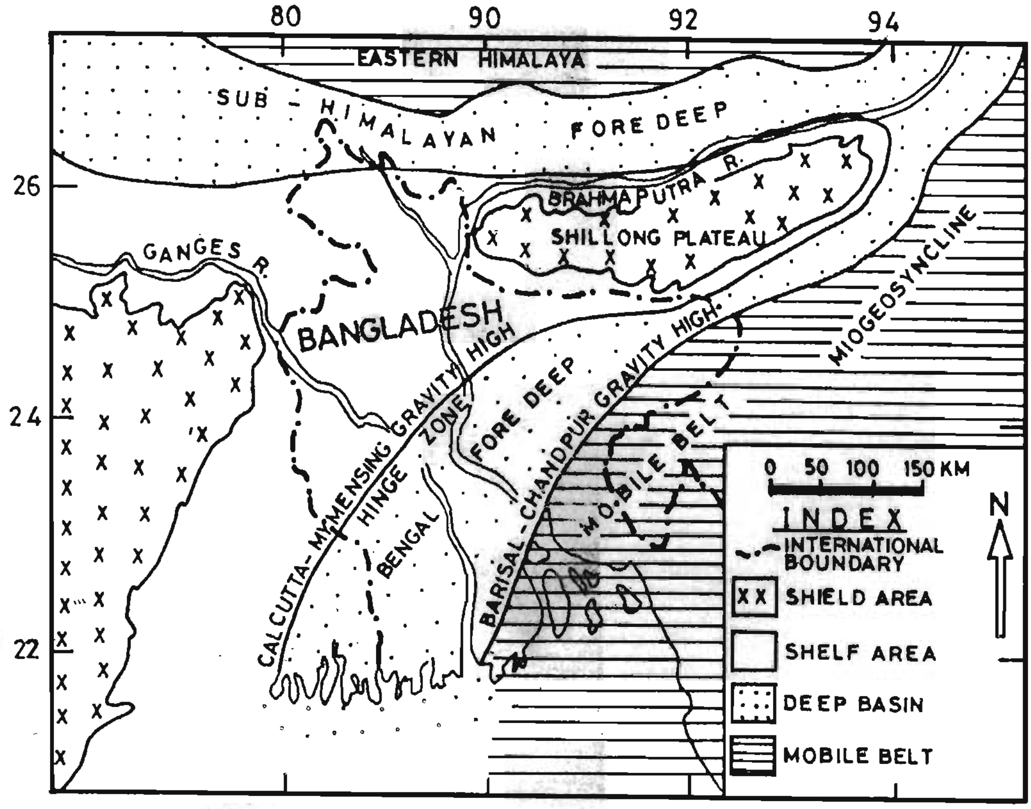


FIG.1-6. GEOLOGICAL MAP SHOWING THE BENGAL EXOGEOSYNCLINE AND THE ADJOINING AREAS (MODIFIED AFTER ALAM,1972)

by the deposition of the Dupi Tila and Dihing Formations of about 2-5 km thick fluvial and deltaic facies. The area was subjected to alternate erosional and depositional phases during the Quaternary period.

According to Lindsay et al. (1991) the development of the Ganges-Brahmaputra-Meghna Delta complex passed through three major stages as described below.

i) The Proto-Delta (126-49.5 Ma): During this stage the sediments accumulated on the subsiding passive margin of the Indian plate which was little influenced by other major plates. The depositional sequences were small bodies that alternated from prograding clastic wedge to mixed platform settings.

ii) The Transitional Delta (49.5-10.5 Ma): At approximately 45 Ma in the Eocene, the Indian plate collided with the Eurasian plate leading to the suturing of the plates and rise of the Himalayas. This resulted in a large influx of sediments and a change from flysch sedimentation to a molasse sedimentation in most of the Bengal Basin. Due to rotation of the Indian plate towards southeast and increase in depth of embayment of the Bay of Bengal a change from river dominated delta to tidal dominated delta also occurred during this stage at about 21 Ma.

iii) The Modern Delta (10.5 Ma - present): Morphologically the modern delta appears to have stabilized in more or less its present form at approximately 10.5 Ma in the Pliocene and the sedimentation was dominated by delta plain to delta-front type of settings.

1.8 IMPACTS OF CLIMATIC AND SEA LEVEL CHANGES DURING THE LATE QUATERNARY

During the last glacial maximum at about 18000 years B.P., the lowering of the sea-level in the Bay of Bengal was about 130 m and the coastline moved over 100 km south than at present (Johnson, 1975 and Alam, 1989). According to Kale and Rajaguru (1985), the sea-level on the continental shelves of India was about 138 m below than at present approximately at 12000 years B.P. This implies that the lowered sea-level continued from about 18000 years B.P. to 12000 years B.P. During this period of lowered sea-level the rivers flowing through the Ganges-Brahmaputra delta system dissected the former surfaces of the system (Umitsu, 1993). Also, due to the influence of the last glacial maximum, the whole of the Indian subcontinent including the study area witnessed a weak SW monsoon and the sea surface temperature in the Indian ocean was about 1.8°C cooler than today. An amelioration of monsoon climate in the early Holocene led to the increased rainfall and run-off in the region. In general, the monsoon climate passed through two major phases - a very arid period at about 22,000 - 18,000 yr. B.P. and a very humid period culminating at 11,000 yr. B.P. (Campo, 1986; Prell et al., 1980; Cullen 1981; Duplessy, 1982; Manabe et al., 1977 and Bryson and Swain, 1981).

Between 12500 and 10500 yr. B.P., the Bengal region was characterized by increased precipitation and run-off by the Ganges - Brahmaputra river system which was caused by the increased intensity of the SW monsoon circulation in the Indian subcontinent (Cullen, 1981). This stage was followed by the deposition of gravelly sands in the incised valleys, gradual rise of sea-level and the lateral accretion of sediments. Following this period, the deltaic sand and silt with occasional peat layers were deposited in response to rapid sea-level rise and increased accommodation space. This stage also promoted the increased importance of delta and floodplain construction by vertical accretion. At about 6000 yr. B.P. the coastline moved about 100 km inland passing through a line with an arc that swung across from the south of Calcutta almost to Dhaka (Alam, 1989 and Banerjee and Sen, 1987). Since 6000 yr. B.P. the Ganges-Brahmaputra- Meghna delta system prograded towards south and finally assumed the present configuration only a few hundred years ago through lateral and vertical accretion of sediments. According to Morgan (1970) about 150 m column of sediments has accumulated on the former delta surfaces since 12500 yr. B.P..

1.9 PREVIOUS WORK

Many geologists from home and abroad have confined their investigations mainly to the geological and tectonic history of the Bengal Basin. Alluvial morphology, depositional environments and stratigraphy have also been studied by some geographers and geologists. Soil scientists have concentrated their efforts to study the genesis and properties of soils of Bangladesh from agricultural and pedological points of view.

Morgan and McIntire (1959) have made a geological reconnaissance of Bangladesh and parts of India principally to determine the morphology of the Ganges-Brahmaputra-Meghna delta complex. Coleman (1969) has studied the channel processes and sedimentation patterns of the Brahmaputra river. To some extent alluvial morphology of Bangladesh have been investigated by Fergusson (1863), Geddes (1960), and Johnson (1975). Late Quaternary sedimentary environments, landform evolution and geomorphology of Bangladesh floodplains have been studied by Umitsu (1985, 1987, 1993), Oya (1977), Alam (1989) and Islam (1976). Hassan (1986) and Monsur and Paepe (1992) have given some outlines of Quaternary stratigraphy.

Basic frameworks and outlines of the development of soil resources of the country have been provided by Brammer (1964, 1971), Brammer and Brinkman (1977), Brinkman (1970, 1977) and Habibullah et al. (1971). These workers had done a great deal of work on the genesis, distribution, and classification of Bangladesh soils based on field morphology, grain-size distribution, chemical analysis, clay mineralogy and micromorphology. Some other workers like Huizing (1971), Hussain (1974), Karim and Hossain (1957), Karim et al. (1978), Monsur and Hossain (1992), Karim (1984) and Ziysvelt (1980) have also contributed to some extent to the understanding of soil formation in the study area.

1.10 OBJECTIVES AND SCOPE OF THE PRESENT STUDY

The basic objective of the present study is to visualize the evolution of soils and landscape of Bangladesh plains since the Late Pleistocene period. Apart from the coastal area, almost the entire plain area of the country has been incorporated within the purview of the present study. Soil formation is considered as the result of interaction of both geomorphological and pedological processes. The history of landscape evolution in an area is intimately tied with the history of soil development and thus, a knowledge of soil development allows predictions to be made of the landscape evolution (McFadden and Kneuepfer, 1990).

In spite of immense scope and opportunities to work on the vast fluvio-delta system of Bangladesh, it has received a little attention so far in comparison to other major fluvio-delta systems of the world. Though some basic works have been carried out by many workers, it is yet not thoroughly studied with particular reference to soil geomorphological evolution of the landscape. The evolution of the fluvio-deltaic plains of the study area can be visualized through an understanding of the varying degree of soil development on the different geomorphic units. Soil-geomorphological studies may also be used as powerful tools to evaluate the impacts of neotectonics, palaeoclimatic and sea level changes and the patterns of major river shifting since the Late Pleistocene in the area. Studies on buried soils may provide a better understanding and insights to recapitulate the past tectonic events.

Keeping all these points in view, the main objectives and scope of the present study are summarized as follows:

(i) To refine the delineation of the different soil-geomorphic units by using Landsat images (both B&W TM and FCC images) and field checks.

(ii) To study the evolution of the fluvio-deltaic plains through an understanding of the degree of pedogenesis on the different soil-geomorphic units.

(iii) To prepare a soil chronoassociation for the study area.

(iv) To reconstruct the neotectonic events since the Late Pleistocene period and

(v) To understand the impacts of the palaeoclimatic and sea level changes on the geomorphic and pedogenic processes in the study area.

To fulfill the above objectives the following stages of work have been completed.

(i) With the help of Landsat (both B&W TM and FCC) images the different soil-geomorphic units have been delineated and mapped.

(ii) Field investigations were carried out to check the boundaries between the soil-geomorphic units along three traverses and 45 typical pedons were thoroughly studied in field by recording morphological characters of the sub-horizons of each pedon. Both disturbed (bulk) and in-situ (oriented and undisturbed) soil samples from the sub-horizons of pedons were collected for laboratory analyses.

(iii) The soil samples were analysed in the laboratory for studying the grain - size distribution, clay mineralogy, distribution of major elements, pH, micromorphology, free iron contents and microprobe analyses of cutans, biotites and Fe-Mn concretions. and

(iv) Finally, an attempt has been made to synthesize the field and laboratory data and work out the geomorphological and pedological evolution of the study area.

CHAPTER 2

SOIL-GEOMORPHIC UNITS AND FIELD MORPHOLOGY OF SOILS

CHAPTER 2

SOIL-GEOMORPHIC UNITS AND FIELD MORPHOLOGY OF SOILS

2.1 INTRODUCTION

In order to investigate the field morphology of soils of the study area a total of twelve soil-geomorphic units (Fig.2.1) were first demarcated with the help Landsat images. Following the demarcation, field work was carried out to check and confirm the delineation of the soil- geomorphic units by studying the field characteristics of the representative pedons from each soil-geomorphic unit. Then, both bulk and in-situ (undisturbed) soil samples were collected for laboratory analyses.

2.2 IDENTIFICATION OF SOIL-GEOMORPHIC UNITS BY REMOTE SENSING TECHNIQUES

This was carried out by using the Landsat Black and White (B & W) Thematic Mapper (TM) images of bands 3 and 4 on 1:1000000 scale and False Colour Composites (FCC images) of bands 4, 5 and 7 on 1:250000 scale (Figs. 2.2 and 2.3). Topographic sheets were also used. The Landsat images and topographic sheets were obtained from the Space Research and Remote Sensing Organisation (SPARRSO), Dhaka and the Deptt. of Geology, Dhaka University, Bangladesh, respectively. The demarcation of the twelve soil-geomorphic units was based on the Landsat image elements such as tone, colour, vegetation, texture, moisture and drainage patterns of the landscape. The major Landsat image characteristics of the study area are as follows: (i) Dark grey tone in

B&W images and dark blue colour in the FCC images represent active channels, (ii) Black lines/patches in both B&W and FCC images represent abandoned palaeochannels/ox-bow lakes with stagnant water, (iii) Dry channels with sand bodies are seen by very light grey tone in B&W images and very light yellow colour in FCC images, (iv) The intensity of blue colour in FCC images depend on the amount of moisture present in the soils/sediments, (v) Red colour in FCC images mainly represent vegetation, (vi) Higher reflections in both B&W and FCC images indicate upland parts of the study area and are clearly visible as large patches.

2.3 FIELD INVESTIGATIONS

To check the demarcation of the soil-geomorphic units and to determine the morphological characteristics of typical pedons representing each soil-geomorphic unit, proper site selections were done with the help of the topographic maps and almost in every case excavation was preceded by augering. 45 excavations of 1m x 1.5m sizes were made along three traverses 'R', 'S' and 'T' in order to cover the entire study area (Fig.1.1). The pedons were excavated through the sola of the soils and extended upto the parent materials or upto some reasonable depths.

Different horizons and sub-horizons were designated as A1, Ap, B1, B2, C etc. following the nomenclature used by the Soil Survey Staff (1975). The depths and thicknesses of each horizon and subhorizon have been recorded. Each sub-horizon was described in field, directing attention mainly to the following aspects:

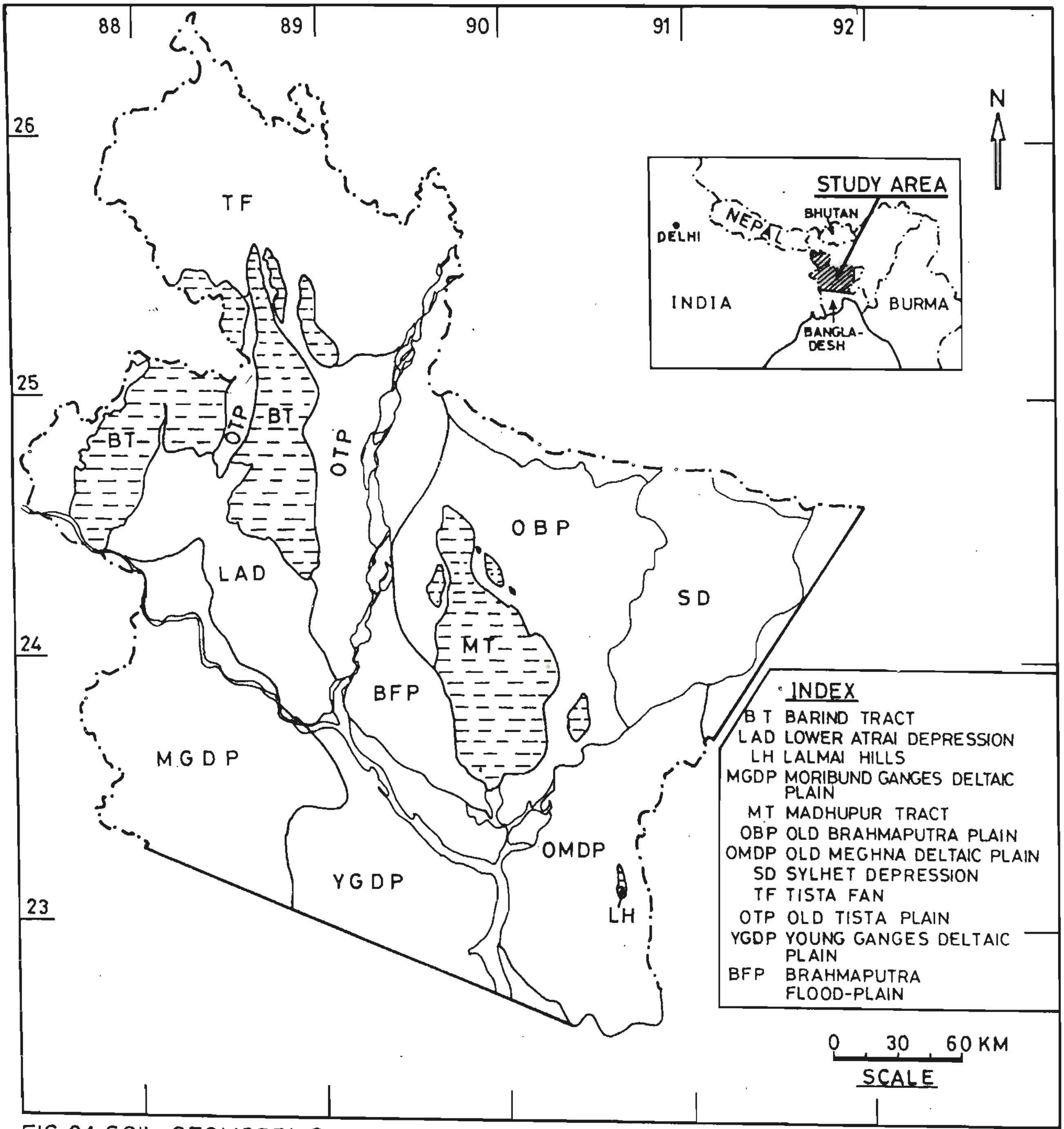


FIG. 2·1. SOIL-GEOMORPHIC MAP OF THE STUDY AREA SHOWING TWELVE SOIL-GEOMORPHIC UNITS IDENTIFIED BY REMOTE SENSED DATA.

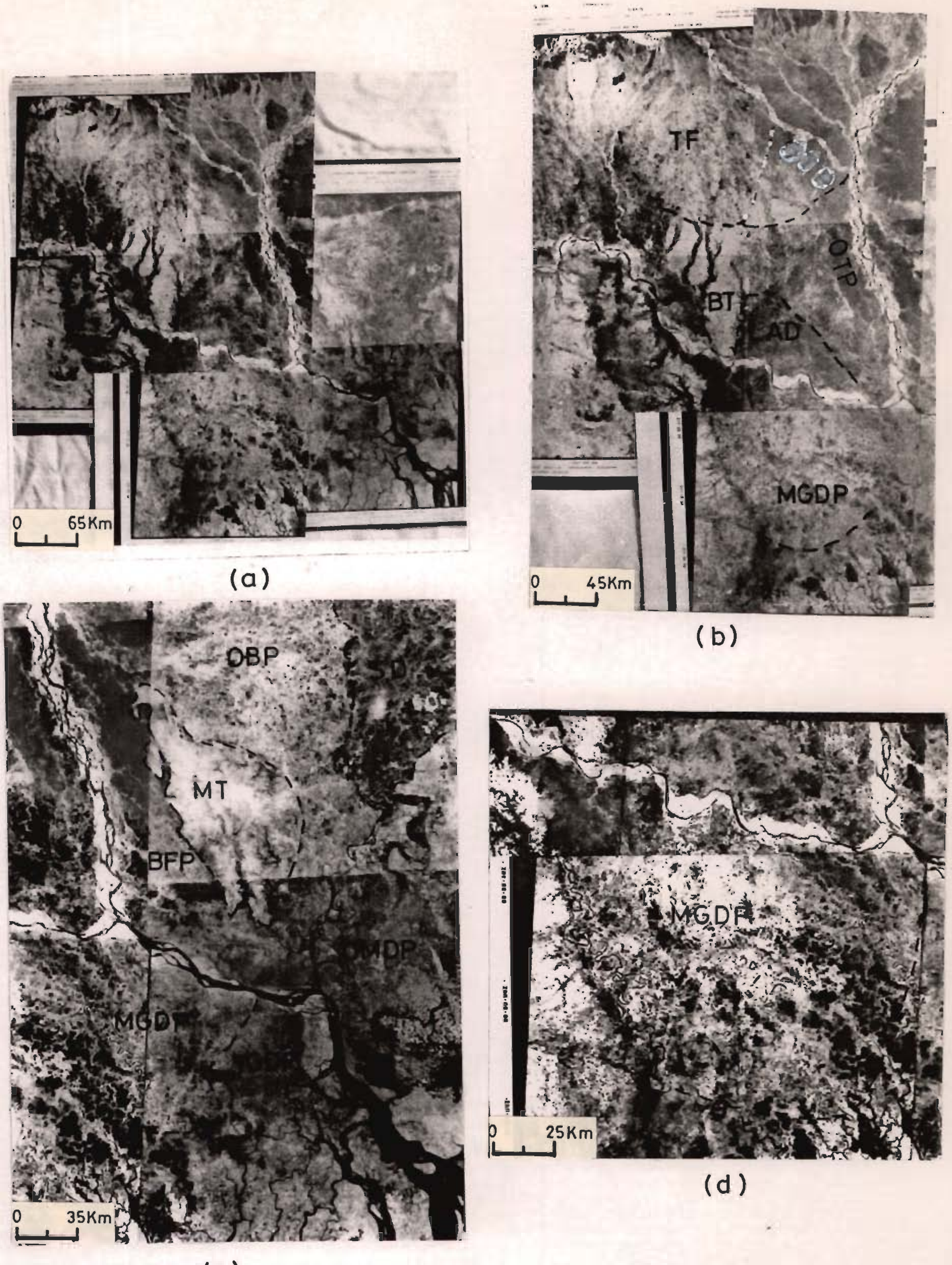
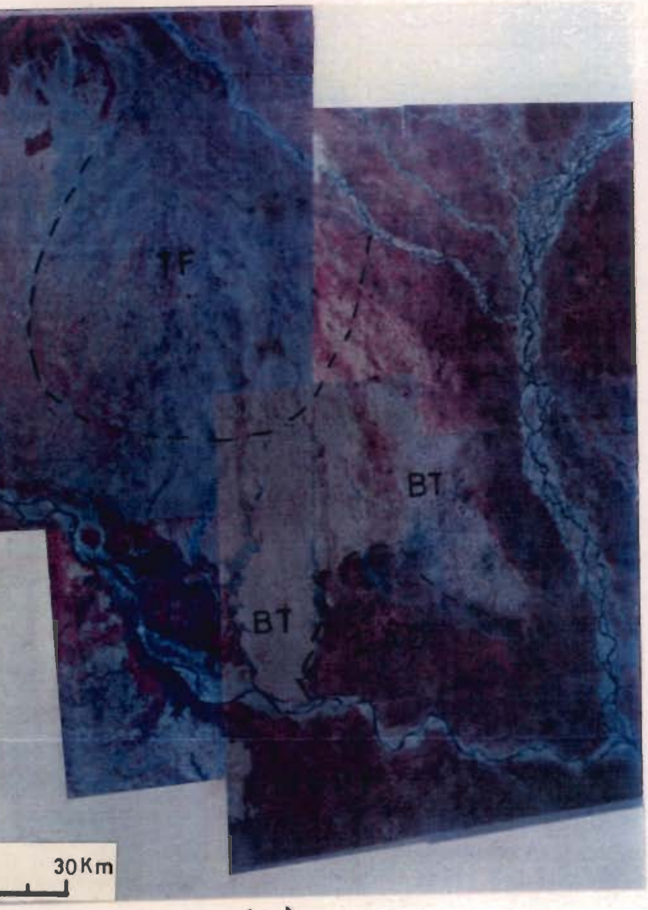
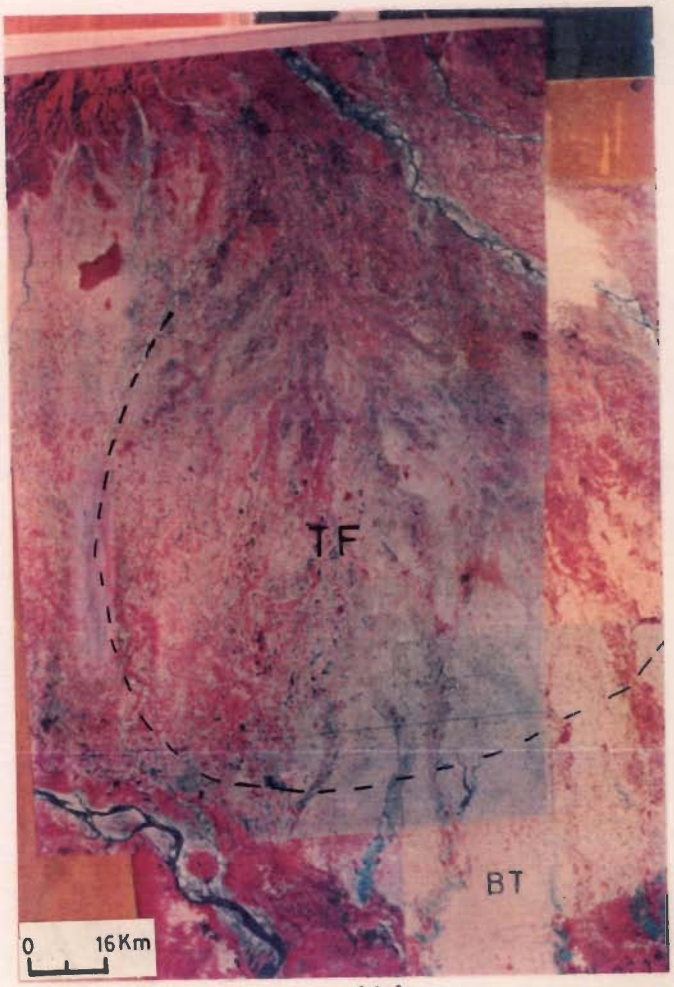


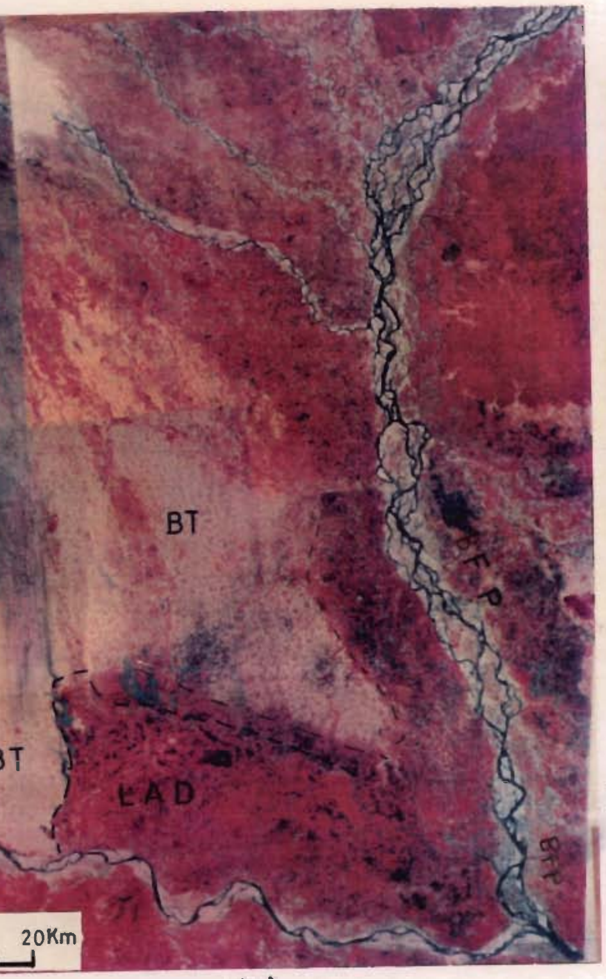
Fig.2.2. **(a)** Mosaic of Landsat Black & White TM images showing the study area. **(b)**, **(c)** and **(d)** show parts of **(a)**; the abbreviations are same as in Fig.2.1.



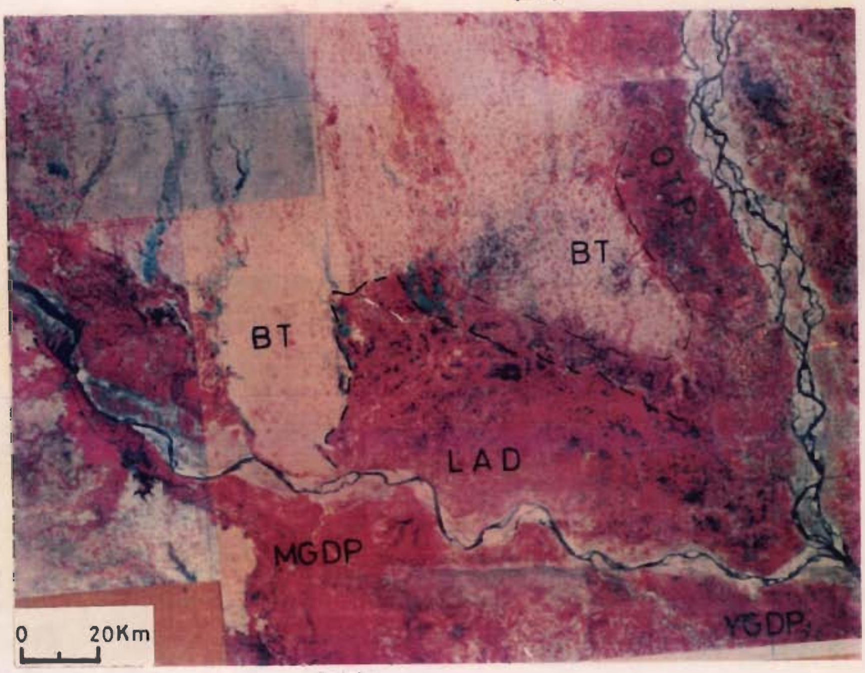
(a)



(b)



(c)



(d)

Fig.2.3. **(a)** Mosaic of Landsat False Colour Composite (FCC) images showing the different soil-geomorphic units of the study area. **(b)**, **(c)** and **(d)** show parts of **(a)**; the abbreviations are same as in Fig.2.1.

2.3.1 Colour

Colour is one of the most useful, important and easily observable soil characteristics. Colours were determined by comparing with the Munsell colour chart. Hue, values and chroma were noted according to the Munsell notations. An accurate and closest match was obtained by holding the soil sample close to the colour chips being compared. Soil colour changes with the moisture condition. Hence, moisture condition was also stated in the field.

2.3.2 Mottles

Mottling in the soils was described according to the Munsell notation by recording (i) the colour of both matrix and mottles, and (ii) the pattern of mottling. The pattern of mottling was described by three sets of notations: i) contrast (faint, distinct, and prominent), (ii) abundance (few, common and many) and (iii) size (fine, medium and coarse).

2.3.3 Consistence

Soil consistence is a measure of the degree and kind of cohesion and adhesion or the resistance to deformation or rupture. Because this property varies with moisture contents, it is determined in dry, moist and wet conditions. The wet consistence (natural wetness or artificial wetness) is useful in determining the soil texture classes in the field and it comprises two elements - stickiness and plasticity. Stickiness was measured by compressing the soil between the thumb and the forefinger and noting the adherence of soil upon release of pressure. The classes recognised were sticky, slightly sticky and non-sticky.

Plasticity was measured by rolling the wet soil between the thumb and the forefinger in an attempt to form a thin rod. Several classes were recognized: non-plastic - no rod forms; slightly plastic - a weak rod forms; and plastic - a better rod forms.

2.3.4 Texture

Soil texture refers to the relative proportions of sand, silt and clay present in a mass of soil. The range of particle sizes exists below 2 mm in diameter. Several textural classes were recognized in the field but these were determined later more accurately in the 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 separated from adjoining aggregates by surfaces of weakness. An individual natural soil aggregate is called a ped, in contrast to a clod, caused by disturbance, such as ploughing or digging (Soil Survey Manual, 1966). In field, the soil structure is described by noting (1) the shape and arrangement of peds (2) their sizes and (3) their distinctness and durability. There are four primary types of structure: (1) platy, with particles arranged around a plane, generally horizontal; (2) Prismlike (prismatic and columnar), with particles arranged around a vertical line and bounded by relatively flat vertical surfaces; (3) block like or polyhedral (angular blocky and subangular blocky), with particles arranged around a point and bounded by flat or rounded surfaces and (4) Spheroidal or polyhedral (granular and crumb), with particles arranged around a point and bounded by curved or very irregular surfaces.

Grade of structure is the degree of aggregation and expresses the difference between cohesion within aggregates and adhesion between aggregates. Grade of structure varies with the conditions of soil moisture. The terms for grade of structure are as follows:

0.	Structureless	-	without aggregation
1.	Weak	-	with poorly formed indistinct peds and much unaggregated material
3.	Moderate	-	peds are easily observable and most material is aggregated
3.	Strong	-	the entire mass comprises distinctly visible peds

2.3.6 Carbonates

In the field, concretions and indurated accumulations of carbonates were noted and their sizes and volume percentages were estimated. The presence of free carbonates both in the soil and the parent materials was identified by the appearance of effervescences after treating with dilute HCl and they are: very slight - when few bubbles appear; slight - bubbles are readily observed; strong - bubbles produce foam; and very strong - violent foams appear.

2.3.7 Soil Pores

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

2.3.8 Horizon Boundary

The width of the transition zone between the overlying and the underlying horizon (distinctness) and topography of the zone were recorded. Horizon boundaries were described as abrupt (<2 cm wide); clear (2-5 cm wide); gradual (5-12 cm wide) and diffuse (>12 cm wide) and topography of the boundary as smooth, wavy, irregular and broken.

2.3.9 Roots

Size, abundance and penetration of roots were recorded. Different classes of size are very fine (<1 mm); fine (1-2 mm); medium (2-5 mm) and coarse (>5 mm).

After recording various soil characteristics systematically, representative samples from each pedon were collected for laboratory analyses. From each horizon/subhorizon loose/disturbed samples were collected in polythene bags and with special care oriented/undisturbed samples were collected in tin boxes. Lime concretions and iron and manganese concretions were also collected.

2.4 MORPHOLOGY OF SOILS OF THE VARIOUS SOIL-GEOMORPHIC UNITS

Based on the studies of Landsat images and field investigations the study area has been divided into the following three major landform types and twelve soil-geomorphic units (Fig.2.1).

Major landform types	Soil-geomorphic units	Abbreviated as
1. Fluvio-deltaic plains	i) Brahmaputra Floodplain	BFP
	ii) Young Ganges Deltaic Plain	YGDP
	iii) Tista Fan	TF
	iv) Old Tista Plain	OTP

Major landform types	Soil-geomorphic units	Abbreviated as
	v) Moribund Ganges Deltaic Plain	MGDP
	vi) Old Brahmaputra Plain	OBP
	vii) Old Meghna Deltaic Plain	OMDP
2. Palaeofluvio-deltaic uplands	viii) Barind Tract	BT
	ix) Madhupur Tract	MT
	x) Lalmai Hills	LH
3. Depressions	xi) Sylhet Depression	SD
	xii) Lower Atrai Depression	LAD

An account of the above soil-geomorphic units and morphology of typical pedons from each soil-geomorphic unit is given below.

2.4. 1. BRAHMAPUTRA FLOODPLAIN (BFP)

This unit lies between the Brahmaputra-Padma river and the Madhupur Tract (Figs.2.1, 2.2.c and 2.3.c). It comprises Brahmaputra sediments laid down mainly since the river changed into its Jamuna course about 200 years. It also includes remnant floodplain of the old Tista river that flowed successively between the Madhupur and the Barind Tracts. This young floodplain comprises a typical meander floodplain pattern of broad ridges and basins. The deposits are mainly silty on the ridge and clayey in the basins. Flooding is mainly shallow in the north of this unit, but is deep in the south (Tangail and Dhaka districts). This unit is seen by a mosaic of blue, bluish white and red colours in FCC images and by grey to dark grey tone with white mottles and patches in Black and White images. In FCC images some localities appear as dark blue colour representing water-logged conditions. The description of one representative pedon (Fig.2.4) from this unit is given below.

PEDON # T5

Classification	:	Aeric/Typic Fluvaquents
Location	:	Dhala, Singair Upazila, Manikganj
Date of Examination	:	11.3.91
Parent materials	:	Brahamputra alluvium
Erosion	:	Nil
Slope	:	Nearly level
Drainage	:	Poorly drained
Moisture condition	:	Moist
Depth of ground water	:	5 - 6 m
Physiography	:	Lower part of ridge
Flooding	:	1.5 - 2m; 3 - 4 months
Landuse	:	Broad-cast Aman paddy/Wheat, sugarcane

Typifying Pedon

Ap 0 - 16 cm; grey (2.5 YN5) moist with few fine faint light yellowish brown (2.5 Y 6/4) mottles; silty clay loam; massive; friable moist, slightly plastic and slightly sticky wet; fine tubular pores; common fine roots; abrupt smooth boundary; pH 7.5

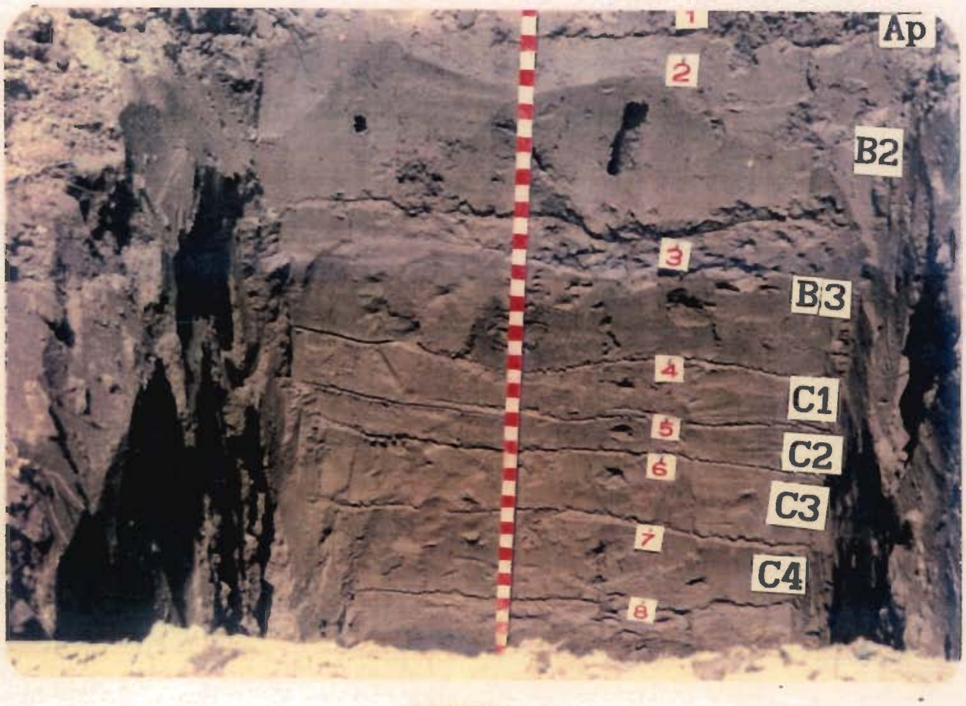
B2 10 - 40 cm; olive grey (5Y 4/2) moist with common fine distinct yellowish brown (10 YR 5/6) mottles; silty clay loam; weak to moderate coarse prismatic; friable moist, slightly plastic and slightly sticky wet; common fine tubular pores; few fine roots; abrupt wavy boundary; pH 8.0

B3 40- 62 cm; light olive brown (2.5 Y 5/4) moist with few fine distinct yellowish brown (10 YR 5/6) mottles; silty loam; massive; friable moist, slightly plastic and slightly sticky wet; few fine tubular pores; very few fine roots; abrupt wavy boundary; pH 8.0

C1 60 - 72 cm; olive (5Y 5/3) moist with few fine distinct yellowish brown (10 YR 5/6) mottles; loam; massive; very friable moist; few fine tubular pores; very few fine roots; abrupt smooth boundary; pH 8.0

C2 72 - 79 cm; olive (5 Y 5/3) moist with few fine distinct yellowish brown (10 YR 5/6) mottles; silt loam; massive; friable moist; few fine tubular pores; very few fine roots; abrupt smooth boundary; pH 8.0

(a)



(b)

Fig.2.4. Photographs showing **(a)** Field view and **(b)** A typical pedon (T5) from the Brahmaputra Floodplain.

2.4.2 YOUNG GANGES DELTAIC PLAIN (YGDP)

This unit comprises a part of the vast Ganges Deltaic Plain (Figs.2.1, 2.2.c and 2.3.d) and it has been incorporated on the basis of Landsat image studies and work of Brammer (1971). This unit represents a smooth landscape of nearly level to very gently sloping broad ridges, and inter-ridge depressions and it comprises a large number of cut-off channels/ox-bow lakes (beels) of palaeochannels. The landscape has locally irregular reliefs with narrow ridges and inter-ridge depressions. This unit is seen by both bluish white and red colour in FCC images and by grey tone with dark grey mottles or patches in black and white images. The soils are olive or olive brown to dark greyish brown or dark grey in colour and loamy to clayey in texture and calcareous. This unit has weakly developed soils. The top soils appear to be lighter in texture and consistence than the subsoil; they are commonly paler in colour. There is no evidence of leaching of fine materials or iron oxides from the topsoil into the subsoil.

2.4.3 TISTA FAN (TF)

This soil-geomorphic unit constitutes major part of the Tista Fan formed at the foot of the Himalayas (Figs.2.1, 2.2.b and 2.3.d). The Tista Fan occupies northern parts of both West Bengal (India) and Bangladesh. Sandy materials deposited by constantly changing rivers formed a complex braided landscape of a criss-crossing network of abandoned river channels. Major rivers in the area are well entrenched and river beds lie 5-6 metres below the surrounding landscape. Sediments are mainly sandy and silty on the ridges and clayey in the depressions. The area of this unit is about 10000 km^2. In the FCC images this unit is seen by radiating elongated patches/lines of light blue, bluish white and bright red colours. In the black and white TM images the area is clearly seen as light grey tone with a few patches of dark grey tone and radiating drainage of medium texture. About 90 - 120 cm thick permeable loamy soils have formed on the sandy parent materials. Soil patterns are often complex because of differences in soil texture and drainage within short distances. The northern part of this unit comprises black Terai soils which become waterlogged during the monsoon by flash floods. Soils of the Tista Fan have been studied by investigating pedons R_1 - R_4 along traverse 'R'. It is observed that the thicknesses of the B horizons increase from the north to south in accordance with decreasing rate of sedimentation towards the distal part of the fan. Descriptions of two pedons R1 and R4 (Figs. 2.5.b,d) are given below.

PEDON # R1

Classification	:	Typic Haplumbrepts
Location	:	Sitagram, Panchagarh Upazilla, Dinajpur
Date of examination	:	31.3.91
Parent material	:	Tista Alluvial Fan deposits
Erosion	:	Nil
Slope	:	< 1%
Drainage	:	Poorly drained
Moisture condition	:	Fully moist profile
Depth of ground water	:	6 - 7 m
Physiography	:	Nearly level middle part of a ridge
Landuse	:	Transplanted Aman paddy - Fallow/Millet

Typifying pedon

Ap 0 - 16 cm; very dark grayisk brown (10 YR 3/2) moist; sandy clay loam; massive; friable (moist); slightly sticky and slightly plastic (wet); common very fine and fine tubular pores; abrupt wavy boundary; pH 4.5.

A1 16 - 42 cm; very dark grayish brown (10 YR 3/2) moist; sandy clay loam; distinct mottles of light olive brown colour (2.5 Y 5/6); weak, very coarse prismatic structure; friable (moist),

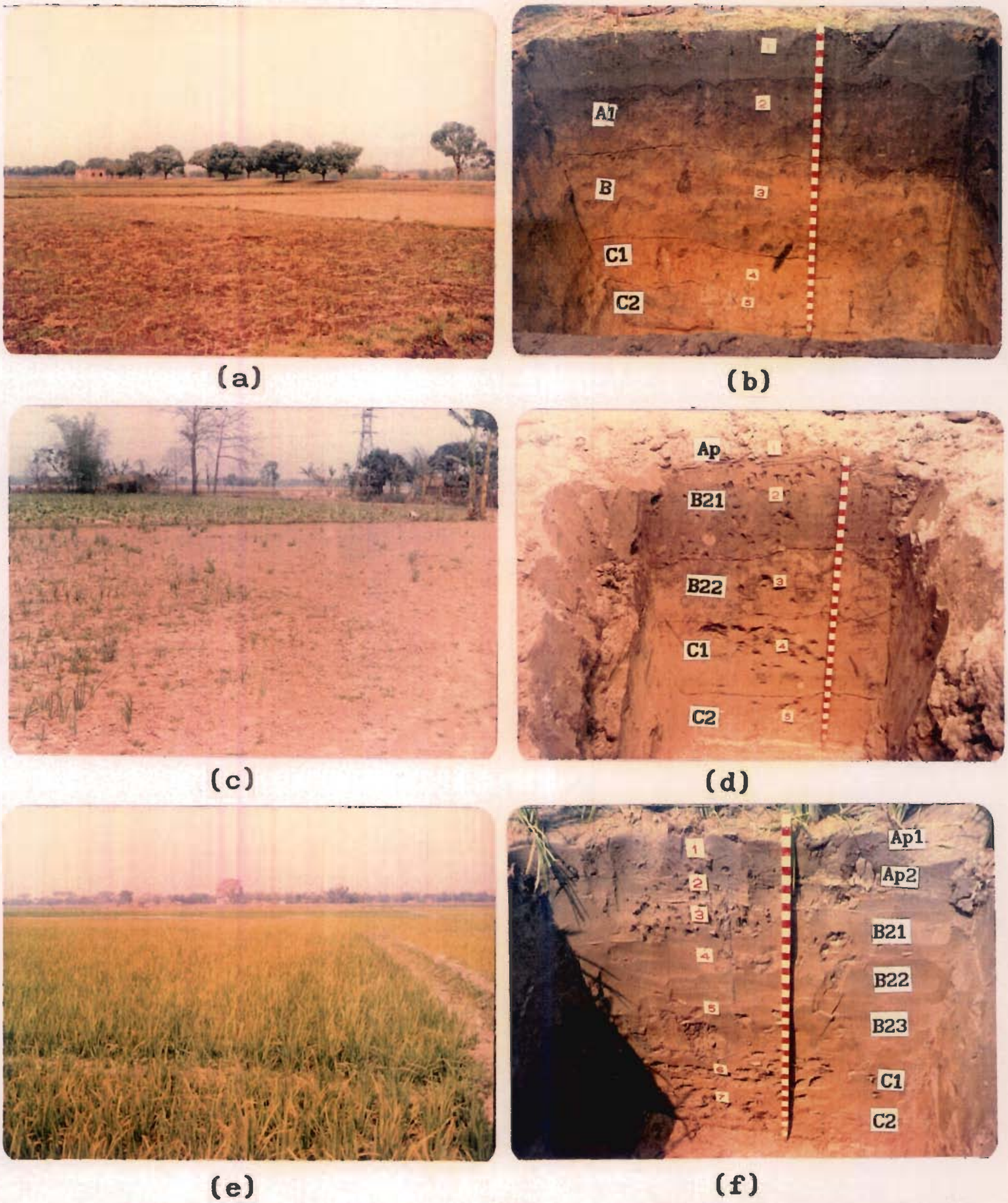


Fig.2.5. Photographs showing **(a)** Field view and **(b)** A typical pedon (R1) rich in organic matter from the proximal part of the Tista Fan; **(c)** Field view and **(d)** A typical pedon (R4) at the upper part of a moderately drained levee from the Tista Fan; **(e)** Field view and **(f)** A typical pedon (R2) at lower site of a poorly drained backswamp from the Tista Fan.

slightly sticky and slightly plastic (wet); many fine and very fine tubular pores; clear wavy boundary; pH 4.5.

B	42-86 cm; olive brown (2.5 Y 4/4) and grayish brown (2.5 Y 5/2) moist; sandy loam; weak, very coarse prismatic breaking into subangular blocky; very friable (moist); slightly sticky and slighty plastic (wet); many very fine and fine tubular pores; clear wavy boundary; pH 5.0
C1	86 - 106 cm; light olive brown (2.5 Y 5/6) moist; fine to medium ;sands; massive; very friable (moist), nonsticky and nonplastic (wet); many very fine and fine tubular pores; clear wavy boundary; pH 5.0.
C2	106 - 115 cm; light olive brown (2.5 Y 5/6) moist; coarse sands; massive; very friable (moist), nonsticky and nonplastic (wet); few medium tubular pores; pH 5.0.

PEDON # R4

Classification	:	Typic Dystrochrepts/Ustrochrepts
Location	:	Islampur, Pairabandha, Mithapukar upazilla, Rangpur
Date of Examination	:	29.3.91
Parent materials	:	Tista alluvium
Erosion	:	Nil
Slope	:	nearly level, about 1%
Drainage	:	Moderately well drained
Moisture condition	:	moist
Depth of ground water	:	12 - 15 m
Physiography	:	Upper part of a ridge
Flooding	:	Above flood level
Landuse	:	Aus/Jute - Rabi vegetables

Typifying Pedon

Ap	0-13 cm; light olive brown (2.5 Y 5/4) moist; silt loam; massive; friable moist; nonsticky and nonplastic; common fine tubular pores; abrupt smooth boundary; pH 5.5.
B21	13-48 cm; olive brown (2.5 Y 4/4) moist; silty loam; weak coarse subangular blocky structure, friable moist, nonsticky and nonplastic, patchy thin cutans along vertical and horizontal ped faces; many fine tubular pores; abrupt wavy boundary; pH 5.5
B22	48 - 72 cm; olive (5 Y 5/6) moist; silt loam, weak medium to coarse subangular blocky structure; friable moist, nonsticky and non plastic; many fine tubular pores; clear smooth boundary; pH 6.0

C1	72 - 106 cm; olive (5 Y 5/6) moist; silt loam; massive; friable moist, non sticky and non plastic; common fine tubular pores; abrupt smooth boundary; pH 6.0
C2	106-130 cm; olive yellow (5 Y 6/6) moist; sands; massive; loose moist; nonsticky and non plastic; pH 7.5.

2.4.4 OLD TISTA PLAIN (OTP)

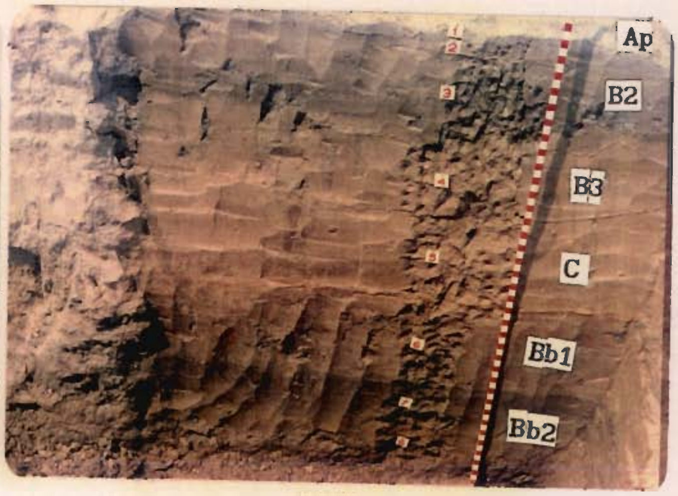
This unit comprises parts of Rangpur, Bogra and Pabna districts and covers an area of about 4000 km^2 (Figs. 2.1, 2.2.b and 2.3.d). This floodplain has been constructed mainly through lateral accretion of north-south flowing and occasionally shifting rivers like Tista, Karatoya, Little Jamuna and other minor rivers and is characterized by curved ridges and saucer shaped basins.

In the FCC images this unit is seen by elongated patches of blue, bluish white and bright red colours. In the black and white images the area as a whole shows light grey tone with some patches/mottles of dark grey tone. In the lower part of the unit mainly along east side of the Barind Tract, patches of dark blue colour are seen in the FCC images indicating accumulation of water bodies. In black and white images the lower part appears as grey and dark grey tones and the north-western part as light grey tone. This unit has coarse textured drainage. From this unit one pedon S7 (Fig. 2.6.b) has been described.

PEDON # S7

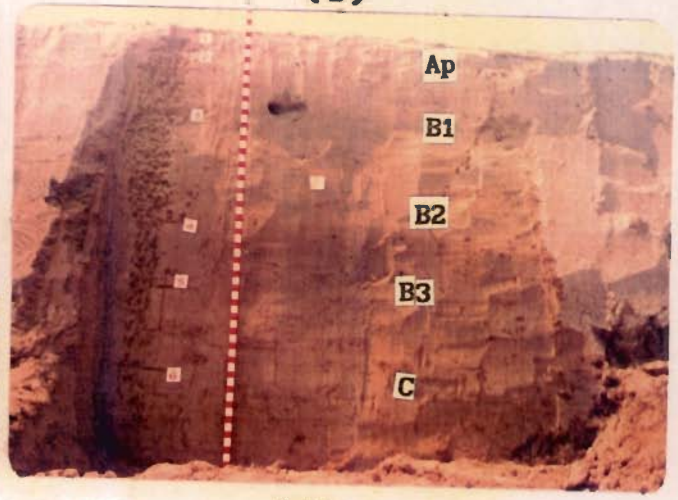
Classification	:	Aeric Haplaquepts
Location	:	Dhawapara, Sabgram union, Bogra Sadar
Date of Examination	:	27.3.91
Parent materials	:	Tista alluvium
Erosion	:	Nil
Slope	:	About 1%, almost flat
Drainage	:	Poorly drained
Moisture condition	:	Fully moist soil

(a)



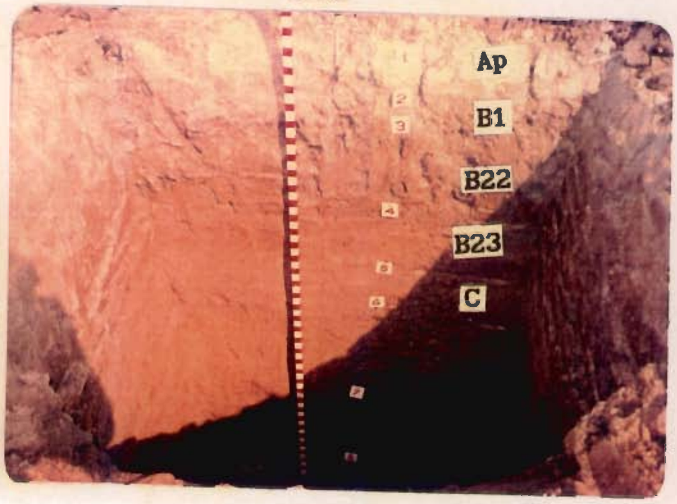
(b)

(c)



(d)

(e)



(f)

Fig.2.6. Photographs showing **(a)** Field view and **(b)** A typical pedon (S7) at poorly drained site with buried B horizons (Bb) from the Old Tista Plain; **(c)** Field view and **(d)** A typical pedon (T2) at the top of a levee from the Moribund Ganges Deltaic Plain; **(e)**Field view and **(f)** A typical pedon (T3) at the centre of a backswamp from the Moribund Ganges Deltaic Plain.

Depth of ground water	:	2.5 - 3.5 m
Physiography	:	Middle part of a ridge
Flooding	:	30 cm, 3-4 months by rain water
Landuse	:	Transplanted Aman - Boro

Typifying Pedon

Ap1	0 - 10 cm; grey (3 Y 6/1) moist with few fine faint olive (5 Y 5/4) mottles and strong brown, iron stainings along the root channels; silt loam; massive; slightly sticky, nonplastic, friable moist, hard dry; common fine and medium tubular pores; many fine roots; abrupt smooth boundary; pH 6.
Ap2	10 - 15 cm; olive grey (5Y 5/2) moist with few fine faint olive (5Y 5/4) mottles; silty clay loam; massive; slightly sticky, slightly plastic, friable moist; few fine tubular pores; few fine roots; abrupt smooth boundary; pH 8.0.
B2	15-43 cm ; grey (5 Y 5/1) moist with common fine distinct yellowish brown mottles (10 YR 5/4); silty clay loam; strong coarse prismatic breaking into coarse angular blocky; slightly sticky and slightly plastic, friable moist; continuous moderately thick dark grey cutans along vertical and horizontal ped faces; many very fine and fine tubular pores; few fine roots; abrupt wavy boundary; pH 8.0.
B3	43 - 71 cm; grey (5Y 5/1) moist with many fine and medium distinct yellowish brown mottles (10 YR 5/4); silt loam; weak very coarse prismatic; slightly sticky and slighty plastic, friable moist; patchy thin cutans; many very fine tubular pores; abrupt wavy boundary; pH 8.0.
C	71-105 cm; light olive brown (2.5 Y 5/4) moist with many medium distinct gray mottles (5 Y 5/1) and common medium district brown mottles (10 Y 5/3); silt loam; slightly sticky and slightly plastic, friable moist; common very fine and fine tubular pores; abrupt smooth boundary; pH 8.0.
Bb1*	105-142 cm; light olive brown (2.5 Y 5/4) moist with common medium district grey mottles (5Y 5/1) and many fine prominent strong brown mottles (7.5 YR 4/6); silty clay, moderate coarse prismatic sticky; and plastic, firm moist; few fine tubular pores; abrupt smooth boundary; pH 8.0.

Bb* = buried B horizon

Bb2 — 142-159 cm; dark grayish brown (10 YR 4/2) moist with few fine faint gray mottles (5Y 5/1) and many fine prominent dark brown (7.5 YR 3/4) mottles; silty clay; weak, coarse prismatic; sticky and plastic firm moist; few fine and medium tubular pores; abrupt smooth boundary; pH 8.0.

Cb — 159-186 cm; olive (5 Y 5/3) moist with few fine distinct brown (10 YR 4/3) mottles; silty clay; sticky and plastic, firm moist; abrupt smooth boundary; pH 8.0.

Bb — 186-200 cm; dark grayish brown (10 YR 4/2) moist with many fine distinct yellowish brown (10 YR 5/6) mottles; silt loam; moderate coarse prismatic; slightly sticky and slightly plastic, friable moist; abrupt smooth boundary; pH 8.0.

Cb — 200-230$^+$ cm; light olive brown (2.5 Y 5/4) moist with few fine faint gray (5 Y 5/1) mottles; very fine sandy loam; abrupt smooth boundary; pH 8.0.

2.4.5 MORIBUND GANGES DELTAIC PLAIN (MGDP)

This unit comprises northwestern part of the vast Ganges Deltaic Plain (Figs. 2.1, 2.2.b and 2.3.d) and characterizes a smooth to very gently undulating landscape with nearly level to very gently sloping broad old floodplain ridges, inter-ridge depressions and nearly level broad basins. The Ganges Deltaic Plain as a whole is marked by an increasing rate of sedimentation towards the south and southeast due to progradation of the delta to the south and easterly shifting of the Ganges discussed later in section 5.7.3. The Bhagirathi was the main outlet of the Ganges (Fig.5.1) till 2300 years B.P. (Umitsu, 1985). Some cut-off channels/oxbow lakes (haors) occur in this unit representing the palaeochannels of the Ganges or its major distributaries. In FCC images this unit is clearly seen by an overall uniform red colour with bluish white mottles. The southeastern part of this unit appears as a mosaic of red and bluish white colours. In black and white images this unit is seen by an overall grey tone but its northwestern part is visible as dark grey tone and southeastern part as light grey tone with dark grey mottles. The unit has a medium textured drainage. The soils of this unit are medium to fine textured on the ridges and fine textured on the basin centres. Soils of this unit are moderately developed with solum thickness ranging from 50 to 100 cms. From this unit two pedons T2 and T3 (Figs. 2.6.d,f) have been described as follows:

PEDON # T2

Classification	:	Eutrochrepts/Dystrochrepts
Location	:	Fulbari, Mirpur Upazilla, Kushtia
Date of Examination	:	25.2.91
Parent materials	:	Ganges floodplain alluvium
Erosion	:	Nil
Slope	:	Gently sloping
Drainage	:	Imperfectly drained
Moisture condition	:	Moist
Depth of ground water	:	5 - 6 m
Physiography	:	Top of a ridge
Flooding	:	Above flood level
Landuse	:	Transplanted Aman/Jute - wheat/ Tobacco

Typifying Pedon

Ap 0 - 12 cm. pale yellow (5 Y 7/4) dry with few fine and medium prominent strong brown (7.5 YR 4/6) mottles; silt loam; massive; slightly hard dry, friable moist, slightly plastic and slightly sticky; many fine and medium tubular pores; many very fine and medium roots, abrupt smooth boundary; pH 8.0

B1 12 - 36 cm; light olive brown (2.5 Y 5/4) moist with common fine and medium prominent dark brown (7.5 YR 4/4) mottles; silt loam; weak subangular blocky; friable moist, slightly sticky and slightly plastic; many fine and medium tubular pores; few fine and medium roots; clear smooth boundary; pH 8.0

B2 36 - 83 cm; olive grey (5Y 4/2) moist with common fine and medium prominent dark brown (7.5 YR 4/4) mottles; silt loam; weak coarse angular blocky; friable moist, slightly plastic and slightly sticky; thin broken cutans along ped faces; many

	thin and medium tubular pores; few fine and medium roots; clear smooth boundary; pH 8.0
B3	83 - 103 cm; dark grayish brown (2.5 Y 4/2) moist with common fine and medium prominent dark brown (7.5 YR 4/2) mottles; silt loam; moderate coarse prismatic breaking into angular and subangular blocky; friable moist, slightly plastic and slightly sticky; thin broken cutans along ped faces; many fine and medium tubular pores; few fine and medium roots; gradual wavy boundary; pH 8.0
C1	103 - 138 cm; olive brown (2.5 Y 4/4) moist with few fine and medium faint dark grayish brown (2.5 Y 4/2) mottles; very fine sandy loam; massive; friable moist, slightly plastic and slightly sticky; many fine and medium tubular pores; pH 8.0
C2	138 - 169^{+} cm; olive brown (2.5 Y 4/4) moist with few fine distinct very dark grayish brown (10 YR 3/2) mottles; very fine sandy loam; massive, friable moist, slightly plastic and slightly sticky; common fine and medium tubular pores; pH 8.5

PEDON # T3

Classification	:	Typic/Aeric Haplaquepts
Location	:	Fulbari, Mirpur Upazilla, Kushtia
Date of Examination	:	22.2.91
Parent materials	:	Ganges alluvium
Erosion	:	Nil
Slope	:	-
Drainage	:	Poorly drainaged
Moisture condition	:	Fully Moist
Depth of ground water	:	6 m
Physiography	:	Centre of a basin
Flooding	:	Remains under 4-5 feet deep water for about 6 months
Landuse	:	Transplanted Aman/Aus - Rabi crops

Typifying Pedon

Ap	0 - 11 cm; light olive brown (2.5 Y 5/4) moist with common medium distinct strong brown (7.5 YR 4/6) mottles; clay; massive; hard dry, firm moist, sticky and plastic; many very fine and medium tubular pores; many very fine and medium roots; abrupt smooth boundary; pH 4.5.
B1	11 - 20 cm; very dark grayish brown (2.5 Y 3/2) moist with few fine faint dark yellowish brown (10 YR 4/6) mottles; clay; moderate subangular and angular blocky; hard dry, firm moist, plastic and sticky; thick continuous dark grey cutans along ped faces; many very fine and medium tubular pores; many very fine and medium roots; abrupt smooth boundary; pH 5.5

B22	20 - 40 cm; very dark grayish brown (2.5 Y 3/2) moist with few fine distinct dark brown (7.5 YR 4/4) mottles; clay; strong medium angular and subangular blocky; hard dry, firm moist, plastic and sticky; many fine and medium continuous tubular pores; many fine and medium roots; abrupt smooth boundary; pH 5.5
B23	48 - 71 cm; very dark grayish brown (2.5 Y 3/2) moist with few fine distinct black (10 YR 2/1) mottles; clay; weak coarse angular blocky; hard dry, firm moist, plastic and sticky; many fine and medium tubular pores; few fine and medium roots; clear smooth boundary; pH 8.0
C1	71 - 87 cm; olive brown (2.5 Y 4/4) moist with few fine faint very dark grayish brown (2.5 Y 3/2) mottles; silt loam; massive; friable moist, slightly plastic and slightly sticky; many fine tubular pores; few fine roots; clear wavy; pH 8.0
C2	87 - 134 cm; olive brown (2.5 Y 4/4) moist with few fine distinct black (10 YR 2/1) mottles; silt loam; massive friable moist, slightly sticky and slightly plastic; many fine tubular pores; few fine roots; clear wavy boundary; pH 8.0
Bb1	134 - 167 cm; very dark grayish brown (2.5 Y 3/2) moist with few medium distinct dark yellowish brown (10 YR 4/4) mottles; clay weak angular blocky; hard dry, firm moist, slightly plastic and slightly sticky; thick continuous dark grey cutans; few fine tubular pores; abrupt smooth boundary; pH 8.0
Bb2	167 - 181 cm; olive brown (2.5 Y 4/4) moist with common medium distinct dark brown (7.5 YR 4/4) mottles; clay; massive; firm moist, slightly plastic and slightly sticky; pH 8.0

2.4.6 OLD BRAHMAPUTRA PLAIN (OBP)

This floodplain has been constructed successively by the ancient Brahmaputra river flowing towards the east and south-east (Figs. 2.1 and 2.2.c). The different palaeochannels of the Brahmaputra indicate that the Brahmaputra river mainly followed a meandering pattern and its meander floodplain comprises the broad ridges and basins. The sediments are mainly silty on the ridges and clayey in the basin. The highest ridges in the west and south lie above normal flood level. The area adjacent to the Sylhet Depression remains under flood water for about 4 - 5 months. This unit as a whole is marked by light grey tone with dark grey mottles and patches in black and white images and by a mosaic of blue and red colours with dark blue mottles and patches in the FCC images. This soils of this unit are moderately to well developed with solum thickness ranging from 60 - 100 cm. Two typical pedons (Fig.2.7.b) from this unit have been described below.

PEDON # S10

Classification	:	Typic/Aeric Haplaquepts
Location	:	Kismat, Mymensingh Sadar
Parent materials	:	Brahmaputra floodplain
Erosion	:	Nil
Slope	:	Gentle
Drainage	:	Poorly drained
Moisture condition	:	Moist
Depth of ground water	:	1 m
Physiography	:	Middle part of a nearly level ridge
Flooding	:	50 - 90 cm for about 2 months
Landuse	:	Transplanted Aman - Boro.

Typifying Pedon

Ap1 0 - 10 cm; olive grey (5 Y 4/2) moist with common medium distinct dark yellowish brown (10 YR 4/4) mottles; silty clay loam; massive; hard dry, firm moist, sticky and plastic; many fine tubular pores; common medium roots; abrupt smooth boundary; pH 6.5

Ap2 10 - 16 cm ; dark grayish brown (2.5 Y 4/2) moist with common medium distinct dark yellowish brown (10 YR 4/4) mottles; silty clay loam; massive; very firm moist, plastic and sticky; many very fine tubular pores; common medium roots; abrupt smooth boundary; pH 6.5

B21 16 - 42 cm; dark grey (5 Y 4/1) moist with many medium distinct dark grayish brown (2.5 Y 4/2) and few medium distinct very dark grayish brown (10 YR 3/2) mottles; silty clay loam; moderate coarse prismatic/angular blocky; firm moist, plastic and sticky; continuous thick dark grey cutans on ped faces; many fine tubular pores; common fine and medium roots; abrupt smooth boundary; pH 7.5

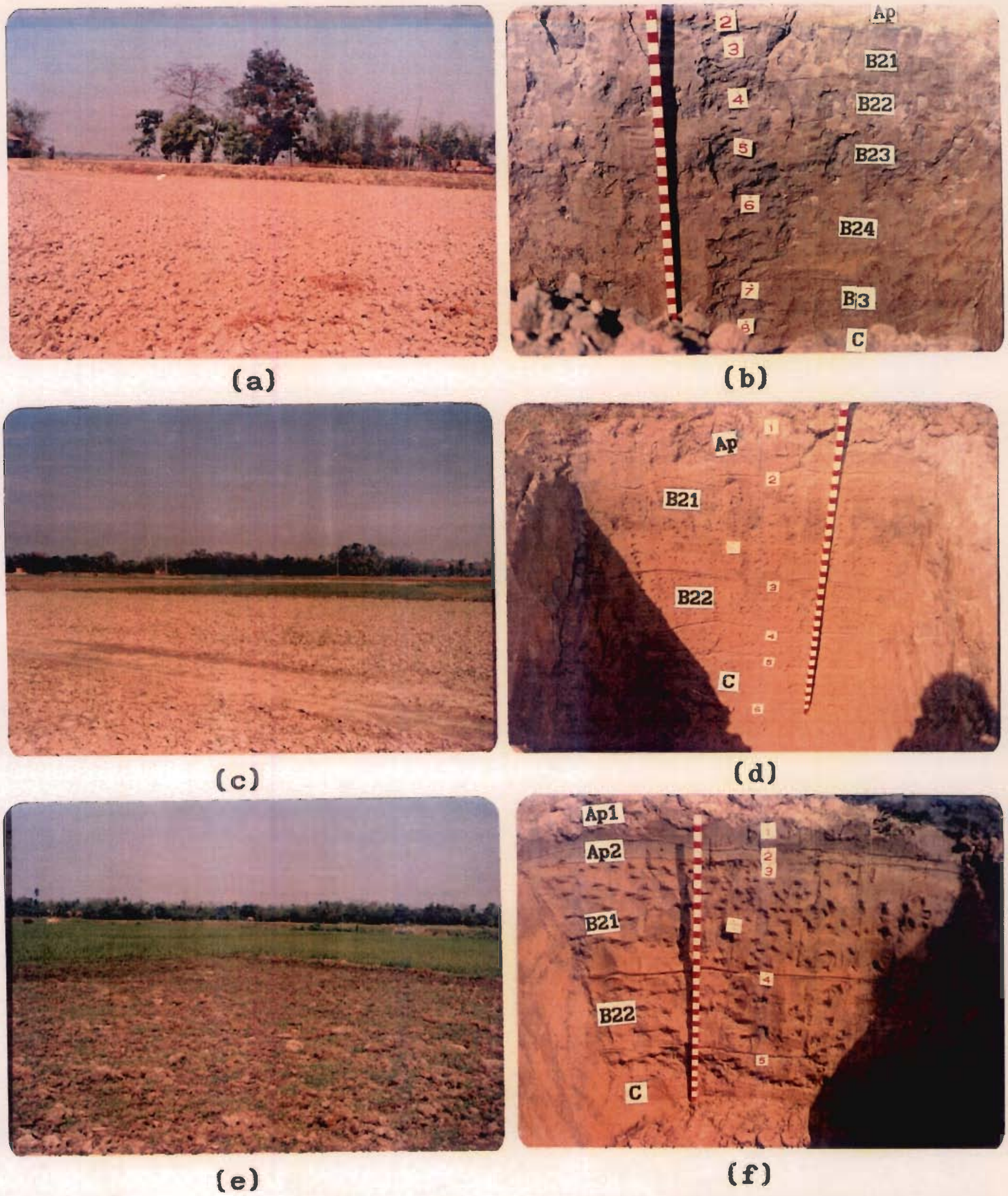


Fig.2.7. Photographs showing **(a)** Field view and **(b)** A typical pedon (S12) from the Old Brahmaputra Plain; **(c)** Field view and **(d)** A typical pedon (T11) at the top of a nearly level levee from the Old Meghna Deltaic Plain: **(e)** Field view and **(f)** A typical pedon (T9) at a poorly drained site from the Old Meghna Deltaic Plain.

C 42 - 58 cm; olive grey (5 Y 5/2) moist with common fine distinct dark yellowish brown (10 YR 5/4) mottles; very fine sandy loam; weak angular blocky; very friable moist, nonsticky and nonplastic; many very fine tubular pores; few fine roots; abrupt smooth boundary; pH 7.0

Bb1 58 - 85 cm; dark grey (5 Y 4/1) moist with common fine distinct dark yellowish brown (10 YR 4/4) mottles; silt loam; weak angular blocky; friable moist, nonsticky and nonplastic; continuous dark grey cutans on ped faces; many fine tubular pores; few fine roots; abrupt smooth boundary; pH 7.5.

Bb2 85 - 98 cm; olive grey (5Y 4/2) moist with many fine distinct dark yellowish brown (10 YR 4/4) mottles; silt loam; massive; friable moist, nonsticky and nonplastic; broken cutans on ped faces; many fine pores; few fine roots; pH 7.0

Cb 98 - 105 cm; light brownish grey (2.5 Y 6/2) moist with many medium distinct dark yellowish brown (10 YR 4/4) mottles; silt loam; massive; friable moist, nonsticky and nonplastic; many fine tubular pores; pH 8.0

PEDON # S12

Classification	:	Typical/Aeric Haplaquept
Location	:	Ramgopalpur, Gauripur upazilla, Mymensingh
Parent materials	:	Brahmaputra alluvium
Erosion	:	Nil
Slope	:	Very gentle
Drainage	:	Poorly drained
Moisture condition	:	Moist
Depth of ground water	:	1.5 m
Physiography	:	Basin margin
Flooding	:	About 1.5 m for 4 - 5 months
Landuse	:	Transplanted Aman - Boro

Typifying Pedon

Ap1 0 - 10 cm; gray (5 Y 5/1) moist with common fine dark yellowish brown mottles; silty clay loam; massive; hard dry, firm moist, sticky and plastic; many fine and medium tubular pores; many fine and medium roots; abrupt smooth boundary; pH 6.5.

Ap2 10 - 17 cm; dark grey (5Y 4/1) moist with many fine and medium distinct dark yellowish brown, dark brown and grey mottles; silty clay loam; massive; very firm moist, plastic and sticky; many fine and medium pores; many fine roots; abrupt smooth boundary; pH 6.5.

B21	17 - 39 cm; dark grey (5 Y 4/1) moist with common fine and medium distinct dark yellowish brown, yellowish brown and grey mottles; silty clay loam; strong coarse prismatic breaking into angular blocky; firm moist, plastic and sticky; broken cutans on ped faces; many fine and medium tubular pores; common fine and medium roots; abrupt smooth boundary; pH 7.5.
B22	39 - 63 cm; dark grey (5 Y 4/1) moist with common fine and medium distinct dark yellowish brown, dark brown and grey mottles; silty clay loam; strong coarse prismatic breaking into angular blocky; firm moist, plastic and sticky; continuous moderately thick cutan along vertical and horizontal ped faces; many fine and medium tubular pores; common fine roots; gradual smooth boundary; pH 7.5
B23	63 - 85 cm; dark grey (5 Y 4/1) moist with few fine and medium distinct dark yellow brown, dark brown and yellowish brown mottles; silty clay loam; strong coarse prismatic breaking into angular blocky; firm moist, plastic and sticky; continuous moderately thick cutans along vertical and horizontal peds; many fine and medium tubular pores; few fine roots; gradual boundary; pH 7.5
B24	85 - 111 cm; gray (5 Y 5/1) moist with many fine and medium dark yellowish brown and yellowish brown mottles; silt loam; weak coarse prismatic breaking into angular blocky; slightly firm moist, slightly plastic and slightly sticky; continuous moderately thick cutans along ped faces; many fine tubular pores; common fine and medium roots; gradual smooth boundary; pH 7.5.
B3	111 - 120 cm; olive gray (5 Y 5/2) moist with common fine and medium distinct dark grey and yellowish brown mottles; silt loam; weak coarse angular blocky; friable moist, nonsticky and nonplastic; thin continuous cutans on ped faces; many fine tubular pores; many fine roots; clear wavy boundary; pH 8.0
C	120 - 130 cm; olive gray (5 Y 5/2) moist with common fine and medium distinct yellowish brown and dark yellowish mottles; silt loam; massive; friable moist non sticky and nonplastic; few fine pores; pH 8.0

2.4.7 OLD MEGHNA DELTAIC PLAIN (OMDP)

This unit represents the floodplain of the ancient Meghna river. This river deposited sediments into the Sylhet Depression and constructed the Meghna river floodplain through gradual progradation towards south and caused the Bay of Bengal waters to retreat which originally extended into the Sylhet Depression. Rivers draining directly from the Chittagong - Tripura hills also contributed in the construction of the floodplain. Now, this unit (Fig.2.1) occupies an almost level landscape of smooth, broad ridges and basins. The unit lies at about 2 m higher than the recent Meghna floodplain (Morgan and McIntire, 1959) and it is no longer affected by river sedimentation. Re-distribution of material by surface wash has almost obliterated the evidence of the former levees and basins. It has well developed soils with oxidized subsoils and underlying non-calcareous sediments. The solum thickness varies from 70 cm to 90 cm. This unit shows grey tone with dark grey patches in black and white images (Fig.2.2.c) and a mosaic of blue and red colours with dark blue patches in FCC images. The unit has a coarse textured drainage. The description of 2 pedons T11 and T9 (Figs.2.7.d,f) from this unit is given below.

PEDON # T11

Classification	:	Aeric/Typic Haplaquepts
Location	:	Baghmara, Laksham upazila, Comilla
Parent materials	:	Old Meghna alluvium
Erosion	:	Nil
Slope	:	Nearly level
Drainage	:	Poorly drained
Moisture condition	:	Moist
Depth of ground water	:	5 - 6 m
Physiography	:	Nearly level ridge
Flooding	:	1 foot for 15-20 days by rain water
Landuse	:	Transplanted Aus-transplanted Aman- - Rabicrops.

Typifying Pedon

Ap1g 0 - 13 cm; grey (5 Y 5/1) moist with few fine faint yellowish brown (10 YR 5/6) mottles; silt loam; cloddy; slight hard dry, friable moist, nonsticky and nonplastic; common fine tubular pores; many fine roots; abrupt wavy boundary; pH 7.0

Ap2g	13 - 20 cm; grey (5 Y 5/1) moist with many fine distinct yellowish brown (10 YR 5/6) mottles; silt loam; cloddy; friable moist, nonsticky and nonplastic, common fine pores; many fine roots; abrupt wavy boundary; pH 8.0
B21	20 - 64 cm; olive (5 Y 5/3) moist with common fine distinct grey (5 Y 5/1) and yellowish brown (10 YR 5/8) mottles; silt loam; moderate coarse prismatic breaking into angular blocky; friable moist, nonsticky and nonplastic; continuous thick grey cutans along horizontal and vertical ped faces; many fine tubular pores; few fine roots; clear smooth boundary; pH 8.0
B22	64 - 88 cm; olive (5 Y 5/3) moist with common medium distinct yellowish brown (10 YR 5/8) mottles; silt loam; moderate to strong coarse prismatic breaking into angular blocky; friable moist, nonsticky and nonplastic; patchy moderately thick cutans along horizontal and vertical ped faces; many fine tubular pores; very few fine roots; abrupt wavy boundary; pH 8.0
C1	88 - 104 cm; olive ;grey (2.5 Y 5/2) moist will few fine distinct yellowish brown mottles; silt loam; weak coarse prismatic angular blocky; friable moist, nonstickly and nonplastic; many fine tubular pores; very few fine roots; clear smooth boundary; pH 8.0
C2	104 - 127 cm; olive gray (2.5 5/2) moist with common medium prominent yellowish brown (10 YR 5/8) and few medium prominent very dark greyish brown (2.5 Y 3/2) mottles; silt loam; massive; friable moist, nonsticky and nonplastic, many fine tubular pores; very few fine roots; pH 8.0

PEDON # T9

Classification	:	Aeric/Typic Haplaquepts
Location	:	Suchipara, Shahrasti, Chandpur
Parent materials	:	Old Meghna alluvium
Erosion	:	Nil
Slope	:	Nearly level
Drainage	:	Very Poorly drained
Moisture condition	:	Moist
Depth of ground water	:	4 - 5 m
Physiography	:	Margin of a basin
Flooding	:	5 - 6 feet for 5 - 6 months
Landuse	:	Broadcast Aman- Fallow

Typifying Pedon

Ap1	0 - 10 cm; grey (N5) moist with few fine distinct light olive brown (2.5 Y 5/6) mottles; silty clay; massive; hard dry, firm moist, plastic and sticky; common fine tubular pores; common fine and medium roots; abrupt wavy boundary, pH 6.5.
Ap2	10 - 15 cm; dark grey (10 YR 4/1) moist with few fine distinct light olive brown (2.5 Y 5/6) mottles; silty clay; massive; firm moist, plastic and sticky; common fine tubular pores; common fine and medium roots; abrupt wavy boundary; pH 8.0
B21	15 - 54 cm; dark grey (10 YR 4/1) moist with few fine faint yellowish brown (10 YR 5/6) mottles; silty clay; strong coarse prismatic breaking into angular blocky; firm moist, sticky and plastic; patchy thick cutans along horizontal and vertical ped faces; many fine tubular pores; few fine roots; clear smooth boundary; pH 8.0
B22	54 - 89 cm; dark grey (10 YR 4/1) moist with many medium distinct yellowish brown (10 YR 5/6) mottles; clay; strong coarse prismatic breaking into angular blocky; firm moist, sticky and plastic; continuous thick cutans along vertical and horizontal ped faces; many fine tubular pores; clear smooth boundary; pH 8.0
C	89 - 115 cm; olive brown (2.5 Y 4/4) moist with few fine faint yellowish brown (10 YR 5/6) mottles; silt loam; massive; friable moist, nonsticky and nonplastic; common fine tubular pores; pH 8.0

2.4.8 BARIND TRACT (BT)

This unit lies on the west of the Jamuna (Brahmaputra) river (Figs. 1.1 and 2.1) and consists of an extensive and uniform homogeneous clayey materials, called the Madhupur clay and despite its similarity with the 'Madhupur Tract' specially in respect of the parent materials, it has less complex reliefs and patterns of soil development. A number of rivers like Atrai, Little Jamuna, Purnabhaba etc. cross the Barind Tract and flowing along fault troughs have divided it into a number of blocks.

In black and white landsat images this unit is clearly seen by very light grey tone (Fig. 2.2.b) with a few grey mottles indicating high reflectance which is due to its almost flat topography and semi-consolidated homogeneous clayey materials as confirmed by field checks. In FCC images this unit is seen by very light yellow colour with some mottles and patches of light red colour (Fig. 2.3.c,d). This unit has a coarse textured drainage.

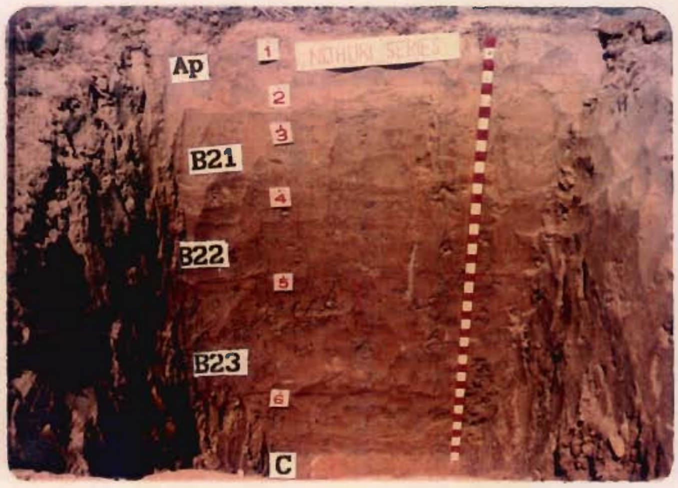
The greater part of the Barind Tract is undissected and has moderately to poorly drained red mottled/grey soils at shallow depths. Well developed 'red' soils occur only in the northeastern part of this unit. Three subunits have been recognised as follows:

(a) **Level Barind tract** : It occupies about 80% area of the whole tract and weathers to a solum depth ranging from 50 to 80 cms. It is marked by moderately to poorly drained soils. This subunit at some places, contains large quantities of big and hard lime nodules.

(b) **High Barind tract** : At the western border of Bangladesh a part of the Barind tract stands about 25 m above the adjoining floodplain of the Punarbhaba river. This landscape with 5-15% slope have developed mainly moderately drained grey soils. This subunit occupies about 10% area of the whole Barind tract and contains lime nodules, and

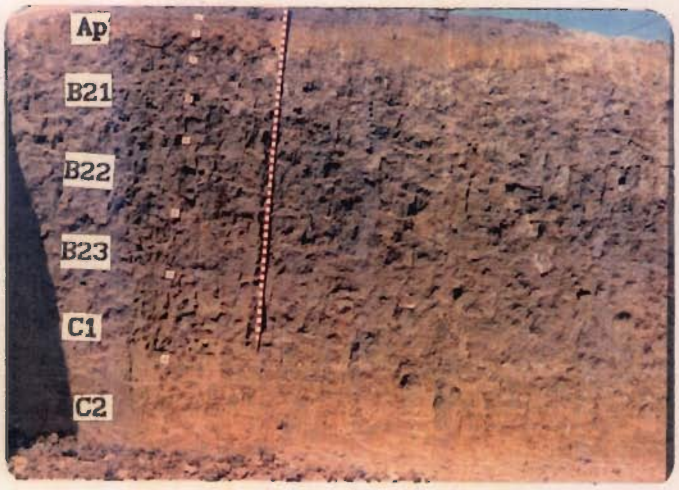
(c) **North-eastern Barind Tract**: This subunit occupies about 10% area of the whole Barind tract with deeply weathered 'red' soils similar to those of the Madhupur tract.

(a)



(b)

(c)



(d)

Fig.2.8. Photographs showing **(a)** Field view and **(b)** A typical pedon (S1) at an imperfectly drained site from the Barind Tract; **(c)** Field view and **(d)** A typical pedon (S6) at a poorly drained site from the Barind Tract.

One representative pedon S1 (Fig.2.8.b) from level Barind tract has been described in this section and the morphology of the red soils has been described in section 2.4.9.

PEDON # S1

Classification	:	Aeric Haplaquepts
Location	:	Sharoil, Godagari upazilla, Rajshahi
Date of Examination	:	12.3.91
Parent materials	:	Madhupur clay
Erosion	:	Nil
Slope	:	1 - 2%
Drainage	:	Imperfectly drained
Moisture condition	:	Moist
Depth of ground water	:	10 - 12 m
Physiography	:	Nearly level terrace
Flooding	:	Above flood level rain water does not accumulate
Landuse	:	Transplanted Aman - Fallow - wheat/mustard

Typifying Pedon

Ap1 0 - 12 cm; light grey (5 Y 7/2) dry with common medium district dark yellowish brown mottles (10 YR 4/4); silt loam; cloddy; slightly hard dry, friable moist, nonsticky and non plastic; few fine and medium tubular pores; common fine roots; abrupt smooth boundary; pH 6.5.

Ap2 12-17 cm; light olive grey (5 Y 6/2) with many medium distinct yellowish brown (10 YR 5/6) mottles; clay loam; cloddy; hard dry, firm moist, slightly plastic and slightly sticky; few fine roots; few fine tubular pores; abrupt smooth boundary; pH 8.0.

B21 17-36 cm; olive grey (5 Y 5/2) with many medium distinct yellowish brown (10 YR 5/6) mottles; silty clay loam; strong medium and coarse angular blocky; hard dry, firm moist, moderately plastic and moderately sticky; few fine roots; few fine tubular pores; clear smooth boundary; pH 8.0.

B22 36 - 58 cm; light olive brown (2.5 Y 5/4) with common fine prominent red (2.5 YR 4/6) mottles; clay; strong coarse angular blocky; very hard dry, very firm moist, plastic and sticky; broken moderately thick cutans; few fine tubular pores; very few fine roots; clear smooth boundary; pH 8.0.

B23 58-92 cm; grayish brown (2.5 Y 5/2) with common fine distinct yellowish brown (10 YR 5/4) and common fine prominent red (2.5 YR 4/6) mottles; clay; strong coarse angular blocky; very hard dry, very firm moist, plastic and sticky; broken moderately thick cutans; very few fine tubular pores; very few fine roots; clear smooth boundary; pH 8.0.

C 92-105^{+} cm; grey (2.5 Y N5) with common fine distinct yellowish brown (10 YR 5/4) and few fine prominent red (2.5 YR 4/6) mottles; clay; strong coarse angular blocky; very hard dry, very firm moist, plastic and sticky; broken moderately thick cutans, very few fine tubular pores, pH 8.0.

2.4.9 MADHUPUR TRACT (MT)

This unit has an area of about 4500 km^2. It consists of uniform Madhupur clay and has been weathered to different degrees under different drainage conditions, giving rise to a wide range of soils. The special characteristic of this unit is the development of deeply weathered 'red soils' on the higher edges of the valleys or uplands, red/yellow mottled soils on the level uplands and grey soils on the valley bottoms. The red soils have developed in the west on the well drained margins of the uplands. They have also developed in the east on closely dissected margins of the valleys/uplands. The rest of the upland comprises moderately developed soils on level upland areas similar to that of the Barind Upland. This unit is characterized by light red colour with bluish white mottles/patches in FCC images and very light grey to light grey tone with grey and dark grey mottles/patches in black and white images (Fig.2.2.c). The description of one well developed pedon (Fig.2.9.b) from this unit is given below. The morphological properties of the moderately developed red mottled/grey soils in this unit are almost similar to those of the red/mottled grey soils in the Barind Tract as described in section 2.4.8.

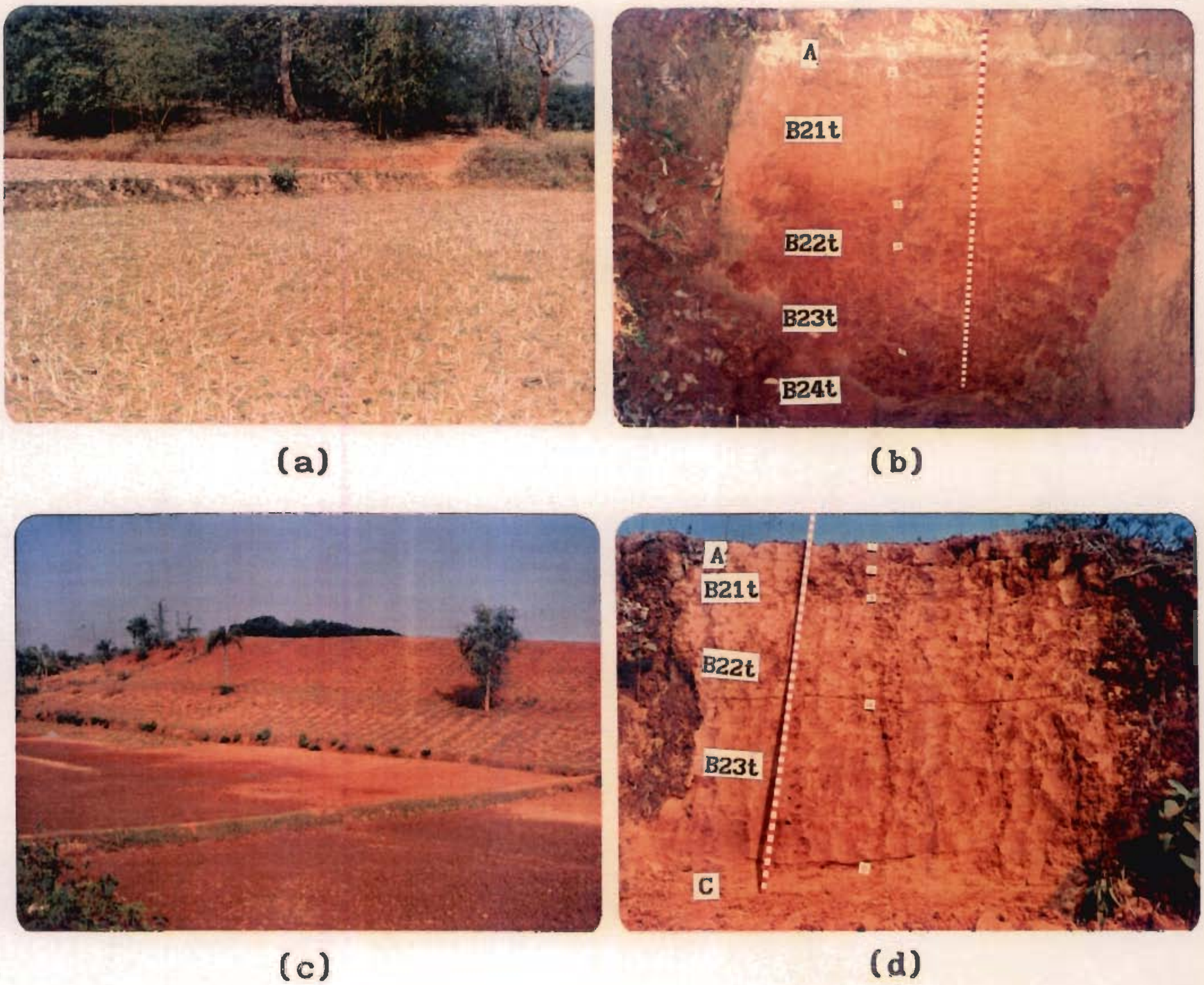


Fig.2.9. Photographs showing **(a)** Field view and **(b)** A typical pedon (T7) at a gently sloping well drained site from the Madhupur Tract; **(c)**Field view and **(d)** A typical pedon (T12) at the margin of a dissected site from the Lalmai Hills.

PEDON # T7

Classification	:	Haplustults/Paleustults
Location	:	Sripur cotton seed farm, Sripur upazilla, Gazipur
Parent materials	:	Madhupur clay
Erosion	:	Nil
Slope	:	Very gently sloping
Drainage	:	Well drained
Moisture condition	:	Moist
Depth of ground water	:	32 - 35 m
Physiography	:	Nearly level Madhupur upland terrace
Flooding	:	Above flood level
Landuse	:	Cotton seed/Sugar cane/Jackfruit

Typifying Pedon

A1 0 - 8 cm; brown (7.5 YR 5/4) moist; clay; massive; slightly hard dry, friable moist, slightly sticky and slightly plastic; common, fine tubular pores; common fine and medium roots; abrupt smooth boundary; pH 6.1.

B21t 8 - 81 cm; yellowish red (5 YR 5/6) moist; clay; moderate fine subangular blocky; hard dry, friable moist, plastic and sticky; continuous moderately thick cutans on ped faces; common fine tubular pores; common fine roots; abrupt smooth boundary; pH 5.2.

B22t 81 - 102 cm; red (2.5 YR 4/8) moist; clay; strong fine sub-angular blocky peds; friable moist, plastic and sticky; continuous moderately thick cutans on ped faces; common, fine tubular pores; common fine roots; gradual wavy boundary pH 5.2

B23t 102 - 180 cm; red (2.5 YR 4/6) moist, few fine distinct very dark brown (10 YR 2/2) and light yellowish brown (10 YR 6/4) mottles; clay; strong fine subangular blocky peds; friable moist, plastic and sticky; continuous moderately thick cutans on ped faces; few fine tubular pores; very few fine roots; gradual wavy boundary; pH 5.5

B24t 180-200 cm; red (2.5 YR 4/6) moist; few fine distinct very dark brown (10 YR 2/2) and light yellowish brown (10 YR 6/4) mottles; clay; strong fine subangular blocky peds; friable moist, plastic and sticky; continuous moderately thick cutans on ped faces; few fine tubular pores; gradual wavy boundary; pH 5.5.

B25t 200 - 300 cm; red (2.5 YR 4/6) moist with common fine distinct very dark brown (10 YR 2/2) and light yellowish brown (10 YR 6/4) mottles; clay; strong fine subangular blocky peds;

friable moist, sticky and plastic; continuous moderately thick cutans; few fine tubular pores; pH 5.5.

2.4.10 LALMAI HILLS (LH)

This is the smallest soil-geomorphic unit and it represents an upland area and is surrounded by the extensive nearly level Old Meghna Deltaic Plain (Fig.2.1). The summit of this unit is flat in many places. The sides are steep and strongly gullied specially in the west. The highest parts are more than 30 m above M.S.L., but the average elevation is about 21 m above M.S.L.

The Lalmai Hills consist mainly of unconsolidated sands and silts. Gravel and cobble layers occur in the central and western part of the hills. All these sediments belong to the Pliocene Dupi Tila Formation but the soil formation occurred in the Late Pleistocene. Some strongly acid 'red soils' have developed on this well drained upland. A yellowish - brown top soil overlies a strong brown to yellowish - red subsoil. This unit is marked by an overall grey tone in the black and white images and by light red colour in FCC images. Detailed description of one typical pedon (Fig.2.9.d) from this unit is given below.

PEDON # T12

Classification	:	Haplustults/Paleustults
Location	:	Baradharmapur, Comilla Sadar
Parent materials	:	Unconsolidated Dupi Tilla sandstones and silt
Erosion	:	Nil
Slope	:	Gently rolling
Drainage	:	Well drained
Moisture condition	:	Moist
Depth of ground water	:	
Physiography	:	Lalmai Hills
Flooding	:	Above flood level
Landuse	:	Mainly grasses, thorny bushes, palm tress and jack fruit trees

Typifying Pedon

A 0 - 15 cm; brownish yellow (10 YR 6/6) moist; clay loam; weak, fine and medium subangular blocky; slightly hard dry, friable moist, slightly plastic and slightly sticky, many fine and medium tubular pores; many medium roots; clear smooth boundary; pH 4.5

B21t 15 - 32 cm; yellowish red (5 YR 5/8) moist with few medium prominent dark reddish brown (5 YR 3/2) and reddish yellow (7.5 YR 7/8) mottles; clay loam; strong fine and medium angular and subangular blocky peds; friable moist, slight plastic and slightly sticky; thin clay skins; common fine and medium tubular pores; common fine and medium roots; clear smooth boundary; pH 5.0

B22t 32 - 48 cm; yellowish red (5 YR 5/8) moist with few medium prominent dark reddish brown (5 YR 3/2) and reddish yellow (7.5 YR 7/8) mottles; clay loam; strong, fine and medium angular and subangular blocky; friable moist, slightly plastic and slightly sticky; thin clay skins; common fine and medium tubular pores; few fine roots; clear smooth boundary; pH 5.0

B23t 48 - 65 cm; yellowish red (5 YR 5/8) moist with few medium prominent reddish yellow (7.5 YR 7/8) and dark brown (7.5 YR 3/2) mottles; clay loam; strong fine and medium angular and subangular blocky; friable moist, slightly sticky and slightly plastic; thin clay skins; common fine and medium tubular pores; few fine roots; clear smooth boundary; pH 5.0

B24t 65 - 165 cm; yellowish red (5 YR 5/8) moist with common fine distinct dark yellowish brown (10 YR 4/4) mottles; loam; moderate fine and medium subangular blocky; friable moist, slightly sticky and slightly plastic; common fine and medium tubular pores; few fine roots; clear smooth boundary; pH 5.0

C1 165 - 200 cm; reddish yellow (5 YR 7/6) moist with many medium prominent pinkish white (5 YR 8/2) mottles; sandy clay loam; massive; friable moist, nonsticky and nonplastic; fine pores; clear smooth boundary; pH 5.0

C2 200 - 250 cm; reddish yellow (5 YR 6/8) moist with many medium prominent pinkish white (5YR 8/2) mottles; sandy clay loam, massive; friable moist, non sticky and non plastic; few fine pores; pH 5.5.

2.4.11 SYLHET DEPRESSION (SD)

This soil-geomorphic unit is bounded by the Shillong Plateau in the north, Tripura hills in the east, the Old Meghna Deltaic Plain in the south and the Old Brahmaputra Plain in the west. This is a low-lying depression (Figs.2.1 and 2.2.c) containing a number of large permanent lakes (haors) with an elevation of 3m from M.S.L. The Barak river originating in the hills of Manipur (India) has bifurcated into Surma and Kushiyara rivers on reaching the border with Bangladesh. These two rivers and other minor rivers comprise one of the highest rainfall areas of the world and this river system passes through the Sylhet Depression and pour sediments into this depression.

The alluvial sediments in this unit contain silts and clays with lower contents of weatherable minerals than the Tista, Brahmaputra and Ganges floodplains. The river channels are more stable than the Brahmaputra and the Ganges due to the absence of sands. Seasonal flooding is more than 6 metres in some parts of the Depression. About 20 - 60 cm thick sediments of the present river system have partially buried the old Brahmaputra soils or sediments in this unit. In FCC images this unit is seen by overall red colour and in black and white images it shows dark grey tone (Fig.2.2.c) fine textured drainage. Detailed description of one typical pedon (Fig.2.10.b) from this unit is given below.

PEDON # S14

Classification	:	Typic/Aeric Haplaguept
Location	:	Raytuli, Itna upazila, Kishorganj
Parent materials	:	Surma-Kushiyara alluvium
Erosion	:	Nil
Slope	:	Gentle
Drainage	:	Poorly drained
Moisture condition	:	Moist

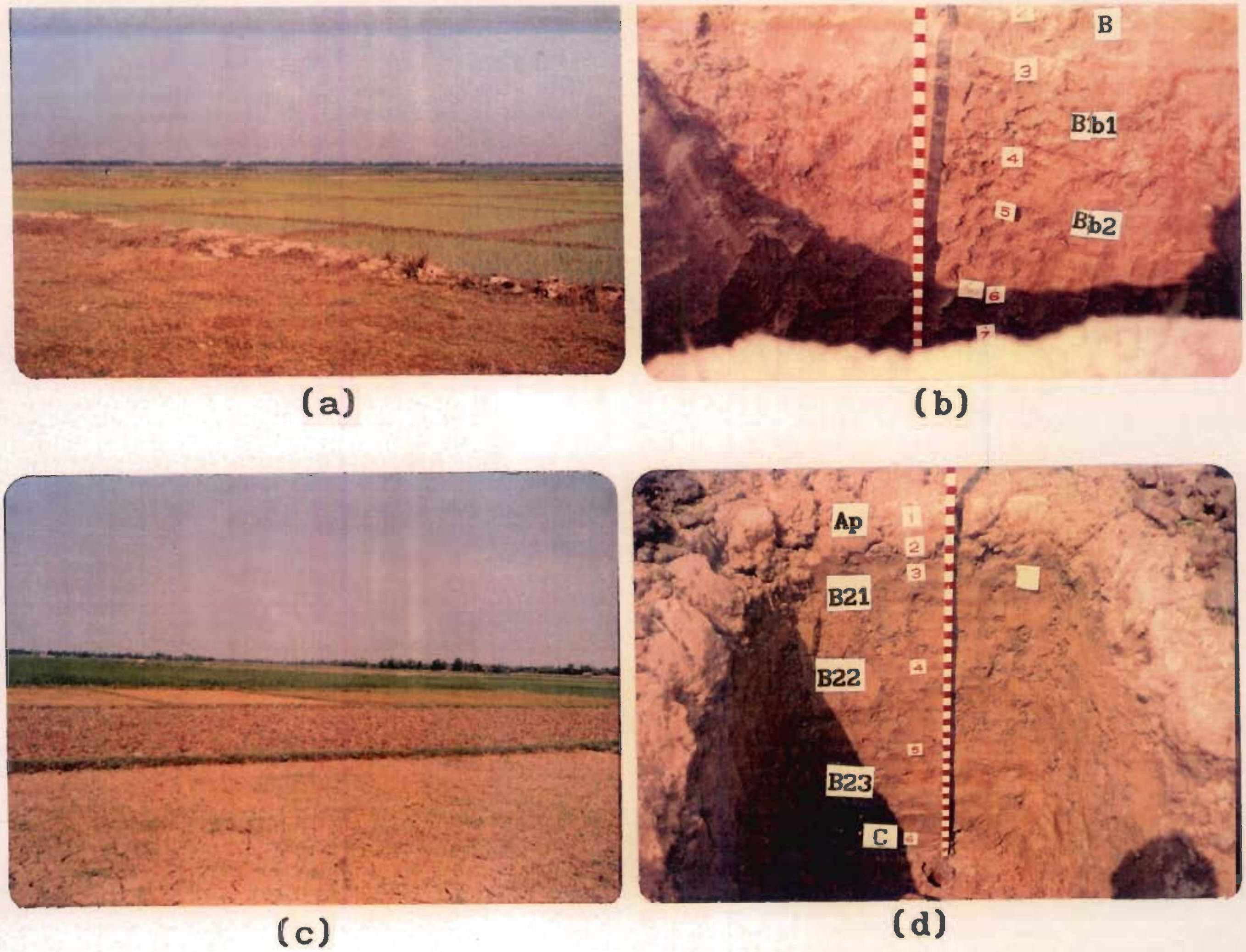


Fig.2.10. Photographs showing **(a)** Field view and **(b)** A typical pedon (S14) at a poorly drained site from the Sylhet Depression; **(c)** Field view and **(d)** A typical pedon (S4) at a poorly drained site from the Lower Atrai Depression.

Depth of ground water	:	1.2 m
Physiography	:	Upper part of a nearly level ridge
Flooding	:	1 - 2m for 4 - 5 months
Landuse	:	Potato/Boro - Fallow

Typifying Pedon

Ap 0 - 15 cm; light brownish gray (2.5 Y 6/2) moist with common fine distinct olive brown (2.5 Y 4/4) and few fine distinct dark yellowish brown (10 YR 4/4) mottles; very fine sandy loam; massive; friable moist, nonsticky and nonplastic; many fine and medium tubular pores; many fine and medium roots; pH 6.5.

B 15 - 27 cm; gray (5 Y 5/1) moist with many fine and medium dark yellowish brown (10 YR 4/4) and few fine distinct strong brown (7.5 YR 5/8) mottles; silt loam; weak coarse prismatic breaking into angular blocky; friable moist slightly sticky and slightly plastic; many fine and medium tubular pores; many fine and medium roots; clear wavy boundary; pH 6.5.

Bb21 27 - 45 cm; grey (5 Y 5/1) moist with many fine and medium distinct olive and dark yellowish brown mottles; silt loam; moderate coarse prismatic breaking into angular blocky; friable moist, slightly sticky and slightly plastic; many fine and medium tubular pores; common fine roots; clear wavy boundary; pH 6.5.

Bb22 45 - 58 cm; grayish brown (10 YR 5/2) moist with common fine and medium distinct dark yellowish brown and dark brown mottles; silty clay loam; moderate coarse prismatic breaking into angular blocky; firm moist, sticky and plastic; many fine and medium tubular pores; common fine roots; clear wavy boundary; pH 6.5.

Bb23 58 - 77 cm; grey (10 YR 5/1) moist with common fine and medium distinct dark yellowish brown, dark brown and strong brown mottles; silty clay loam; moderate coarse prismatic breaking into angular blocky; friable moist, slightly sticky and slightly plastic; continuous moderately thin to thick cutans along horizontal and vertical ped faces; many fine and medium tubular pores; few medium roots; clear wavy boundary; pH 6.0.

Bb24 77 - 98 cm; grey (5 Y 5/1) moist with common fine and medium distinct dark yellowish brown (10 YR 4/4) and dark brown (10 YR 3/3) mottles; silty clay; strong coarse prismatic breaking into medium and fine angular blocky; friable moist, slightly sticky and slightly plastic; continuous thick dark grey cutans along horizontal and vertical ped faces; many fine and medium tubular pores; abrupt smooth boundary; pH 6.5.

Bb25 98 - 110 cm; dark grey (10 YR 4/1) moist with many fine and medium distinct dark brown (10 YR 4/3) and common medium district (7.5 YR 5/6) mottles; silty clay; moderate coarse prismatic angular block; friable moist, slightly sticky and slightly plastic; patchy moderately thick cutans on ped faces; many fine and medium pores; abrupt smooth boundary; pH 6.5.

2.4.12 LOWER ATRAI DEPRESSION (LAD)

This unit mainly occupies the lower reaches of the Atrai river where a network of tributaries join and finally flows to the southeast to meet the Jamuna (Brahmaputra) river. This unit represents a depression (Figs. 2.1 and 2.3.c,d) between the Barind Tract and northern part of the Ganges floodplain. It consists of low-lying areas which remain under deep water for about five to six months. The parent materials are predominantly clayey and usually overlie weathered Madhupur clay at variable depths. The parent materials have accumulated on the low-lying areas from both the Barind tract and the adjoining areas. Major soils are dark grey, often finely mottled yellowish brown and somewhat acidic heavy clays which become very hard when dry.

These soils might have developed under long-continued stable condition with solum thickness ranging from 90 cm to 120 cm. In Landsat black and white images this unit is clearly seen by grey tone with mottles and patches of dark grey tone mainly concentrated at the northwestern and southeastern parts of the unit. In FCC images this low-lying area appears as an overall bright red colour with a concentration of deep blue patches and mottles to the north western and south eastern parts. It has a medium textured drainage. From this unit one typical pedon (Fig.2.10.d) has been described as follows:

PEDON # S4

Classification	:	Vertic Haplaquepts
Location	:	Halti beel, Rai Singapur, Natore Sadar
Date of Examination	:	13.3.91
Parent materials	:	Mixed reworked sediments from the adjoining areas
Erosion	:	Nil
Slope	:	
Drainage	:	Poorly drained
Moisture condition	:	Fully moist
Depth of ground water	:	5 - 6 m
Physiography	:	Margin of a basin
Flooding	:	5 - 6 months under 10 - 12' water
Landuse	:	Boro - Fallow

Typifying Pedon

Ap1 0 - 9 cm; dark grayish brown (2.5 Y 4/2) moist with common fine distinct dark brown (7.5 YR 4/4) and few fine distinct dark yellowish brown (10 YR 4/4) mottles; silty clay; cloddy; hard dry, very firm moist, plastic and sticky; very few very fine tubular pores; common very fine roots; abrupt smooth boundary; pH 6.5.

Ap2 9 - 16 cm; dark grayish brown (2.5 Y 4/2) moist with common fine distinct dark brown (7.5 YR 4/4) mottles; clay; cloddy; hard dry, very firm moist, very plastic and very sticky; very few, very fine tubular pores; common very fine roots; abrupt smooth boundary; pH 8.0.

B21 16-47 cm; olive grey (5Y 4/2) moist with common fine distinct dark brown (7.5 YR 4/4) and few fine distinct yellowish brown (10 YR 5/6) mottles; clay; strong coarse and medium angular blocky breaking into fine angular blocky; very firm moist; sticky and plastic wet; continuous thick dark grey cutans along vertical and horizontal ped faces (pressure faces); few fine tubular pores; few very fine roots; smooth boundary; pH 8.0.

B22 47-78 cm; olive grey (5 Y 4/2) moist with many fine distinct dark brown (7.5 YR 4/4) and few fine distinct yellowish brown (10 YR 5/6) mottles; clay; strong coarse and medium angular blocky breaking into fine angular blocky; very firm moist; sticky and plastic; continuous thick dark grey cutans along vertical and horizontal ped faces (pressure faces); few fine tubular poes; few, very fine roots; clear smooth boundary; pH 8.0.

B23 78-120 cm; olive grey (5Y 4/2) moist with common fine distinct dark yellowish brown (10 YR 4/4) and few fine distinct dark brown (7.5 YR 4/4) mottles; clay; moderate coarse and medium angular blocky breaking into fine angular blocky; very firm moist, sticky and plastic; continuous thick dark grey cutans along vertical and horizontal ped faces (pressure faces); few fine tubular pores; few, very fine roots; clear smooth boundary; pH 8.0

B3 120-180 cm; olive grey (5 Y 4/2) moist with many fine distinct dark yellowish brown (10 YR 4/4) and few fine distinct dark brown (7.5 YR 4/4) mottles; clay; moderate coarse and medium angular blocky breaking into fine angular blocky; very firm moist, sticky and plastic, broken moderately thick cutans along vertical and horizontal ped faces; very few, very fine tubular pores; pH 8.0.

C 180 - 210$^+$ cm; grey (5Y 5/1) moist with many fine distinct yellowish brown (10 YR 5/6) mottles; clay; massive; very firm moist, sticky and plastic; pH 8.0.

2.5 FIELD MORPHOLOGY RATING SCALE

An attempt has been made to develop a field morphology rating scale following Bilzi and Ciolkosz (1977), Meixner and Singer (1981) and Harden (1982) on the basis of 6 morphological properties of soils like colour, texture, structure, consistence, clay films and horizon boundaries. The soils from the different soil-geomorphic units were evaluated and points assinged as described below.

(i) **Colour:** One point is assigned for any class change in hue and for any unit change in value or chroma.

(ii) **Texture:** One point is assigned for each class change on the textural triangle.

(iii) **Structure:** One point is assigned for any change in type of aggregated structure, for each unit change in grade and for each class change in size.

(iv) **Consistence:** One point is assigned for any change in moist

Table 2.1 : Field Characteristics of the soils of the study area

Soil-Geomorphic unit	Soil classification	Depth of Ground water(m)	Flooding	Texture	Colour	Lime concretions/CaCo3%	Fe/Mn concretions	Thickness of Solum (cm)	Thickness of B horizon (cm)	Thickness of B2 horizon (cm)	Structure of B horizon
Brahmaputra Floodplain	Fluvaquents/ Haplaquepts	6-7	2-5 months (1-2 m)	Silt loam	5Y 5/1-6/2	-	-	52	40	20	Weak
Tista Fan	Typic Haplumbrepts/ Aeric Haplaquepts	5-6	Above flood level except by rain water	Silt loam	5Y 4/1-5/6	-	-	90-110	44-76	20-26	Moderate
Old Tista Plain	Haplaquepts (Typic/Aeric)	4-5	2-3 months (0.5 m)	Silt loam/ silty clay loam	5Y 5/1-5/3	-	-	60-90	44-73	30-53	-do-
Moribund Ganges Deltaic plain	-do-	4-6	Above flood level except backswamp areas	Silt loam/ Silty clay loam	5Y 4/2-5/4 & 2.5Y 3/2-4/4	8% CaCO3 in C horizon	-	70-100	55-91	39-60	-do-
Old Brahma- [illegible]	Haplaquepts [illegible]	[illegible]	[illegible] by rain water	[illegible]	[illegible] & 5Y 6/1-7/1	[illegible] in C horizon	[illegible] in C horizon				[illegible] strong
Lalmai Hills	Paleustults	10-15	Above flood level	Clay loam	5YR 5/8-6/8	Carbonate concretions in C horizon	Fe/Mn concretions in C horizon	122-165	94-150	94-150	Moderate to strong
Sylhet Depression	Haplaquepts	2	4-5 months (2-3 m)	Silty clay loam	5Y 5/1-5/2	-	-	92	68	68	Moderate to strong
Lower Atrai Depression	Haplaquepts	4-6	5-6 months (2-3 m)	Silty clay loam	2.5Y 4/2	-	-do-	100-150	80-130	80-100	-do-

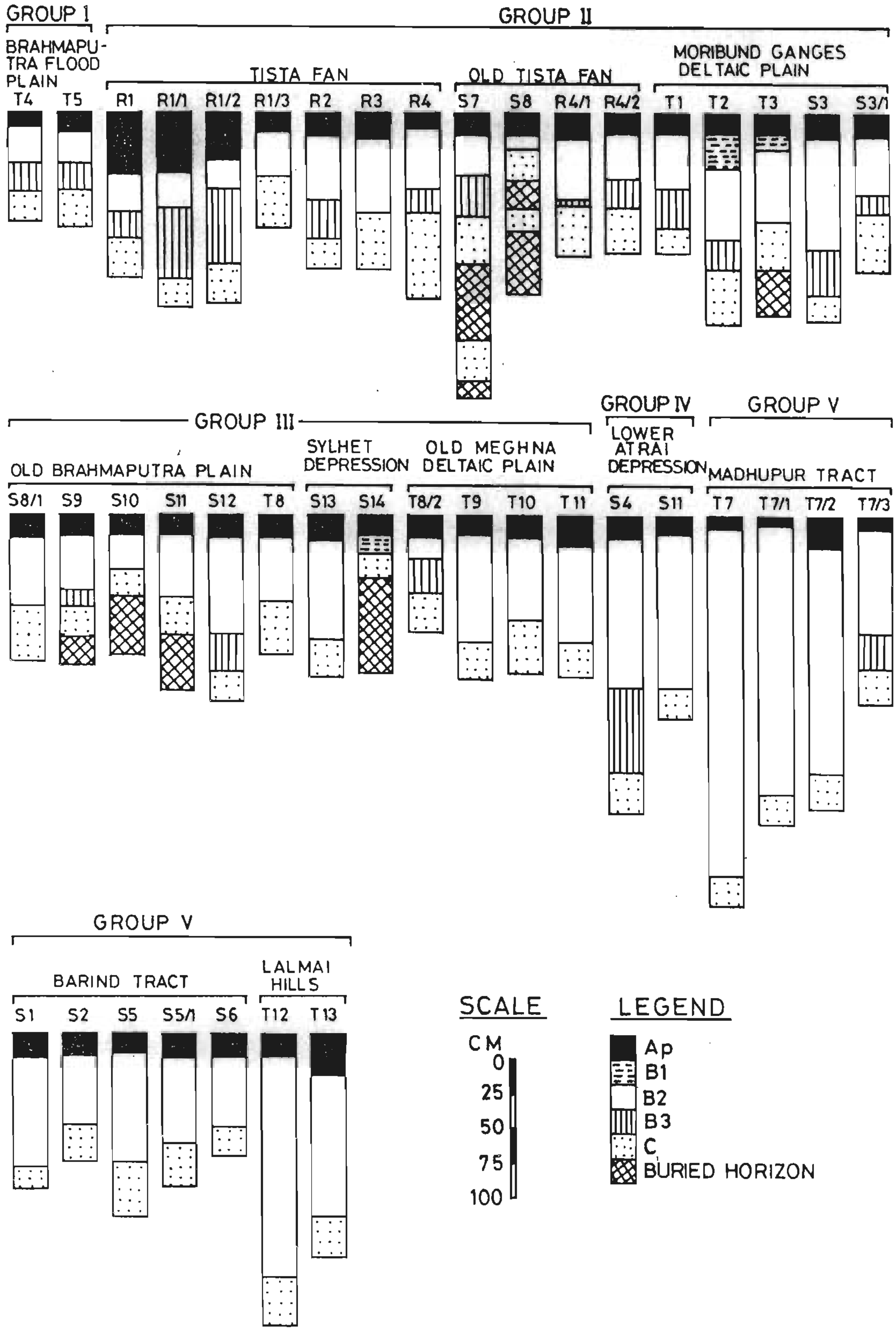


FIG. 2·11. VARIATION IN THE THICKNESSES OF THE HORIZONS OF SOIL PROFILES FROM THE VARIOUS SOIL-GEOMORPHIC UNITS. WITH THE EXCEPTION OF THE BARIND TRACT UNIT THE GROUP I-V SOILS SHOW INCREASING DEGREE OF DEVELOPMENT. R, S AND T DENOTE SOIL PROFILES.

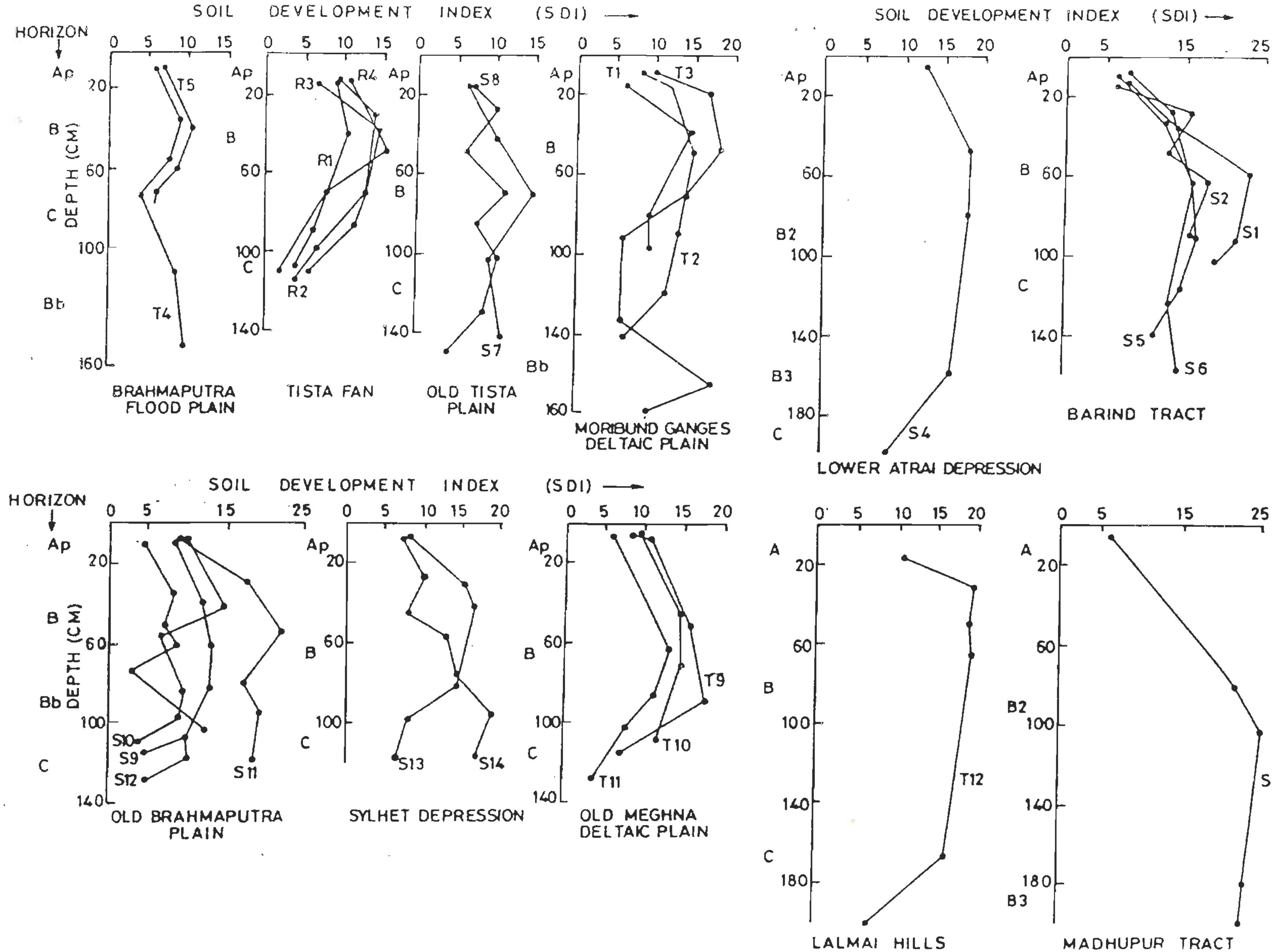


FIG. 2.12. VARIATION OF SOIL DEVELOPMENT INDEX (SDI) FOR VARIOUS SOIL-GEOMORPHIC UNITS.

consistence.

(v) Clay films: One point is assigned for each class change in frequency or thickness at any single location.

(vi) Boundaries: Points are assigned according to distinctness of the lower boundaries of soil horizons as follows: diffuse - 0, gradual - 1, clear - 2 and abrupt - 3.

Following Bilzi and Ciolkosz (1977) and Meixner and Singer (1981) the property values for each horizon were evaluated, summed up and plotted against profile depth (Appendix I and Fig. 2.12). The plotted Soil Development Index (SDI) against profile depth illustrates the relative development of soils in the various soil-geomorphic units. The bulges in the parts of the B horizons in the Fig.2.12 indicate relative development of soils with respect to the C/A horizon.

Following Harden (1982) each property value for each horizon (estimated by the above mentioned procedure) has been normalized by dividing the former by the maximum possible value for that property. This provided a scale ranging from 0 to 1. All the individual property values per horizon were then summed, the total was divided by the number of properties used and the latter was multiplied by the horizon thickness. Finally, the data for each profile were summed and adjusted for 2 m profile depth in case of the Madhupur Tract and the Lalmai Hills and for 1 m profile depth in case of all the remaining soil-geomorphic units. The data obtained were then listed in the **Appendix I** as Profile Development Index (PDI) value.

2.6 RESUME

Using remote sensing technique, twelve soil-geomorphic units have been delineated and then by field checks and morphological studies of soils the demarcation of the units has been confirmed. These units are (i) Brahmaputra Floodplain, (ii) Young Ganges Deltaic Plain, (iii) Tista Fan, (iv) Old Tista Plain, (v) Moribund Ganges Deltaic Plain, (vi) Old Brahmaputra Plain, (vii) Old Meghna Deltaic Plain, (viii) Barind Tract, (ix) Madhupur Tract, (x) Lalmai Hills, (xi) Sylhet Depression (xii) Lower Atrai Depression. Morphological properties of soils from each soil-geomorphic unit have been noted in the field and soil samples (both disturbed and in-situ) have been collected for laboratory analyses. A brief account of the morphological properties of the soils from each soil-geomorphic unit is given in Table 2.1. Thickness of the solums and also of individual soil horizons of some representative soil profile from different soil-geomorphic units are presented as bar diagrams in Fig.2.11.

Soils of the study area are classified following Soil Survey Staff (1975) and Brammer (1971). The various soil classes are: **Brahmaputra Floodplain**-Silt loam, Fluvaquents/Haplaquepts; **Young Ganges Deltaic Plain**-Silt loam, Fluvaquents/Haplaquepts; **Tista Fan** - Silt loam, Typic Haplumbrepts/Aeric Haplaquepts; **Old Tista Plain**-Silt loam to silty clay loam, Haplquepts (Typic/Aeric); **Moribund Ganges Deltaic Plain**-Silt loam to silty clay loam, Haplaquepts; **Old Brahmaputra Plain**-Silt loam to silty clay loam, Haplaquepts; **Old Meghna Deltaic Plain** - Silt loam to silty clay loam, Haplaquepts; **Barind Tract**-Silty clay loam, Dystochrepts; **Madhupur Tract**-Silty clay loam, Haplustults/Paleustults;

Lalmai Hills - Clay Loam, Haplustults/Paleustults; **Sylhet Depression**- Silty clay loam, Haplaquepts; **Lower Atrai Depression** - Silty clay loam, Haplaquepts.

Using the thicknesses of the solums and of the most developed B2 horizons (Table 2.1) as well as SDI and PDI values (Appendix I), the soil-geomorphic units of the study area have been ranked into 5 groups which show an increasing degree of pedogensis from the least developed soils of group I to the most developed soils of group V as given sequentially in Table 2.2. The morphological properties of the soils from the Barind Tract are inconsistent due to its uplift and erosion followed by pedogenesis and therefore, its soil properties have not been considered while ranking it.

Table 2.2: Ranking of soil-geomorphic units on the basis of SDI and PDI values as well as thicknesses of the sola and the B2 horizons

Groups	Soil-geomorphic units	SDI values in the B horizon	PDI values	Solum thickness (cm)	Thickness of B2 horizon (cm)
I	Brahmaputra Floodplain	8-10	50-51	52	20
II	Tista Fan, Old Tista Plain and Moribund Ganges Deltaic Plain	8-16	54-67	60 - 100	20 - 60
III	Old Brahmaputra Plain, Sylhet Depression and Old Meghna Deltaic Plain	10-21	59-75	60 - 110	45 - 68
IV	Lower Atrai Depression	18	84	100 - 150	80 - 100
V	Barind Tract, Madhupur Tract and Lalmai Hills	18-23	142-175	105 - 312	90 - 292

Field studies show that the soils from group I are weakly developed with minimum expression of morphological properties (e.g. horizonation, pedality, development of sturucture, abundance and thickness of clay films etc.). Soils from group II show higher degree of soil development than those of the group I. Morphological properties become more pronounced in case of group III soils which grade into stronger expression for group IV soils. The strongest expression of morphological properties in the study area is observed in group V soils whose colour hue generally varies from 10 YR to 2.5 YR.

CHAPTER 3

PHYSICAL, CHEMICAL AND CLAY MINERALOGICAL PROPERTIES OF SOILS

CHAPTER 3

PHYSICAL, CHEMICAL AND CLAY MINERALOGICAL PROPERTIES OF SOILS

3.1 INTRODUCTION

To study the pedogenic and geomorphic history of an area, particle size distribution and mineralogy are two of the most important characteristics and the best indicators of soil parent materials and some soil-forming processes, such as clay illuviation and weathering (Catt, 1985). Total chemical analysis is the most widely used way of determining the amount of chemical weathering that has taken place in a rock and the values for individual oxides of elements vary as a function of many soil forming processes (Birkeland, 1984). Keeping all these points in view, laboratory analyses were carried out to determine the distribution of particle sizes, contents of major elements and variation of clay minerals in the successive horizons of the soil profiles. A total of 204 samples for grain size distribution (Appendix II), 116 samples for total chemical analysis (Appendix III), 27 samples for determination of free iron contents (Table 3.2) and 61 samples for clay mineralogical studies (Appendix IV) were analysed in the laboratory and these form the subject matter of this chapter.

3.2 GRAIN SIZE ANALYSIS

Grain size analysis was carried out to determine the soil texture and the amount of pedogenic clay present in the soils.

3.2.1 Methodology

To determine the distribution of grain size in the soil profiles it is necessary that individual particles must be separated from each other. For this purpose, the samples were treated for removal of carbonates, organic matter, iron oxide and soluble salts as described below.

(a) Removal of carbonates- Carbonates were removed by treating the samples with 10 percent HCl. For soils having high contents of carbonates additional HCl was added and heated upto 80°C to 90°C until the effervescences stopped as suggested by Ingram (1971).

(b) Removal of organic matter- Organic matter was removed by using the method described by Jackson et al. (1949, in Ingram, 1971). The soil sample was heated at 40°C with 6% H_2O_2 for 1 hour and excess liquid was removed by decantation after gravity settling. Then 30% H_2O_2 was added to the sample very slowly and heated for 10 minutes at 40°C. The latter process was repeated till the organic matter was removed.

(c) Removal of iron oxides- Iron oxides were removed by using the method described by Leith (1950, in Ingram, 1971). The soil sample was placed in a 400 ml beaker containing 300 ml water, 15 gms of oxalic acid and a recoverable aluminium foil and it was boiled gently. If required, more oxalic acid was added to remove all the iron oxides.

(d) Removal of soluble salts- Soluble salts present in the sample were removed by repeated washings of the sample with distilled water. Generally, 5 to 6 washings were needed for good dispersion.

After removing all the binding materials a small amount of dispersing agent namely, Sodium Hexameta-phosphate $[Na(PO_3)_6]$ was added for complete dispersion of the particles. From the dispersed sample, sand fraction was separated by wet sieving with 300 mesh sieve. Silt and clay fractions were collected in a 1000 ml graduated cylinder and were separated by pippette analysis (Galehouse, 1971). Sand, silt and clay percentages were calculated according to the size classification used by Soil Survey Manual (1966) in terms of sand, 2.0 to 0.05 mm; silt, 0.05 to 0.002 mm and clay, below 0.002 mm. Following Birkeland (1984), pedogenic clay content was determined by subtracting the percentages of clay of the A or C horizon from that of the B horizon. Also, clay accumulation index (sum of increase in clay content over that of the A horizon multiplied by the thicknesses of the B subhoriozons) of Levine and Ciolkosz (1983) has been calculated for each pedon.

3.2.2 Variation in texture and amount of pedogenic clay in the soils of the different soil-geomorphic units

The data obtained from grain size analysis were used to determine the textural classes by plotting the sand, silt and clay percentages in a triangular diagram (Soil Survey Manual, 1966). The results of the grain size analyses are given in Appendix II.

Grain size distribution in the successive horizons of soil profiles of the various soil-geomorphic units of the study area shows a wide range of textural classes from sandy loam to silty clay. Except the coarse textured soils from the proximal part of the Tista Fan and the Lalmai Hills, all soil profiles from the different soil-geomorphic units comprise medium to fine textured soils. Apart from the Barind Tract, Madhupur Tract and Lower Atrai Depression units (Fig.2.1), there is an overall development of silt loam soils on the upper ridge areas and silty clay loam soils on the low-lying backswamp areas in all other units. The Barind Tract and the Madhupur Tract and the Lower Atrai Depression consist of silty clay loam to silty clay soils. In most of the soil profiles the silt-sized particles constitute the major portion of the grain size distribution ranging dominantly from 50-80%, whereas the sand-sized particles comprise less than 10%. With a few exceptions, the study area as a whole is characterized by fluvial sedimentation of low energy and is dominated by the deposition of the silt-sized particles.

From the data of the grain size analysis (Appendix II), it is evident that the clay content increases from the A to the most developed B2 horizon. This increase in clay content is attributed to the translocation of the clays from the upper to the lower horizons as well as the in-situ weathering mainly of the silt sized particles. In some cases, the weathering of the sand-sized particles has produced both the silt-and clay-sized particles. All these phenomena were confirmed by the subsequent micromorphological studies (Chapter 4).

Increase in clay content in the B horizon is a useful indicator of relative ages of soils (Birkeland, 1984). Plots of total clay contents and pedogenic clay contents with depth for various pedons from the different soil-geomorphic units (Fig. 3.1) in most cases suggests an increase of pedogenic clay contents in the B horizon over the C horizon. In general, the relative increase in clay contents in the B horizon with

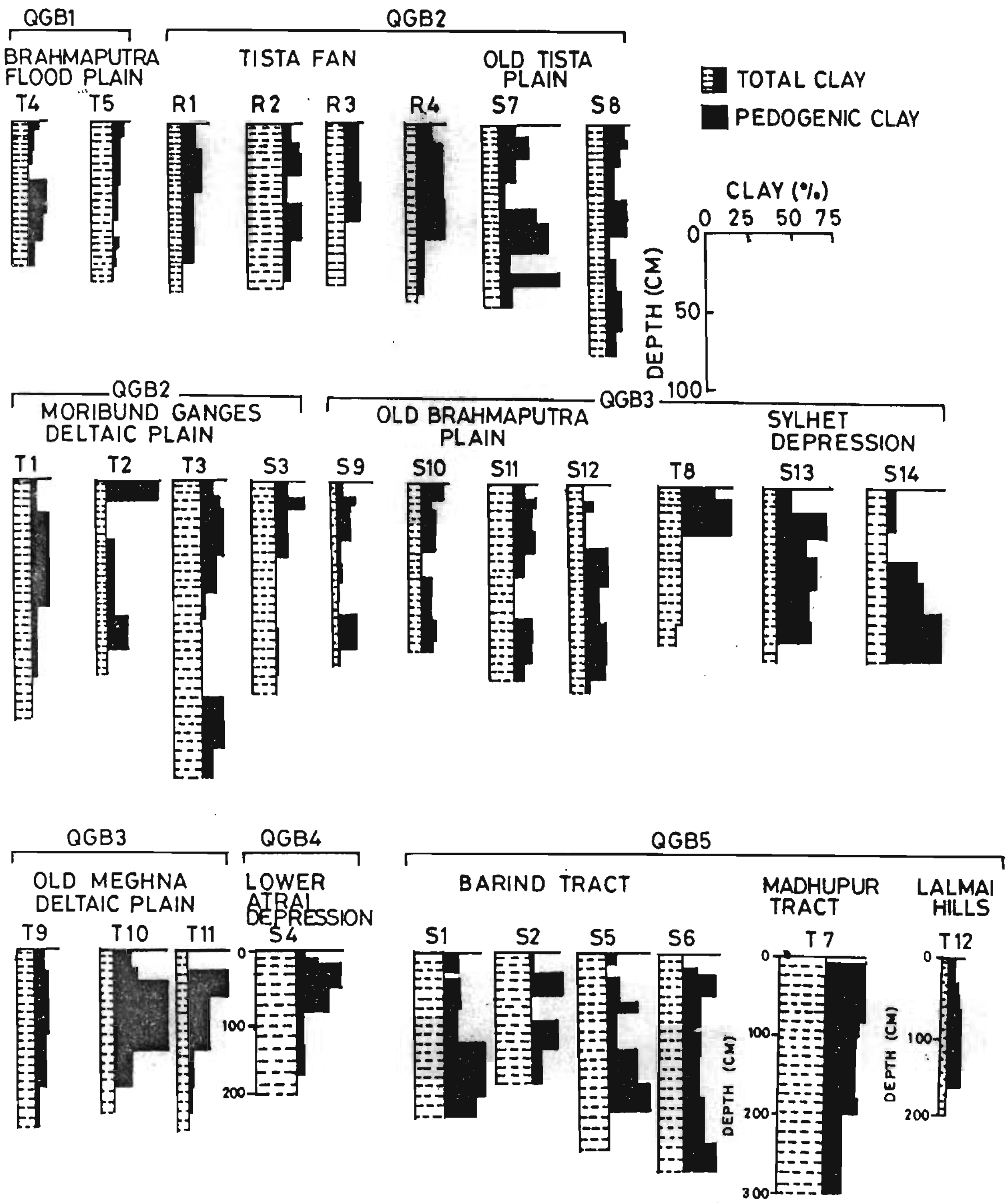


FIG.3.1. VARIATION OF TOTAL CLAY AND PEDOGENIC CLAY IN THE SOIL PROFILES OF THE VARIOUS SOIL-GEOMORPHIC UNITS. QGB1-QGB5 DENOTE SOIL CHRONOASSOCIATION MEMBERS. VERTICAL SCALE IS DIFFERENT FOR S4, T7 AND T12 PROFILES.

respect to A horizon is higher from Group I to V soils ranked in chapter 2.

The relative degree of soil development in the various soil-geomorphic units has been evaluated by calculation of clay accumulation index suggested by Levine and Ciolkosz (1983) and listed in Table 3.1. Ahmad et al. (1977) has suggested that the ratio of (sand+silt)/clay may help in determining the relative degree of pedogenesis. This ratio has been calculated and presented in Appendix II.

A systematic variations in clay accumulation index and (sand+silt) /clay ratio has been observed from group I to V soils. With increasing order from group I to V, the clay accumulation indices are 152-179, 140-713, 393-1946, 1935 and 1385-4354 respectively and percent decrease in (sand+silt)/clay ratios are 13, 24-37, 34-55, 41 and 52-61 respectively (Table 3.3). These variations confirm increase of degree of pedogenesis from group I to V soils.

Table 3.1 :Clay accumulation indices for the soils of the different soil-geomorphic units

Soil-Geomorphic units	Pedons	Clay accumulation index	Clay accumulation index for buried horizons
(1)	(2)	(3)	(4)
Brahmaputra Floodplain (BFP)	T4	152	-
	T5	179	430
Tista Fan (TF)	R1	235	-
	R2	140	400
	R3	458	-
	R4	418	300

Soil-Geomorphic units	Pedons	Clay accumulation index	Clay accumulation index for buried horizons
(1)	(2)	(3)	(4)
Old Tista Plain(OTP)	S7	578	1018 and 424
	S8	44	336 and 138
Moribund Ganges Deltaic Plain(MGDP)	T1	273	-
	T2	526	-
	T3	713	582
	S3	375	-
Old Brahmaputra Plain (OBP)	S11	758	
	S12	821	
	S9	435	
	S10	588	
Sylhet Depression(SD)	S13	1946	-
	S14	55	1786
Old Meghna Deltaic Plain (OMDP)	T9	392	
	T10	1266	
	T11	705	
Lower Atrai Depression (LAD)	S4	1935	
Barind Tract (BT)	S1	1528	
	S2	700	
	S5	1702	
	S6	1955	
Madhupur Tract (MT)	T7	4354	
Lalmai Hills (LH)	T12	1385	

3.3 CHEMICAL ANALYSIS

3.3.1 Introduction

Chemical weathering occurs because rocks and minerals are seldom in equilibrium with near-surface waters, temperatures and pressures. The products that form, however, are more stable in near-surface environments. Minerals go into solution and thereby release ions which either form new compounds at the site of release or more downwards. In a leaching environment, silica is quite soluble over the normal pH range and it is almost always present in the parent minerals in higher amounts than are necessary to form most clay minerals; therefore, some is removed in solution. Aluminium is not very soluble over the normal soil pH range and so it generally remains near the site of release by weathering to form clay minerals or hydrous oxides. Iron also remains near the point of release in most soils and gives the soil or weathered rock the commonly observed oxidation colors (Birkeland, 1984).

For inferring the degree of weathering all the chemical data have been presented as oxides, because the main balancing anion usually is oxygen. Values for individual oxides vary as a function of many soil - forming processes and therefore, the oxide values given as percentages show relative increase or decrease. In a leaching environment, SiO_2 commonly decreases and both Al_2O_3 and Fe_2O_3 increase with higher pedogenesis. Mg and K are associated as interlayer cations for clay minerals. Mn forms bluish black mottles. Ca, K and Na are the major exchangeable cations and are depleted in the humid and hot environments. Ca enriches in the dry environments through accumulation of $CaCO_3$ nodules or indurated carbonates. For an understanding of the extent of weathering that has taken place in the different soil-geomorphic units of the study area, total chemical analysis for major elements of 116 representative soil samples have been carried out.

3.3.2 Methodology

All the soil samples were air-dried and ground till the soils passed through 100 mesh size sieve (150 μm). The total major elemental analysis was carried out by the "two solution method" as suggested by Shapiro (1975). Solution 'A' was used to determine SiO_2, Al_2O_3 and TiO_2 and solution 'B' was used for determination of Fe_2O_3, MgO, CaO, Na_2O, K_2O and MnO.

Solution 'A'

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'

A 200 mg 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% 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. After adding 10 ml of 50% HCl the solution was again heated for 20 minutes and finally diluted to 200 ml.

After preparing both the 'A' and 'B' 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 at the University Scientific Instrumentation Centre, University of Roorkee.

K_2O and Na_2O were analysed on a Flame photometer at the Deptt. of Earth Sciences, University of Roorkee. Results of the analyses are given in Appendix III. Molar ratio of $SiO_2/(Al_2O_3+Fe_2O_3+TiO_2)$ were calculated from the chemical data and were listed in Appendix III.

3.3.3 Variation of the molar ratios in the soil profiles of the different Soil-Geomorphic units

In all the 10 units, a definite trend from the Ap to B horizon is observed. Generally, Fe_2O_3% and Al_2O_3% increase from the Ap to B horizon with a corresponding decrease of SiO_2%. Many of the soil-geomorphic units remain under flood water for 5 to 6 months and thereby undergo ferrolysis. As a result, the general process of pedogenesis under leaching environment becomes complicated. Despite this, a change in the contents of Fe_2O_3%, Al_2O_3% and SiO_2% is observed from the Ap to B horizon. Molar ratios (percent oxide divided by molecular weight) provide the best data for comparison of degree of weathering pedogenesis in soils/rocks in a leaching environment (Birkeland, 1984). In the study area the molar ratio SiO_2/R_2O_3 (where, $R_2O_3 = Al_2O_3 + Fe_2O_3 + TiO_2$) shows significant decrease from the A to B horizon (Appendix III and Fig.3.2). To study the varying degree of pedogenesis in the various soil-geomorphic units the decrease in molar ratio in the B horizon with respect to A horizon has been calculated and expressed in percent. The values of percent decrease of molar ratio in the B horizon with respect to the Ap/C horizons increase systematically (Table 3.3) in most of the soil-geomorphic units included in Group I to V soils ranked in chapter 2.

3.3.4 Total Free Iron (amorphous and cryptocrystalline)

The breakdown of Fe-bearing minerals by chemical weathering leads to accumulation of free iron in the form of amorphous hydrous oxides, cryptocrystalline oxides and organic-bound iron and with time the rate of accumulation of free iron increases in the B horizon under leaching environment. Keeping this point in view, Arduino et al. (1984, 1986) used the ratio of Dithionite - Citrate - Bicarbonate extractable iron (Fe_d) to total iron (Fe_t) for the soils of different river terraces in Italy and found that the ratio did reflect the relative ages of the terraces. This method has been employed in the present study to examine the amount of chemical weathering that has taken place in the soils. To determine the free iron contents from the soils the method suggested by Mehra and Jackson (1960) was employed and following Shapiro (1975) the total iron content was determined as described in the section 3.3.2. From the obtained results the $\frac{Fe_d \times 100}{Fe_t}$ (where, Fe_d = dithionite extractable iron and Fe_t = total iron) ratio has been calculated and expressed as percent increase from the Ap to the B horizon (Table 3.2). It is observed that the Group V soils with colour hue from 10 YR to 2.5 YR contain greater amount of free iron suggesting a higher degree of weathering than other soils. The soils of Groups II and III contain lesser amount of free iron and indicate a relatively lower degree of weathering.

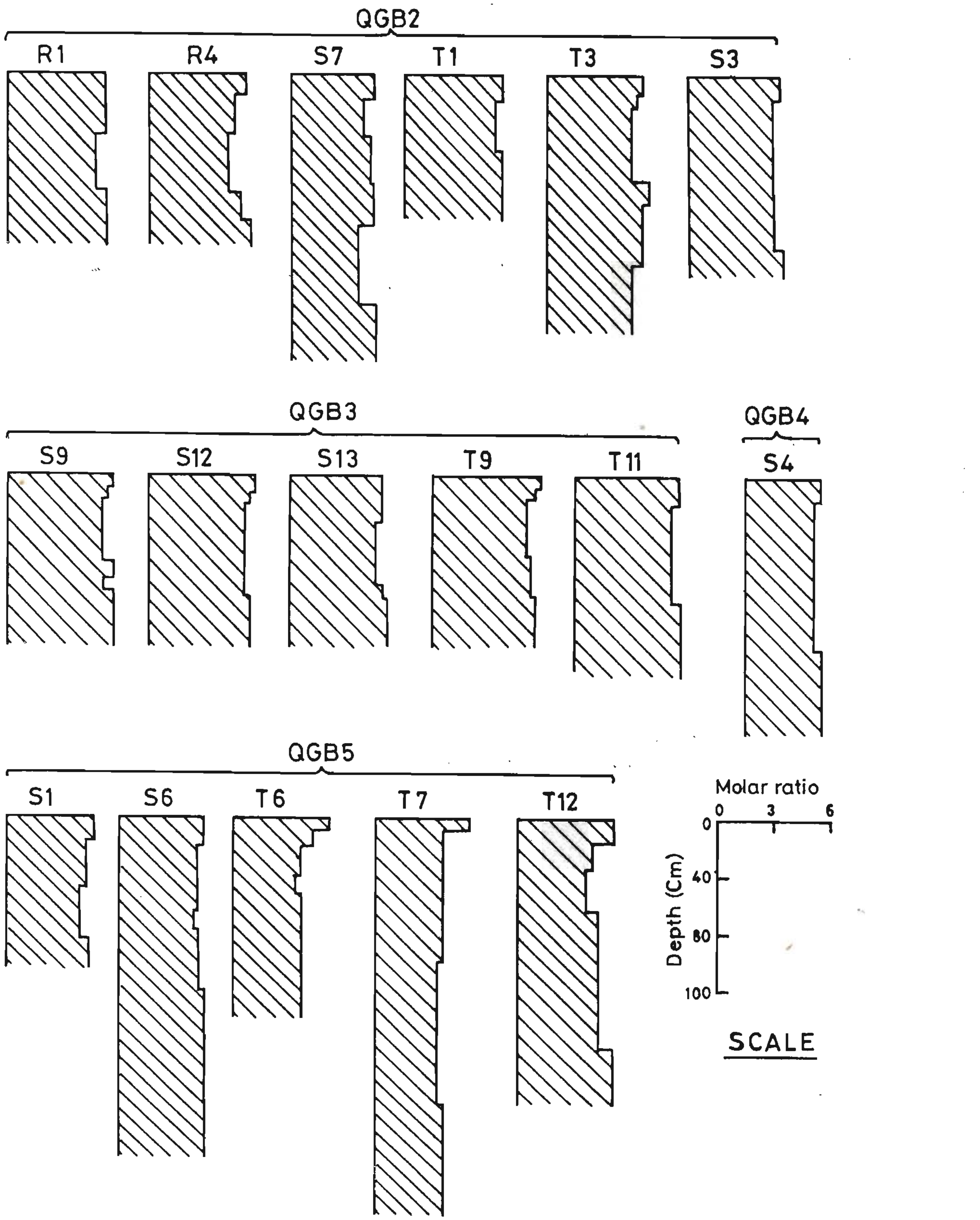


FIG. 3·2. VARIATION OF THE MOLAR RATIO SiO_2/R_2O_3 WITH DEPTH IN THE SOIL PROFILES AND IN THE QGB2 TO QGB5 MEMBERS OF THE SOIL CHRONOASSOCIATION. R, S AND T DENOTE SOIL PROFILES.

Table 3.2 : Variation in $\frac{Fe_d}{Fe_t}$ x 100 value in the soils of the different soil-geomorphic units

Soil-geomorphic units	Horizon	Depth (cm)	Fe_d (%)	Fe_t (%)	$\frac{Fe_d \times 100}{Fe_t}$	$\frac{Fe_d}{Fe_t} \times 100$ Ap/A horizon	B horizon	% increase in the B horizon over the Ap/A horizon
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Tista Fan	Ap1	0-9	0.53	5.1	10.39			
	B21	9-15	0.68	5.9	11.52			
	B23	38-61	0.91	6.5	14.00	10.39	12.76	18.57
	C	88-110	0.31	4.9	6.32			
Moribund Ganges Deltaic Plain	Ap	0-12	0.69	6.1	11.31			
	B2	36-83	0.99	7.54	13.12	11.31	13.12	13.79
	C	103-138	0.75	6.21	12.07			
Old Brahmaputra Plain	Ap2	10-16	0.79	5.91	13.36			
	B22	42-58	0.99	6.46	15.32	13.36	16.21	17.58
	B23	58-85	1.08	6.31	17.11			
	C	98-105	0.80	5.63	14.20			
Old Meghna Deltaic Plain	Ap2	13-20	0.90	6.23	14.44			
	B21	20-64	1.15	7.51	15.31	14.44	17.32	16.62
	B22	64-88	1.45	7.50	19.33			
	C2	104-127	1.12	6.54	17.12			
Barind Tract	Ap2	8-13	0.90	5.6	16.07			
	B21	13-26	1.12	6.2	18.06	16.07	20.18	20.36
	B22	26-64	1.45	6.5	22.30			
	C2	119-140	1.01	5.2	19.42			
Madhupur Tract	A	0-8	1.2	6.44	18.63			
	B22t	81-102	2.28	8.41	27.11	18.63	31.28	40.46
	B23t	102-180	2.27	8.18	27.75			
	B25t	200-300	3.23	8.28	39.00			
Lalmai Hills	A	0-15	1.05	6.5	16.15			
	B22t	32-48	1.82	7.68	23.69	16.15	23.33	30.77
	B23t	48-65	1.71	7.02	24.35			
	B25t	165-200	1.53	6.97	21.95			

3.4 CLAY MINERALOGY

3.4.1 Introduction

The various physical processes and chemical reactions lead to the breakdown of the minerals and formation of a number of secondary minerals and/or clay minerals in the soils. The nature of weathering products depends upon the nature of the reactants and pH of the weathering environment. Some of the soluble cations liberated by weathering may get exchanged with those of the primary minerals or the secondary minerals and are retained. Some of them may be removed from the site of reaction by leaching, but the rest may recombine under specific conditions to form various types of clay minerals and hydrous oxides of iron and aluminium.

Clay mineral formation and transformation in the soil are slow processes and depend upon weathering environment, which in turn is controlled mainly by climate and drainage conditions. Depending upon the environmental conditions, some of the primary minerals present in the soil e.g., microcline, orthoclase, plagioclase, muscovite, biotite, augite, hornblende and quartz may transform themselves into clay minerals like illite, vermiculite, montmorillonite and kaolinite either in-situ or away from the site of weathering.

The clay mineralogy of the soils of the study area may be a function of all or some of the factors listed above. It is difficult to work out the contribution of the individual factor. Under the present circumstances, an attempt has been made to identify the dominant factor/s affecting the clay mineralogy of the study area. The studies of clay mineralogy deal with the semi-quantitative analysis, vertical variation of the clay minerals within the soil profiles and variation of clay minerals within and between the various soil-geomorphic units. An attempt has also been made to work out the factors which control the distribution of clay minerals in the study area.

3.4.2 Procedure for sample preparation

In the present context, x-ray diffraction method has been used for clay mineralogical studies. The method of preparation of oriented clay slides is described below.

About 15 to 20 gms of soil samples was air-dried and passed through 230 mesh sieve (60 μm). The finer fractions (<60 μm) were first mixed with little distilled water taken in a series of graduated 1 litre glass cylinders. These mixtures were kept undisturbed for one day for soaking the sample. Then more distilled water was added to the mixtures, stirred thoroughly and kept undisturbed for 24 hours. This allowed the samples to settle down leaving almost clear water above them. The clear water containing excess salts was removed by decantation and fresh distilled water was added to the samples. This procedure was repeated till dispersion occurred. Finally, the dispersed samples after thorough stirring were kept undisturbed for a period determined according to Stoke's Law for allowing the particles larger than 2 microns to settle down. Then the upper 5 cm of the dispersed samples from each cylinder containing the clay-sized fractions was siphoned out. This procedure was repeated till we got sufficient amount of clay required for the preparation of the clay slides.

The separated clay slurries were divided into three parts for different treatments. The first part was kept untreated and the second and the third parts were saturated with Mg^{+2} and K^{+} using 1N solution of $MgCl_2$ and KCl respectively (Klages and Hopper, 1982).

After complete saturation for 12 hours, excess salt solutions were removed by three distilled water centrifuge washings to obtain a thin paste of clays. The paste was spread with a pippette on the microscope glass slides placed on a horizontal platform. For preparation of the oriented samples care was taken to have a uniform thickness of clay on the glass slides. Then, the clay slides were dried at room temperature. The pipette method is easy and quick. It also provides a fairly good and reproducible orientation (Wilson, 1987).

The Mg^{+2} saturated clay slides were glycolated by putting the slides on a perforated porcelain plate placed inside the desiccator over Ethylene Glycol and treating them for 24 hours at $60^{\circ}C$. Two K^{+} saturated slides were heated to $350^{\circ}C$ (K-$350^{\circ}C$ slide) and $550^{\circ}C$ (K-$550^{\circ}C$ slide) respectively. Heated slides were kept in an air tight desiccator with silica gel to prevent rehydration of some of the minerals before exposing them to the x-rays.

X-ray diffractograms were obtained using a Philips PW 1140/90 x-ray machine at the University Scientific Instrumentation Centre, University of Roorkee. Diffractograms were obtained under the following conditions.

Target : Cuk α, Filter : Ni

Current : 20 mA, Goniometer speed : 1° of 2θ angle/min.

Range : 2 KC/S, Scanned angle : 3^{o} to 30^{o} of 2θ angle

Wavelength: 1.5418 A^{o},   Chart speed : 1 cm/min.

3.4.3 Identification of different types of clay minerals

In the present studies, basal reflections of the oriented clay samples in the X-ray diffractograms have been used for identification of various mineral species. The scheme followed for this purpose is essentially similar to that of Wilson (1987). The following sections provide a general description of soil environments of clay minerals followed by their identification of x-ray diffractograms.

(a) Kaolinite

Kaolinite minerals are characterized by intense first and second order basal reflections at 7.14 A^{o} (001) and 3.57 A^{o} (002) and by prominent groups of non-basal reflections. The presence of kaolinite is confirmed by heating the same to $550^{o}C$ for one hour, which destroys the crystallinity of all kaolinites, thus causing the disappearance of basal reflections. The difftraction patterns of disordered Kaolinite typically show a rather broad reflection at 7.2 - 7.4 A^{o}, often with distinct asymmetry towards low angle side (Wilson, 1987).

(b) Chlorite

The chlorite group of mineral is identified by a series of basal reflections approximately at 14 A^{o}, 7 A^{o}, 4.7 A^{o} and 3.5 A^{o}, which persist on heating the specimen at $550^{o}C$ or treatment with ethylene glycol. Such simple observations have been found to be sufficient for the identification of chlorite even in many complex clay mixtures.

(c) Vermiculite

The strong reflection at 14 A^{o} is the characteristic of the vermiculite minerals. Majority of vermiculites treated with Mg^{+2} yield a basal reflection at 14.3 A^{o} under the action of glycol and this is used as the primary criterion for its differentiation from montmorillonites. The 14.3 A^{o} basal reflection of vermiculite collapses to 10 A^{o} after heating to 350^{o}C and this distinguishes it from chlorite minerals, which are not affected by heating to this temperature (Wilson, 1987).

(d) Illite

Illites are recognized by strong basal reflections at 10 A^{o} and 3.3 A^{o}. In the soil the 10 A^{o} peak of illites is often asymmetrical with a tail extending towards the low angle. Such illites are termed 'degrading' illites (Brown, 1954). Saturation with K^{+} partly removes the asymmetry and produces a relatively strong 10 A^{o} peak in such minerals. Only 1 M type illite has been identified, which shows a rather broad 10 A^{o} refection, often asymmetrical towards low angle side, and has prominent higher order reflections at 5 A^{o}, 3.3 A^{o} and 1.99 A^{o}. The 002 reflection intensity is usually about one third of the intensity of the 10 A^{o} reflection and indicates aluminous dioctahedral nature of the mineral.

(e) Montmorillonite

Montmorillonites were identified by x-ray diffraction patterns characterized by broad and diffuse non-basal reflections or bands that arose from random layer stacking. These bands were typically asymmetrical towards the higher angles. Ethylene glycol-treated montmorillonites yielded generally a basal spacing of ~17 A° with a rational series of higher order reflections. On heating, the peaks of montmorillonite at 17 A° got destroyed. This observation was sufficient for identification of montmorillonites.

(f) Mixed Layer Minerals

The layer silicate minerals illite, vermiculite, montmorillonite, chlorite and kaolinite often occur in a mixed order of stacking because of their structural similarities and are commonly referred as mixed layer or interstratified minerals. The mixed layer structure may show a regular repetition of the different layers or an irregular interstratification of layers. From diffraction patterns of soil samples it is observed that most of the mixed layer minerals in the studied soils are irregularly interstratified as identified by the procedure of Sawhney (1977) discussed below.

(i) **Illite-vermiculite interstratification:** These interstratified minerals are identified from a basal diffraction peak intermediate between 10 A° and 14A° from Mg-saturated samples. On K-saturation and heating at 350°C the layers of vermiculite collapse to 10A° diffraction peak.

(ii) **Illite-smectite interstratification** : Diffraction patterns of these minerals are similar to those of the illite-vermiculite except that on Mg-saturation the intermediate peak increases in spacings.

(iii) **Illite-chlorite interstratification**: They are identified by basal spacings between 10A° and 14A° which do not change either on

Mg-saturation or k-saturation and heating at 350°C.

(iv) **Chlorite-vermiculite interstratification**: It is identified by a 14A° basal diffraction peak from a Mg-saturated sample and a peak intermediate between 10A° and 14A° from K-saturated samples.

(v) **Chlorite-smectite interstratification**: They are characterized by a 15.5 A° basal diffraction peak for Mg-saturated samples which decreases to 11.5A° on heating the samples.

(vi) **Illite-kaolinite interstratification**: They are identified by a diffraction peak intermediate between 7A° and 10A° from Mg-saturated samples.

(g) Semi-quantitative estimation of clay minerals of the study area

The relative sizes of the x-ray diffraction peaks from the basal planes of clay minerals in the 7 to 17 A° range provide a basis for calculating the relative amounts of different clay minerals and mixed layer mineral species. However, factors such as crystallinity, impurities of clay minerals, evenness and thickness of the sample mount and irridation set-up of x-ray machine affect such a relationship. Thus, the method of determining the contents of different clay minerals is semi-quantitative in nature. Care has been taken to minimize the above errors in the present study.

Two methods of estimation of contents of clay minerals i.e. measurement of peak height and peak areas are commonly used (Brindley, 1961; Biscaye, 1965). However, in the present study the method of Schultz (1964) to calculate peak area has been used by taking the sum of five height measurements at half degree intervals across the peak. This technique provides a good compromise between the two methods and it takes peak shape into consideration. It is also less time-consuming as compared to direct measurement of peak area technique.

Quantitative estimation of various groups of clay minerals has been made by using the factors worked out by previous workers (Johns et al., 1954; Schultz, 1964; Galan, E., 1975; Wall and Wilding, 1976). The kaolinite peak area is divided by a factor 1.4 and chlorite peak area by 1.5 for quantitative comparison with 10 A^{o} illite. Vermiculite content is calculated from the difference between the 14 A^{o} peak area of Mg^{+2} saturated and glycolated slides and K^{+} saturated and heated to $350^{o}C$ slides, chlorite from the 14 A^{o} peak area of K^{+} saturated and heated to $350^{o}C$ slides and the rest of the minerals from the Mg^{+2} saturated and glycolated slides as suggested by Wall and Wilding (1976).

3.4.4 Clay Mineralogical Variation in the Different Soil-Geomorphic Units

The major clay minerals identified from the x-ray diffractograms of soils of the study area are illite, kaolinite, vermiculite, chlorite and montmorillonite. Some of the representative diffractograms are shown in Fig. 3.3.1(a,b,c). Clay mineral data of the study area suggest that illite and kaolinite are the dominant minerals followed by minor amounts of chlorite, vermiculite and montmorillonite (Appendix IV). For an appraisal of the genesis and the distribution of the various clay minerals and their relationship with the landscape evolution of the study area, soil samples for x-ray diffraction analysis were selected from the different typical soil - geomorphic units. The clay mineralogical variation with depth in the different units (Fig.3.4) has briefly been described below.

(i) **Tista Fan** - The dominant clay minerals in this unit are illite (49 - 69%) and chlorite (13-31%) followed by kaolinite (7-11%). The illite-chlorite mixed layer minerals range from 7 to 27%. There is a little variation in kaolinite percent with depth from the Ap to the B horizon. The mixed layer mineral amount is 27% (maximum) in the Ap horizon and it decreases with depth. Illite shows an antipathic relationship to the mixed layer minerals.

(ii) **Old Tista Plain**- Investigations on the clay mineralogy of this unit from a composite profile with two sets of buried horizons reveal the dominance of illite (40-64%) and kaolinite (8-30%) followed by chlorite (5-12%). A good proportion (6-38%) of mixed layer minerals (illite-chlorite, illite- vermiculite and illite-kaolinite) are also present. The variation of the clay mineralogy with depth in the surficial and buried soils is discussed below.

(a) The kaolinite percent in the near - surface soils decreases with depth from the Ap to C horizon (viz. 30-8%), whereas the chlorite percent follows the reverse trend (viz. 7-12%). The illite amount decreases from 57% (in the Ap horizon) to 40-41% (in the B and C horizons) accompanied by an increase in mixed layer mineral percent.

(b) In the upper set of buried horizons both kaolinite and chlorite amounts decrease from the buried B to the C horizon viz. from 18% to 10%

and from 8% to 5% respectively, whereas both illite and mixed layer mineral percents increase viz. from 48% to 53% and from 25% to 32% respectively.

(c) The lower buried horizons contain almost the same amount of kaolinite and chlorite in the B and C horizons viz. ~ 19% and ~5% respectively. From the B to C horizon the illite percent increases from 49% to 64%, whereas mixed layer mineral percent decreases from 27% to 12%.

(iii) Moribund Ganges Deltaic Plain- To investigate the clay mineralogical variations in this unit a composite profile with one set of buried horizons has been studied. The soils of this unit are characterized by the dominance of illite (43-66%) and kaolinite (7-20%) in association with chlorite (3-8%) and montmorillonite (5-8%). Mixed layer minerals (illite-chlorite and chlorite-montmorillonite) vary from 4 to 37%. Chlorite percent is slightly higher in the near surface Ap and B1 horizons as compared to the subsurface horizons. To some extent kaolinite percent increases in the B/Bb* horizon. Montmorillonite occurs in both the near surface and the buried soils but it is absent either in the Ap or in the C horizons.

In the near surface soils illite percent decreases in the B22 horizon with corresponding increase in mixed layer mineral percent. Likewise, in the buried Bb1* horizon a decrease in illite percent corresponds to an increase in mixed layer mineral percent.

Bb* = Buried B horizon

(iv) Old Brahmaputra Plain - The soils of this unit comprise dominantly illite (32 - 49%) and kaolinite (21 - 38%). Chlorite is next in abundance (4 - 9%). There are no appreciable variations in kaolinite and chlorite percents with depth except substantial increase in the Ap1 horizon. Generally, illite percent decreases with a corresponding increase in mixed layer minerals (e.g. illite - chlorite and illite - kaolinite).

(v) Old Meghna Deltaic Plain - Clay mineral analysis of this unit by x-ray diffraction shows the dominance of illite (29 - 47%) and kaolinite (25-48%) followed by chlorite (6 - 12%), vermiculite (6-8%) and montmorillonite (4-5%). Mixed layer mineral contents (e.g.illite-chlorite, chlorite-vermiculite and chlorite-montmorillonite) range from 3 to 30%. Both kaolinite and illite percents decrease with depth from the Ap/B to C horizon.

(vi) Barind Tract - In this unit illite (41-61%) and kaolinite (12-21%) are found to be dominant minerals in association with vermiculite (3-16%) and montmorillonite (7-10%). A significant amount (10 - 34%) of mixed layer minerals (e.g. illite- vermiculite, illite-montmorillonite and illite-kaolinite) are also present. Except decrease in Ap1 horizon there is a little variation in kaolinite percent with depth from the Ap2 to C4 horizon. With increasing depth a decrease in illite percent corresponds to an increase in mixed layer mineral percent. Montmorillonite occurs only in the lower horizons. The proportion of vermiculite increases significantly in the C horizons.

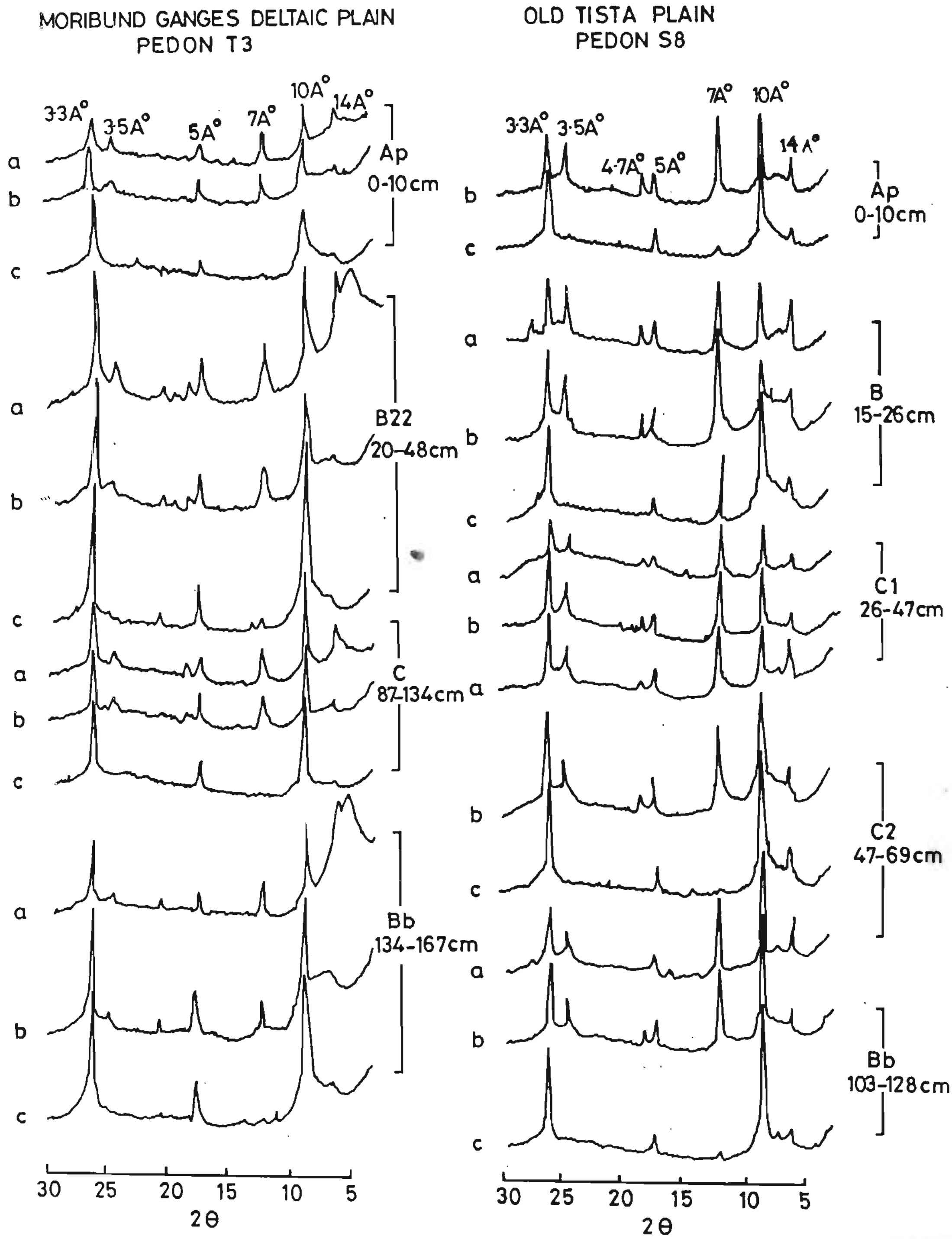


FIG. 3·3·1a X-RAY DIFFRACTOGRAMS OF CLAY FRACTIONS FROM THE SELECTED SOIL PROFILES OF THE DIFFERENT SOIL-GEOMORPHIC UNITS. a - Mg SATURATED AND GLYCOLATED SLIDE, b - K SATURATED AND HEATED TO 350°C SLIDE AND c - K SATURATED AND HEATED TO 550°C SLIDE.

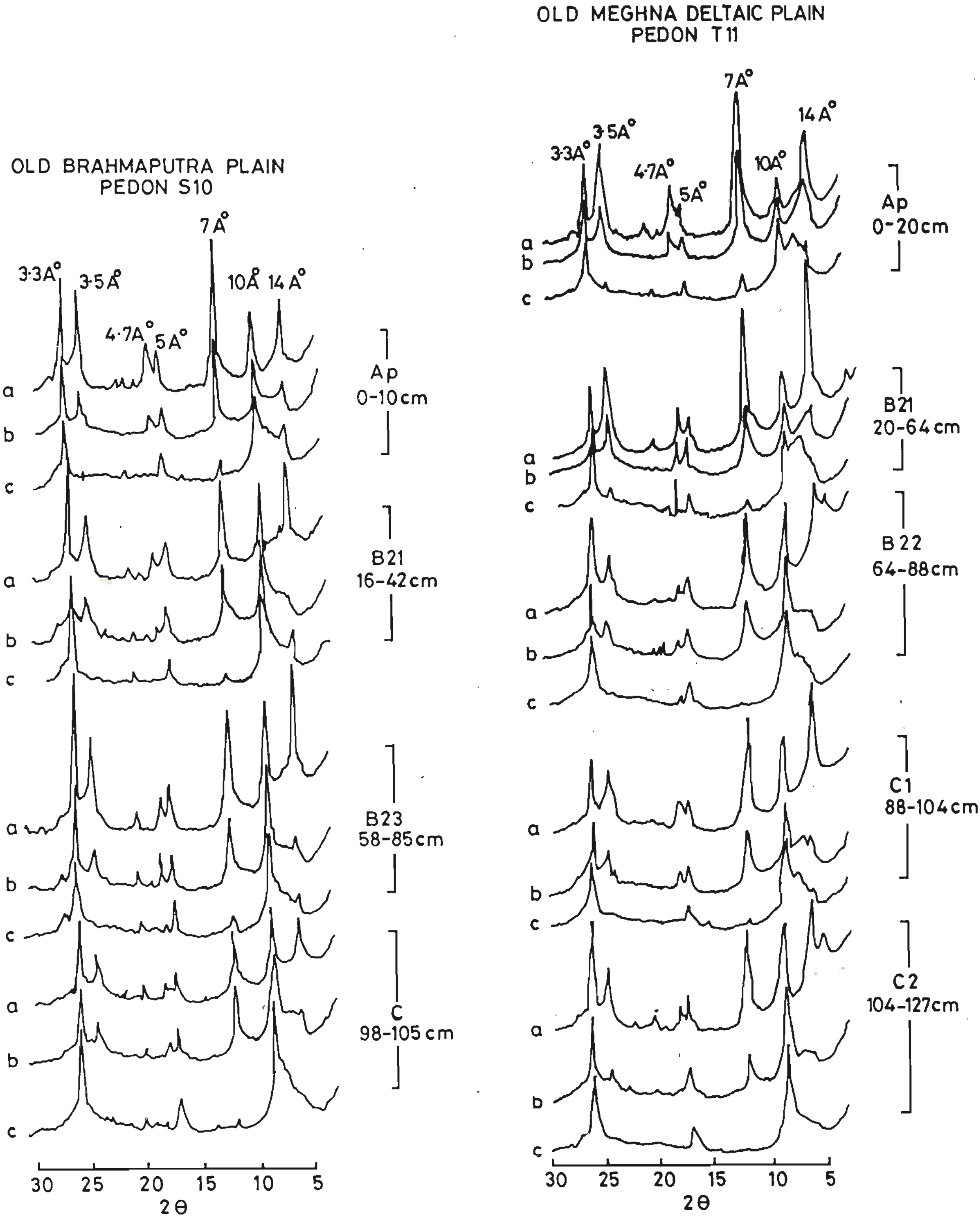


FIG.3·3·1b X-RAY DIFFRACTOGRAMS OF CLAY FRACTIONS FROM THE SELECTED SOIL PROFILES OF THE DIFFERENT SOIL-GEOMORPHIC UNITS. a-Mg SATURATED AND GLYCOLATED SLIDE, b-K SATURATED AND HEATED TO 350°C SLIDE AND HEATED TO 550 °C SLIDE.

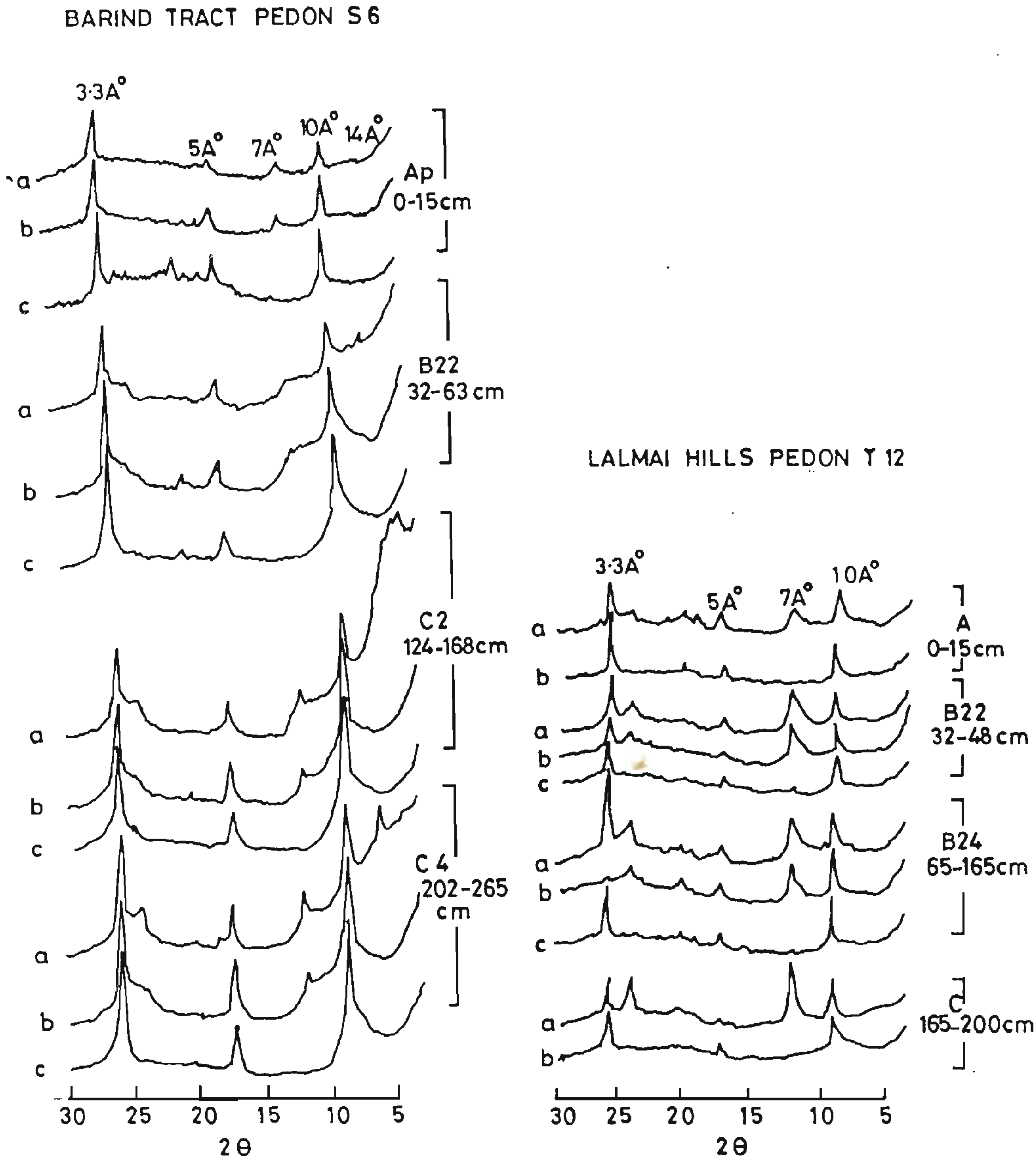


FIG. 3·3·1C X-RAY DIFFRACTOGRAMS OF CLAY FRACTIONS FROM THE SELECTED SOIL PROFILES OF THE DIFFERENT SOIL-GEOMORPHIC UNITS. a-Mg SATURATED AND GLYCOLATED SLIDE. b-K SATURATED AND HEATED TO 350°C SLIDE AND c - K SATURATED AND HEATED TO 550° SLIDE.

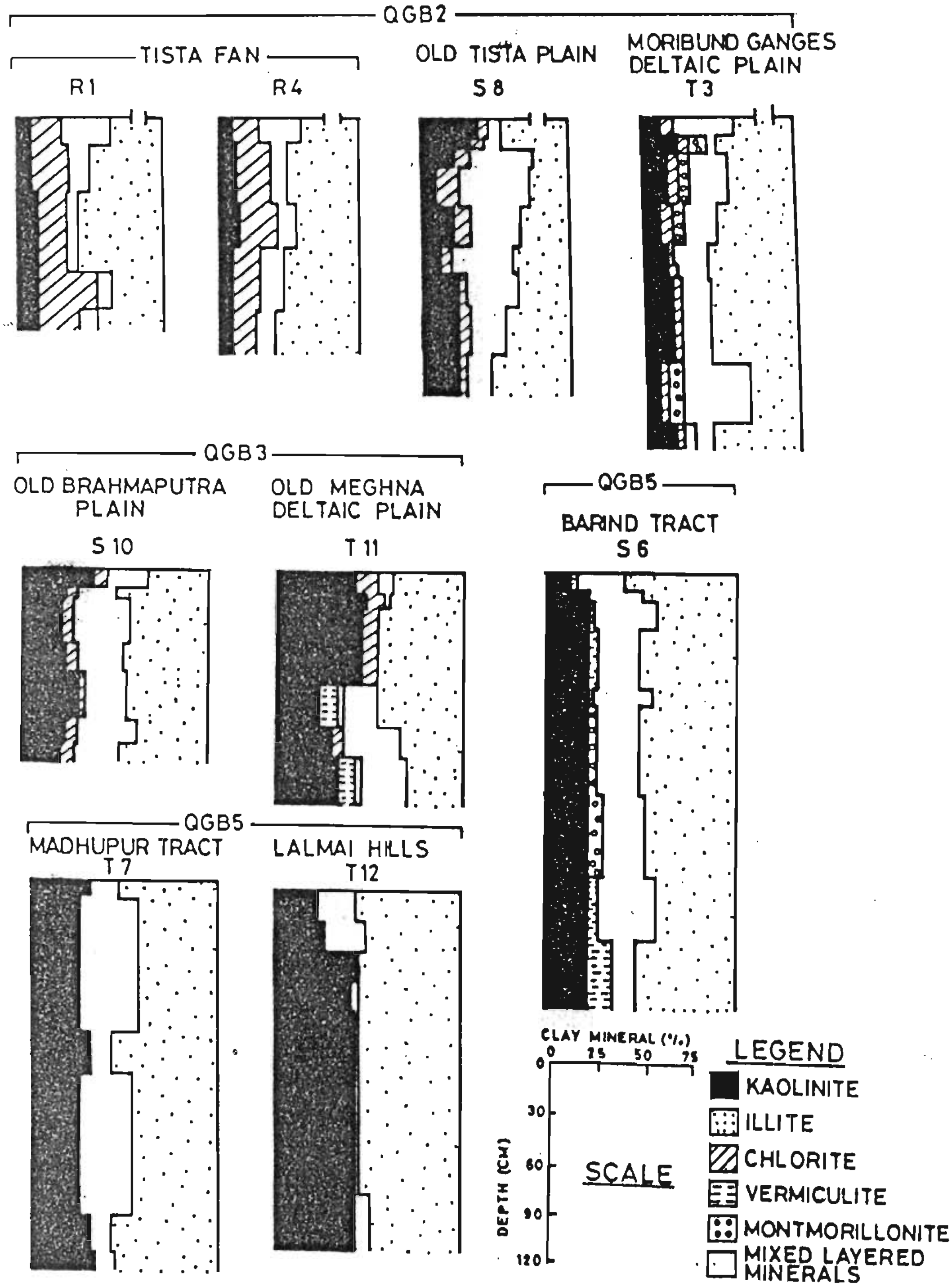


FIG.3·4. VARIATION OF CLAY MINERALS WITH DEPTH IN THE SOIL PROFILES OF THE VARIOUS SOIL-GEOMORPHIC UNITS. R,S AND T DENOTE SOIL PROFILES. QGB2, QGB3 AND QGB5 ARE THE MEMBERS OF THE SOIL CHRONOASSOCIATION.

(vii) **Madhupur Tract** - X-ray diffraction analysis shows that clay fractions from this unit (Tejgaon series) constitute only three minerals viz. illite (42 - 58%) and kaolinite (25 - 34%) in association with mixed layer minerals (10 - 32%). Throughout the profile a decrease in illite amount corresponds to increase in the amount of mixed layered minerals (mainly illite-kaolinite).

(viii) **Lalmai Hills** - In this unit only three minerals viz. illite (48 -57%) and kaolinite (34-46%) in association with illite-kaolinite mixed layer minerals (2-13%) were identified by x-ray diffraction analysis. The studied soil profile from this unit as a whole is characterized by a lesser amount of mixed layer minerals.

Table 3.3 : Variation in physical, chemical and clay mineralogical properties of the soils from Group I to V

Group	Clay accumulation Index	Percent decrease sand+silty/clay ratio in the B hor. over the Ap/C hor.	Percent decrease in molar ratio of $SiO_2/R_2O_3^*$ in the B hor. over the Ap/C hor.	Percent increase of $(Fe_d/Fe_t)\times100$ in the B hor. over the Ap/C hor.	Abundance of clay minerals	
					Dominant	Minor
I	152-179	13	-	-	-	-
II	140-713	24-37	7-11	14-18	I,K,C	V,M
III	392-1946	34-55	6-15	17-18	I,K	V,M
IV	1935	41	7	-	-	-
V	1385-4354	52-61	23-30	31-41	I,K	V,M

$R_2O_3^* = Fe_2O_3+Al_2O_3+TiO_2$, I - Illite, K - Kaolinite,

C = Chlorite, V - Vermiculite and M - Montmorillonite

3.5 RESUME

The analytical studies of the soils of the study area show a systematic variation in textural, chemical and clay mineralogical properties from the least developed soils of group I to the most developed soils of group V (Section 2.6, Chapter 2). With increasing degree of weathering (From group I to V), the values of clay accumulation index, percent decrease in (sand + silt)/clay, percent increase in $\frac{Fe_d x100}{Fe_t}$ and percent decrease in SiO_2/R_2O_3 from the Ap/C horizons to the B horizons gradually become higher and the maximum discrimination between the B and Ap/C horizons occurs in the soils of group V (Table 3.3). The systematic variation in the textural and chemical properties of soils reflect an increasing degree of soil development from Group I to V soils.

The distribution of clay minerals vary with different degree of pedogenesis as observed from Group II to V soils (section 2.6, Ch.2). The variation of clay minerals with depth for the various soil-profiles from the different soil-geomorphic units is shown in Fig.3.4. The amount of chlorite decreases systematically from Group II to V soils. The soils of the Tista Fan at the Himalayan foothills contain 15 to 31% chlorite (Group II soils) which decreases to 3 to 12% in the Group III soils and becomes completely absent in the upland soils (Group V soils). Therefore, chlorite is found to be sensitive to increasing degree of pedogenesis except some neoformation of 'soil-chlorite' in the Ap horizon by a process called ferrolysis (Brinkman, 1970). Investigation of a soil profile from the Old Meghna Deltaic Plain (Appendix IV) shows the absence of chlorite only in the B3 and C2 horizons where it transforms to vermiculite and then to montmorillonite. Kaolinite amount in the Tista Fan and Moribund Ganges Deltaic Plain soils varies from 8-22%. The Old Tista Plain, Old Brahmaputra Plain and Old Meghna Deltaic Plain soils (Group II and III soils) show an increase in kaolinite percent (30 to 48%) in the Ap horizons than in the B horizons (18 to 25%). A significant increase in kaolinite amount is found throughout the profile of the Madhupur Tract and Lalmai Hill soils (Group V soils) reaching a maximum value of 46%. The neoformation of kaolinite is attributed to alteration of feldspars as well as illite through a mixed layer mineral stage/ desilication. A composite profile from a backswamp of the Moribund Ganges Deltaic Plain contains 5 to 9% montmorillonite in the B horizons. The C horizon contains no montmorillonite. This suggests that montmorillonite might have formed by synthesis under a poorly drained condition. A soil profile from the Barind Tract (Group V soils) contains no chlorite. But vermiculite is present throught the profile except the B32 and B33 horizons (Appendix IV) where it has transformed to montmorillonite. The presence of chlorite in the Barind soils has been reported by Ghosh and Datta (1974). This suggests that chlorite/biotite might have transformed to vermiculite and then to montmorillonite in the studied profile of the Barind Tract (Group V soils).

Despite variability in parent materials due to their depositional conditions and pre-weathering in the source area, the changes in textural, chemical and clay mineralogical properties are mainly attributed to soil forming processes. An overall dominance of the silt-sized particles suggests that the parent sediments deposited under a low energy condition.

CHAPTER 4

MICROMORPHOLOGY AND MICROPROBE ANALYSIS OF SOILS

CHAPTER 4

MICROMORPHOLOGY AND MICROPROBE ANALYSIS OF SOILS

4.1 INTRODUCTION

Micromorphology is concerned with the studies of the arrangements of primary particles, voids, various pedofeatures, microstructures and groundmass in the soil thin sections. It is used as a powerful tool in the understanding of the processes involved in the development of soil profile, and also in refining macromorphological observations. Microprobe analysis of some features also provides insights into the pedogenic processes.

This chapter deals with the procedures involved in the preparation of thin sections of undisturbed soil samples and their descriptions under a polarizing microscope. A total of 150 thin sections were studied and out of them 40 typical sections from different soil-geomorphic units have been described in detail. Microprobe analysis of some weathered biotite, Fe-Mn concretions, hypocoatings and argillans are also included in this chapter. The objective of the present study is to understand the relationship of the various microscopic and submicroscopic features with the varying degree of soil development in the study area.

4.2 PROCEDURE

During the field study of pedons in the various soil- geomorphic units, undisturbed (in-situ) soil samples from the horizons of the pedons were collected in metal boxes of size 5x6x8 cm. The collected samples were air-dried for 15-20 days at a temperature of 25°C to remove

The samples were then impregnated by the method suggested by Jongerius and Heintzberger (1963) and Miedema et al. (1974). Crystic resin with catalyst was poured into the soil samples and they were kept in a vacuum chamber for a day. The samples were cured for 20 - 30 days at room temperature which facilitated the curing of the samples into hard blocks. These impregnated blocks were used for preparation of thin sections. Description of the thin sections (Appendix V) has been given mainly according to the system described by Bullock et al. (1985) under the main headings such as microstructure, basic mineral components, groundmass and pedofeatures. In some cases, the terms according to Brewer (1964) were also used for the description of thin sections.

Soil thin sections have been studied in two stages. In the first stage, microstructures have been studied in comparatively thick sections (about 50 - 60 μm) for investigating the development of pedality, voids and their abundance, sizes, shapes and arrangement. In the second stage, the thin sections have been ground to 25 - 30 μm and studied for other features like basic mineral components, groundmass, pedofeatures etc. under a Carl Zeiss Polarizing Microscope.

4.3 MICROPHOLOGICAL CHARACTERS OF SOILS

Following Brewer (1964), Brewer and Sleeman (1960, 1969), and Bullock et al., (1985) the micromorphological investigations of soils were carried out emphasing mainly on the features described below. These features bear the imprints of pedogenic processes and are suggestive of the varying degree of soil development in the study area. (a) **Grade of pedality**: The grade of pedality was described by terms such as apedal, weakly, moderately and strongly developed based on the degree of separation of the peds by voids. (b) **Argillans/quasiargillans**: These features occur as coatings on voids, peds and grains in the study area. Their abundance and thicknesses were noted. (c) **Plasma separation/ b-fabrics**: The degree of b-fabric development (e.g. unistrial, cross-, parallel-, and poro-striated) was described by terms such as weakly, moderately, strongly and very strongly developed. (d) **Sesquioxidic nodules**: The various forms and degree of development of these features were described as diffused mottles, weakly, moderately and strongly impregnated nodules. (e) **Ferriargillans**: These features were found to be associated with hydromorphic soils in the study area. Their thicknesses and degree of development were noted. (f) **Hypocoatings**: They were found to occur as coatings on voids. They consist of impure clay associated with iron hydroxides. (g) **Calcretes**: Their forms, crystallinity and relationship with voids were noticed. (h) **c/f ratio and c/f related distribution**: Approximate values of the c/f ratio were determined and the c/f related distribution was expressed as monic, gefuric, chitonic, enaulic and porphyric (open, single-and double-spaced). (i) **Alteration of biotite**: The degree of alteration of biotite was noticed and expressed as weakly, moderately and strongly altered and (j) **Voids**: Type of voids and roughness of their walls were noticed.

Detailed micromorphological descriptions of the various soil-geomorphic units are given below. These are based mostly on the terminology suggested by Bullock et al. (1985). In a few cases, terminology used by Brewer (1964) was also followed. Typical micromorphological characters of soils from the various soil-geomorphic units are presented briefly in Table 4.1.

4.3.1 Micromorphological characters of the Brahmaputra Floodplain Soils

From this floodplain 2 soil thin sections from B2 and buried B horizons (Table 4.1 and Appendix V) of a composite profile have been described. Micromorphological investigations show that the surficial soils are apedal and are characterized by single and bridged grain microstructures. Simple packing voids are observed. The c/f ratio is 70/40. The c/f related distribution varies from monic to gefuric. The micromass shows weakly developed stipple-speckled b-fabrics. Degree of alteration of biotite is moderate. Diffused mottles of iron hydroxides are also noticed.

The buried soils, on the other hand, show strong development of subangular blocky peds and contain elliptical and planar voids. The c/f ratio is 30/70 and the c/f related distribution is open porphyric. The micromass show moderate development of unistrial, cross and parallel striated b-fabrics. Alteration of biotite is moderate to strong. Diffused mottles of iron hydroxides are also seen. The micromorphological features suggest that surficial soils are weakly developed, whereas the buried soils are moderately developed. Lamination of silt and fine sand is still visible in the C horizon of the surficial soils (Fig. 4.1.a,b).

4.3.2 Micromorphological characters of the Tista Fan Soils

From this alluvial Fan 4 soil thin sections (Table 4.1 and Appendix V) have been described from three pedons. These sections show that the soils are characterized by weakly developed subangular blocky peds. Mainly compact, single and bridged grain microstuctures are observed. The observed voids are elliptical, planar and circular. The c/f ratio varies from 90/10 to 70/30 and the c/f related distribution from monic to gefuric. Weak to moderate degree of alteration of biotite is observed. The micromass shows moderate to strong development of

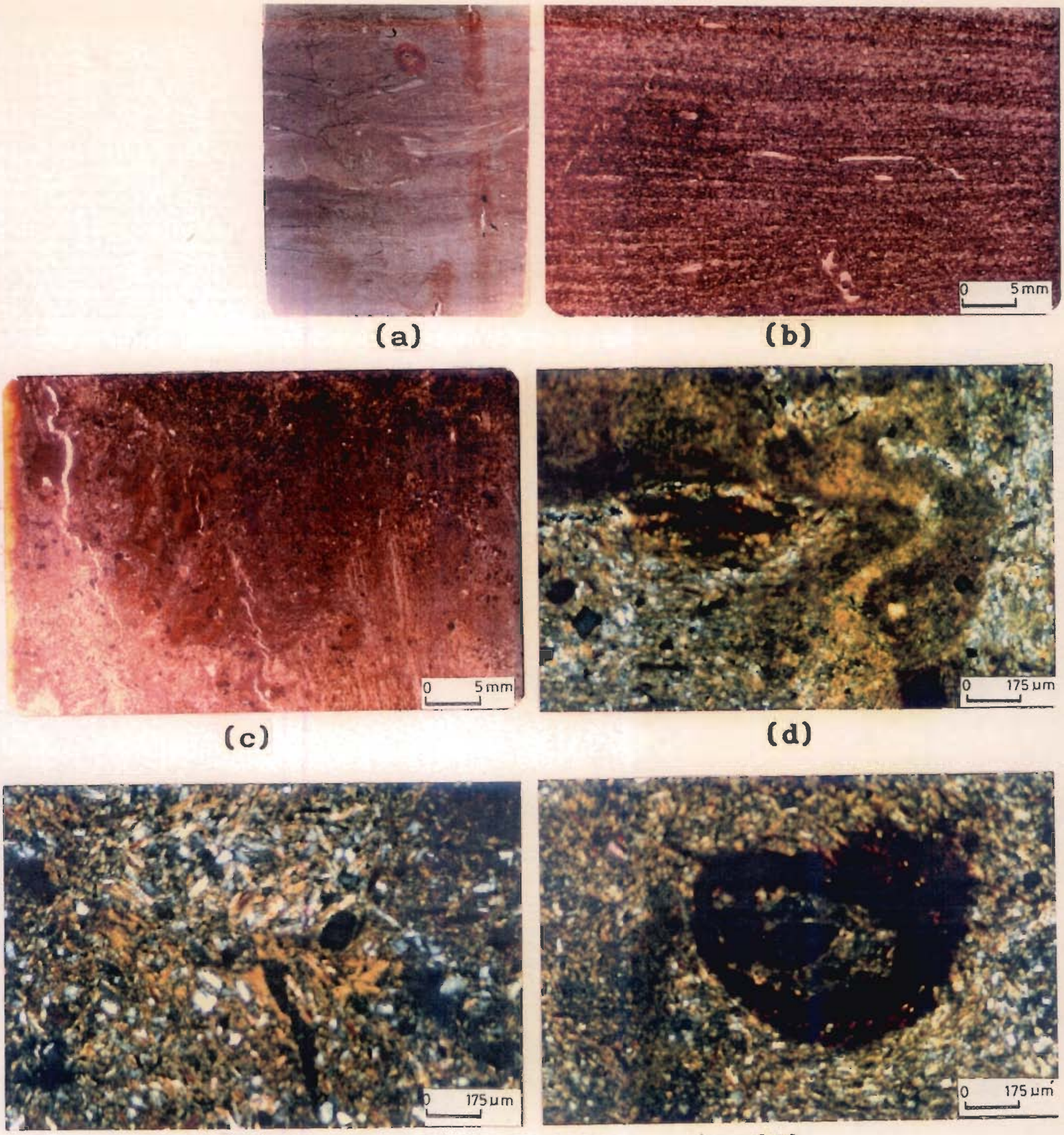


Fig.4.1. Photomicrographs showing **(a)** Laminae of silt and fine sand and ferruginous mottles, C hor., Pedon T4, Brahmaputra Flood plain (without magnification), Ord. Light; **(b)** As in (a) with integrain channel structure, Ord. Light; **(c)** Micropans and fissure structure, B23 hor., Pedon R3, Tista Fan, Ord. light; **(d)** Movement/orientation of finer material, B23 hor., Pedon R3, Tista Fan, XPL; **(e)** Argillans/hypocoatings (50-60 µm) of limpid clay along a planar void and papules/embedded clay aggregates, B22 hor., Pedon R2, Tista Fan, XPL and **(f)** Ferriargillan/Hypocoating (100-150 µm), infilling of ferruginous material, B23 hor., Pedon R2, Tista Fan, XPL.

mosaic-speckled, unistrial, parallel-, and cross-striated b-fabrics. A few hypocoatings (50 - 300 μm) of impure clay are noticed. Argillans (50-60μm) are rare. The other observed features are the diffused mottles and segregations of iron hydroxides, ferriargillans, papules and stress cutans (see Brewer, 1964). Some of the micromorphological characters of these soils such as micropans, fissure structure, orientation of finer material, argillans and ferriargillans are shown in Fig.4.1(c,d,e,f).

4.3.3 Micromorphological Characters of the Old Tista Plain Soils

From this soil-geomorphic unit 3 soil thin sections from a composite profile (Table 4.1 and Appendix V) have been described. These sections belong to Ap (0 - 10 cm), B2 (15 - 32 cm) and buried B2 (105-142 cm) horizons. Micromorphological studies of the sections show a systematic change in the degree of soil- development with increasing depth from the surficial to buried horizons. The soils are characterized by weakly to moderately developed subangular blocky peds. Bridged and pellicular grain microstuctures are observed. The voids are elliptical and planar. The c/f ratio ranges from 60/40 to 5/95 and the c/f related distribution from monic to open porphyric implying a significant change in distribution patterns of primary particles (e.g. sand, silt and clay). With increasing depth biotite mineral undergoes moderate to very strong degree of alteration. The amount and grain size of quartz decrease significantly with depth. The micromass shows moderate to strong development of unistrial, parallel, cross and porostriated b-fabrics. A few hypocoatings (15 - 20 μm) of impure clay and ferriargillans (20 - 50 μm) are noticed. The other observed features are diffused mottles, segregations and impregnative nodules of iron hydroxides. The effects of swelling and shrinkage are observed by features such as stress cutans and skew planes (see Brewer, 1964). Some of the diagnostic characters of these soils such as accumulation of clayey and ferruginous material, crescentic shaped papule, cross-striated b-fabric, hypocoating of dusty clay, compound ferruginous nodule and goethite mineral are shown in Fig. 4.2.

4.3.4 Micromorphological characters of the Moribund Ganges Deltaic Plain Soils

From this deltaic plain 6 thin sections (Table 4.1 and Appendix V) have been described. The sections T3/1, T3/3 and T3/7 belong to Ap, B22 and buried B2 horizons of a composite profile. The sections T1/3, T2/3 and S3/4 represent B2 horizons of three different pedons. Micromorphological investigations show that the soils are characterized by moderately to strongly developed subangular blocky peds. Mainly bridged and pellicular grain microstructures and planar, elliptical and subrounded voids are observed. The c/f ratio varies from 50/50 to 3/97 and the c/f related distribution from gefuric to open porphyric. This variation, particularly in case of composite profile indicates a significant change in distribution patterns of primary particles from the surficial to buried horizons. Here, both the percentage and size of quartz grains decrease significantly and the groundmass consist almost entirely of very fine-grained micaceous particles. The micromass generally shows moderate to strong development of unistrial, parallel and cross striated b-fabrics. Moderate to strong degree of alteration of biotite mineral is observed. A few argillans (40-90 μm) and many hypocoatings (50 - 200 μm) of impure clay are noticed. The other observed features include diffused mottles, segregations and weakly developed impregnative nodules of iron hydroxides. A few moderately developed micritic calcite nodules are also seen and they are classified

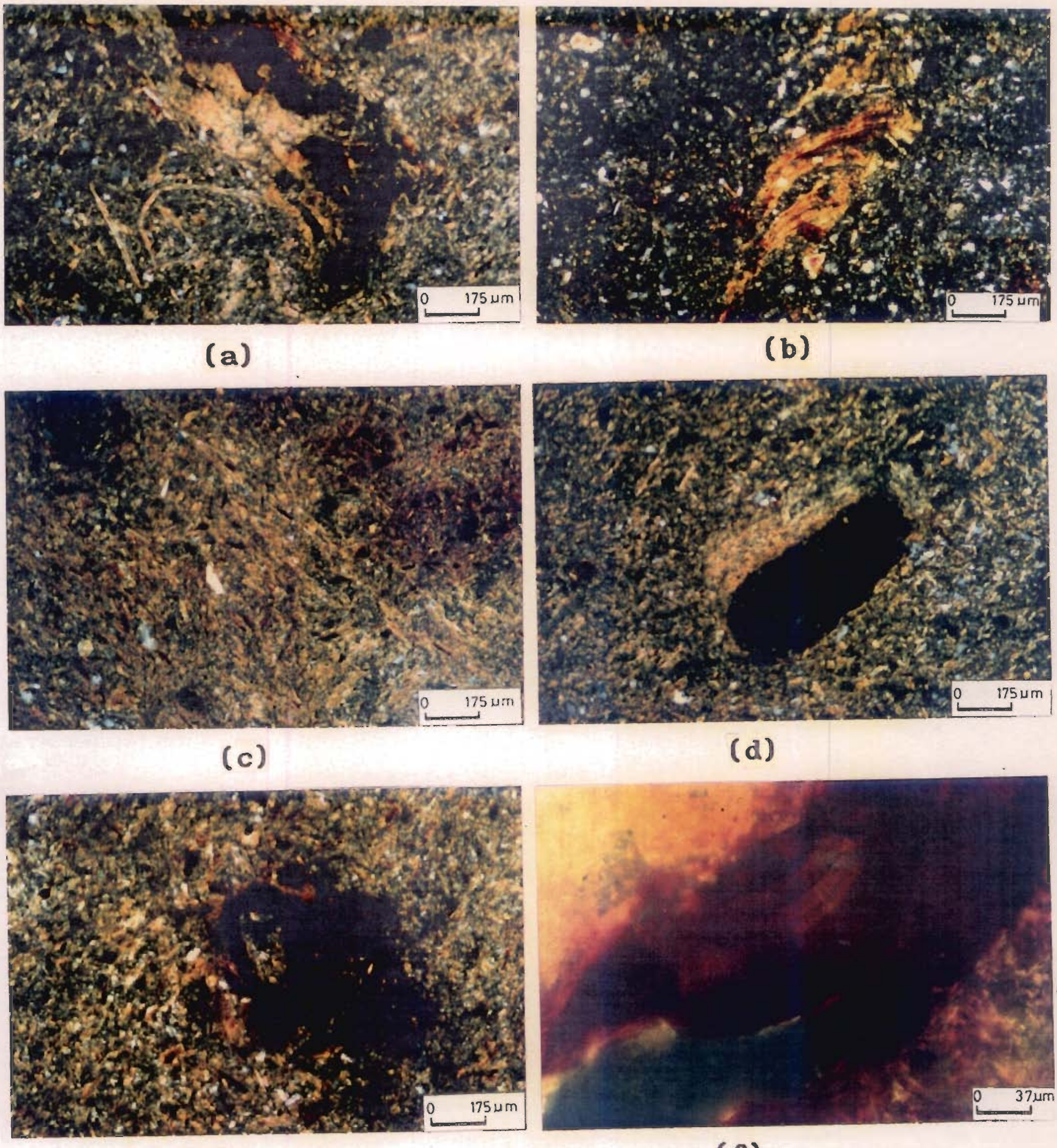


Fig.4.2. Photomicrographs of soil thin sections from the Old Tista Plain showing **(a)** Accumulation of clayey and ferruginous material along a disturbed planar void, Ap1 hor., Pedon S7, XPL; **(b)** Crescentic shaped papule (1 mm in length) with microlaminations, Ap2 hor., Pedon S7, XPL; **(c)** Moderately developed cross striated b-fabric, B2 hor., Pedon S7, XPL; **(d)** Hypocoating (130-160 µm) of dusty clay along a void and weakly developed parallel striated b-fabric, Ap1 hor., Pedon S7, XPL; **(e)** Compound ferruginous nodule, C hor., Pedon S7, XPL and **(f)** Infilling of a void by goethite, B hor., Pedon S7, XPL.

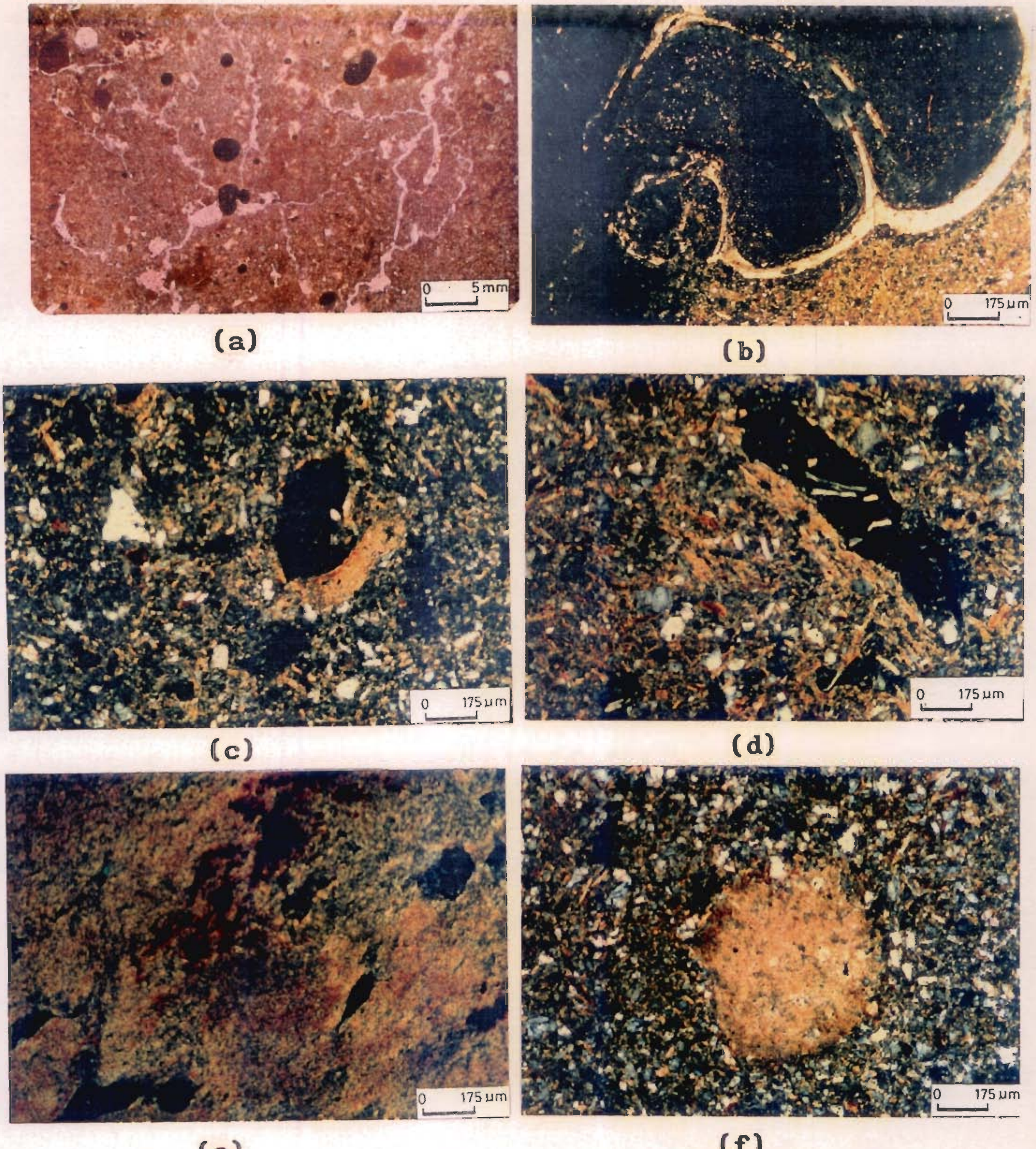


Fig.4.3. Photomicrographs of soil thin sections from the Moribund Ganges Deltaic Plain showing **(a)** Moderately developed subangular blocky peds and many well developed ferruginous nodules, B21 hor., Pedon S3, Ord. light; **(b)** A part of a gastropod shell, Ap hor., Pedon T3, XPL; **(c)** Argillan/ hypocoating (80-90 µm) of limpid clay, B2 hor., Pedon T1, XPL; **(d)** Moderately developed porostriated b-fabric and gefuric/enaulic related distribution, B3 hor., Pedon S3, XPL; **(e)**strongly developed unistrial b-fabric, segregations of ferruginous material and monic related distribution consisting of clayey and fine silty material, Bb hor., Pedon T3, XPL; **(f)** Moderately developed calcite nodule, calcrete of stage I, B2 hor., Pedon T2, XPL.

as stage I calcretes (see Birkeland, 1984). Some of the diagnostic characters of these soils such as subangular blocky peds, argillan, porostriated b-fabric, unistrial b-fabric and calcite nodule are shown in Fig.4.3.

4.3.5 Micromorphological characters of the Old Brahmaputra Plain Soils

From this plain 6 thin sections (Table 4.1 and Appendix V) have been studied in detail. Three sections (S9/4, S9/5 and S9/8) belong to a composite profile. The other three sections have been selected from two different pedons. The soils are generally characterized by weakly to moderately developed subangular blocky peds. Compact, bridged, chitonic and pellicular grain microstructures are observed. Simple packing, elliptical and planar voids are noticed. The c/f ratio ranges from 80/20 to 10/90. The c/f related distribution varies from monic to open porphyric implying significant changes in the distribution patterns of primary particles that occur mainly in the buried B horizon of the composite profile. Alteration of biotite is moderate to strong. Significant decrease both in amount and grain size of quartz takes place with increasing degree of pedogenesis. The micro-mass generally shows weakly to moderately developed unistrial, parallel and cross striated b-fabrics. A few to many hypocoatings of impure clay are observed. Thick argillans (100-150 μm) are rare. The other observed features are many impregnated and aggregate nodules of iron hydroxides. A few ferriargillans (50-70μm) are also seen. Some of the diagnostic characters of these soils such as vughy structure, Mn-nodule, argillan, elongated papule, hypocoating of clay and silt and reticulate b-fabric are shown in Fig.4.4.

4.3.6 Micromorphological characters of the Sylhet Depression Soils

From this depression 4 thin sections from two different pedons have been described (Table 4.1 and Appendix V). The soils are characterized by moderately to strongly developed angular and subangular blocky peds. The soils are massive. Elliptical, planar, subrounded and irregularly shaped voids are seen. The c/f ratio ranges from 65/35 to 10/90 and the c/f related distribution varies from single-spaced porphyric to open porphyric. The micromass shows moderate to strong and sometimes, very strong development of unistrial, parallel and cross striated b-fabrics. The degree of alteration of biotite is moderate to strong. Many hypocoatings of impure clay and a few ferriargillans are observed. The other observed features are segregations, aggregate and impregnative nodules of iron hydroxides. All micromorphological characters suggest that these soils are strongly developed but no argillans are observed and this may be attributed to strong hydromorphism of the soils (see Duchaufour, 1977). Some of the micromorphological features of these soils such as vughy structure, strongly developed subangular blocky peds, hypocoatings of clay, aggregates of impure clay, porphyric related distribution, ferriargillan/hypocoating quasi-coating are presented in Fig. 4.5.

4.3.7 Micromorphological characters of Old Meghna Deltaic Plain Soils

From this deltaic plain 4 thin sections from 2 pedons have been described (Table 4.1 and Appendix V). Micromorphological investigations show that the soils are characterized by weakly to moderately developed subangular blocky peds. Single, bridged and pellicular grain microstructures are observed. Simple packing, elliptical and subrounded voids are noticed. The c/f ratio ranges from 90/10 to 40/60 and the c/f related distribution from monic to single-spaced porphyric. The micromass shows weak to moderate development of mosaic-speckled

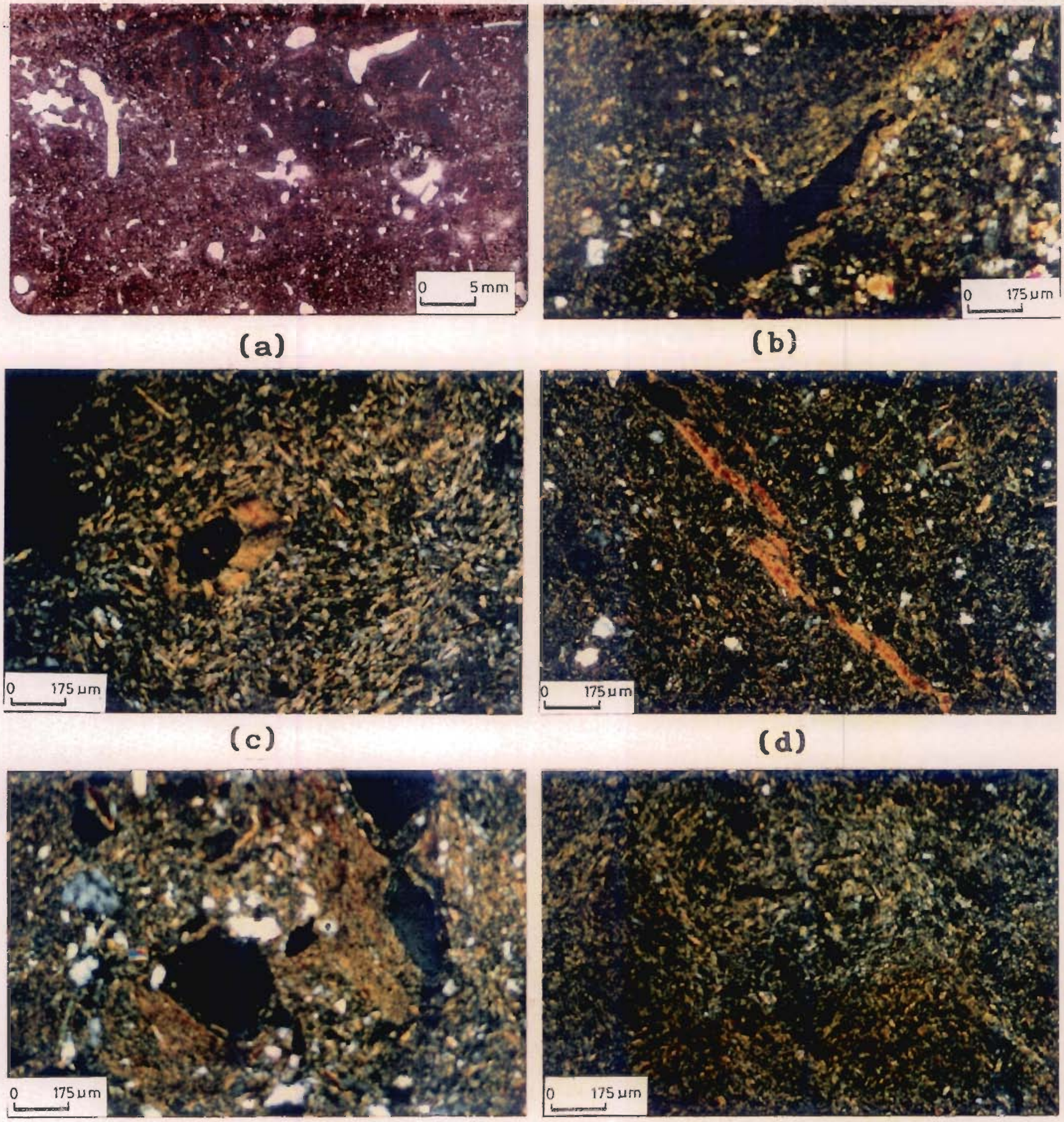


Fig.4.4. Photomicrographs of soil thin sections from the Old Brahmaputra Plain showing **(a)** Vughy structure and **segregations** of ferruginous and clayey material, B3 hor., Pedon S12, Ord. light; **(b)**Mn-nodule (black) and aggregates of clay embedded in the groundmass, B22 hor., Pedon S9, XPL; **(c)** Argillan/ hypocoating (100-150 μm) of limpid clay and modertely developed cross striated b-fabric, B22 hor., Pedon S9, XPL; **(d)** Elongated discontinuous (disrupted) papule, Ap2 hor., Pedon S11, XPL; **(e)** Hypocoatings of clay and silt, B23 hor., Pedon S12, XPL; **(f)** Reticulate b-fabric, the groundmass consists mainly of finer material, C hor., Pedon S11, XPL.

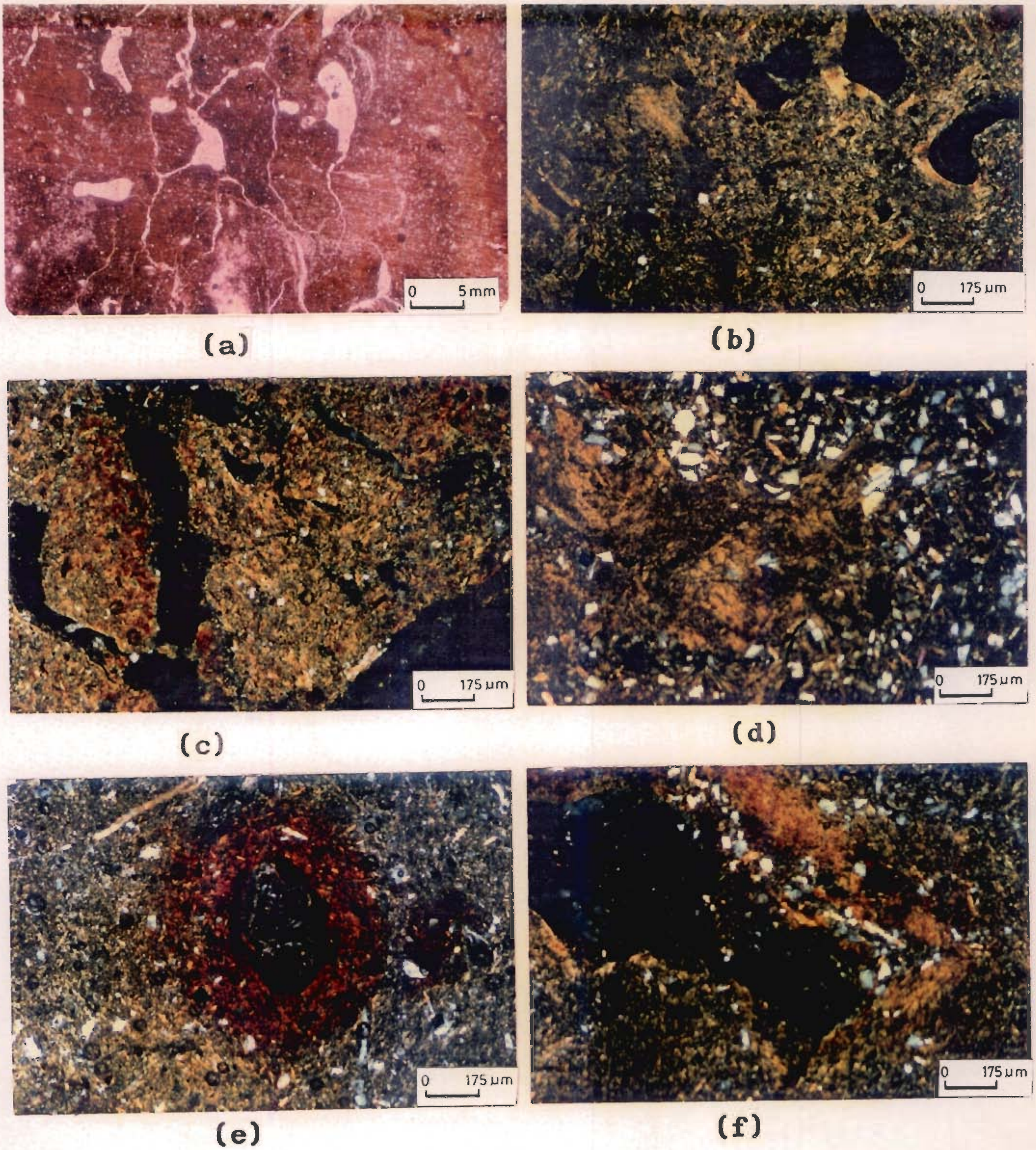


Fig.4.5. Photomicrographs of soil thin sections from the Sylhet Depression showing **(a)** Vughy structure and moderately developed subangular blocky peds, B24 hor., Pedon S14, Ord. light; **(b)** Hypocoatings (50-70 µm) and aggregates of clay embedded in the groundmass, B22 hor., Pedon S13, XPL; **(c)** Strongly developed subangular blocky peds and porphyric related distribution, Ap hor., Pedon S14, XPL; **(d)** Aggregates of impure clay and porphyric related distribution, B24 hor., Pedon S14, XPL; **(e)**Hypocoating of ferruginous material/ ferriargillans (60-80 µm) along a void, C hor., Pedon S14, XPL and **(f)** Quasi-coating along a void, C hor., Pedon S14, XPL.

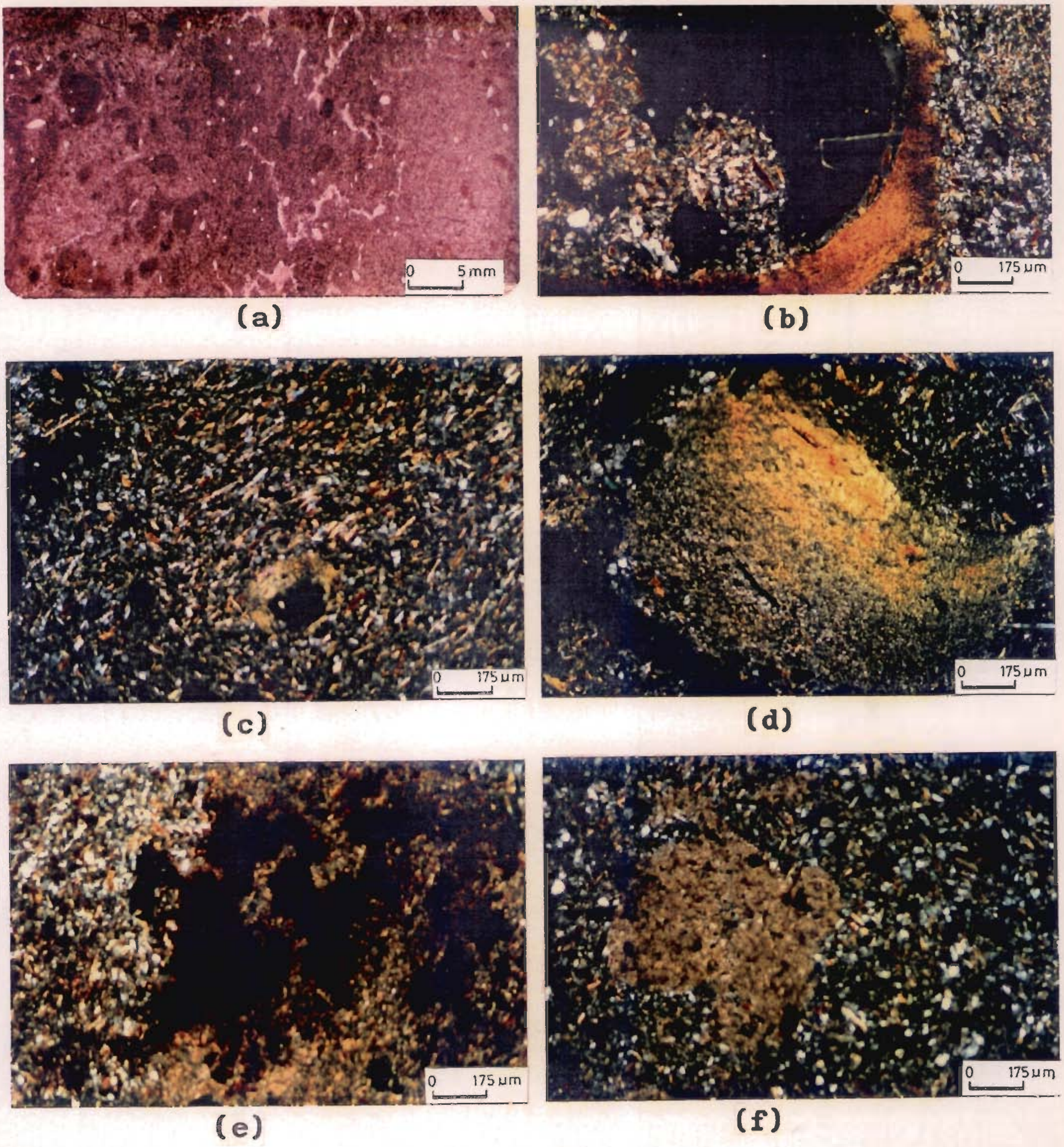


Fig.4.6. Photomicrographs of soil thin sections from the Old Meghna Deltaic Plain showing **(a)** Weakly developed peds and accumulation of ferruginous material, C hor., Pedon T11, Ord. light; **(b)** Flood coating consisting of clay and silt along a void, C hor., Pedon T11, XPL; **(c)** Argillan/ hypocoating (70-80 µm) of limpid clay and weakly developed parallel striated b-fabric, B21 hor., Pedon T9, XPL; **(d)** Aggregates of clay embedded in the groundmass, B21 hor., Pedon T9, XPL; **(e)** Compound ferruginous nodules impregnating the groundmass, B22 hor., Pedon T9, XPL and **(f)** Moderately developed micritic calcite nodule, calcrete of stage I, C hor., Pedon T9, XPL.

b-fabrics. Alteration of biotite is moderate to strong. Argillans (30-80 μm) are rare. A few papules and hypocoatings of impure clay are observed. The other observed features are many impregnative and aggregate nodules of iron hydroxides. The various micromorphological features of these soils such as weakly developed peds, flood coating, argillan, aggregates of clay, compound ferruginous nodules and micritic calcite nodule are presented in Fig.4.6.

4.3.8 Micromorphological characters of the Lower Atrai Depression Soils

From this depression 2 thin sections (Table 4.1 and Appendix V) have been studied in detail. The soils exhibit moderately to strongly developed angular to subangular blocky peds and are characterized by elliptical and planar voids. The c/f ratio varies from 40/60 to 5/95 and the c/f related distribution ranges from single-spaced to open porphyric indicating a significant variation in basic distribution patterns of primary particles. The biotite mineral is strongly to very strongly altered. The percentage and size of quartz grains decrease significantly in the B horizon as compared to the Ap horizon. The micromass is characterized by strong development of unistrial, parallel and cross striated b-fabrics. A few hypocoatings of impure clay and many moderately developed impregnative nodules of iron hydroxides occur mainly in the C horizon. Mainly the micromass and the voids have been affected by the swelling and shrinkage effects as shown by the features such as skew planes and stress cutans of Brewer (1964). Some of the important micromorphological characters of these soils such as crack structure, flood coating, unistrial b-fabric, cross striated b-fabric and well developed ferruginous nodule are shown in Fig.4.7.

4.3.9 Micromorphological characters of the Barind Tract Soils

A total of 4 soil thin sections (Table 4.1 and Appendix V) from 3 pedons have been studied in detail from this soil- geomorphic unit. Micromorphological investigations show generally moderately to strongly developed angular to subangular blocky peds. Bridged and pellicular grain microstructures and elliptical and irregularly shaped voids are observed. The c/f ratio varies from 70/30 to 30/70 and the c/f related distribution from gefuric to double-spaced porphyric. Moderate to strong degree of alteration of biotite is observed. The micromass is characterized by weakly to moderately developed parallel, cross and porostriated b-fabrics. The other observed features are many papules and microlaminated clay. Many moderately to strongly developed impregnative and nucleic nodules of iron hydroxides and calcrete pedofeature of stage III are also observed. Some of the diagnostic characters of these soils such as moderately developed peds, typical ferruginous nodule, unistrial b-fabric, orientation of clay aggregates, microlaminated clay coating and microcrystalline calcite (calcitan) are shown in Fig. 4.8.

4.3.10 Micromorphological characters of the Madhupur Tract Soils

This upland is characterized by two different types of soils e.g. moderately developed brown/red mottled soils and intensely weathered 'red soils'. The former have similar micromorphological characteristics as that of the Barind Tract described in the preceding section 4.3.9. In the present study, the micromorphological characteristics of the 'red soils' are described below by investigating two soil thin sections from Tejgaon Series (see Brammer, 1971) developed on clayey parent materials (Table and Appendix V).

These soils are characterized by strongly developed subangular

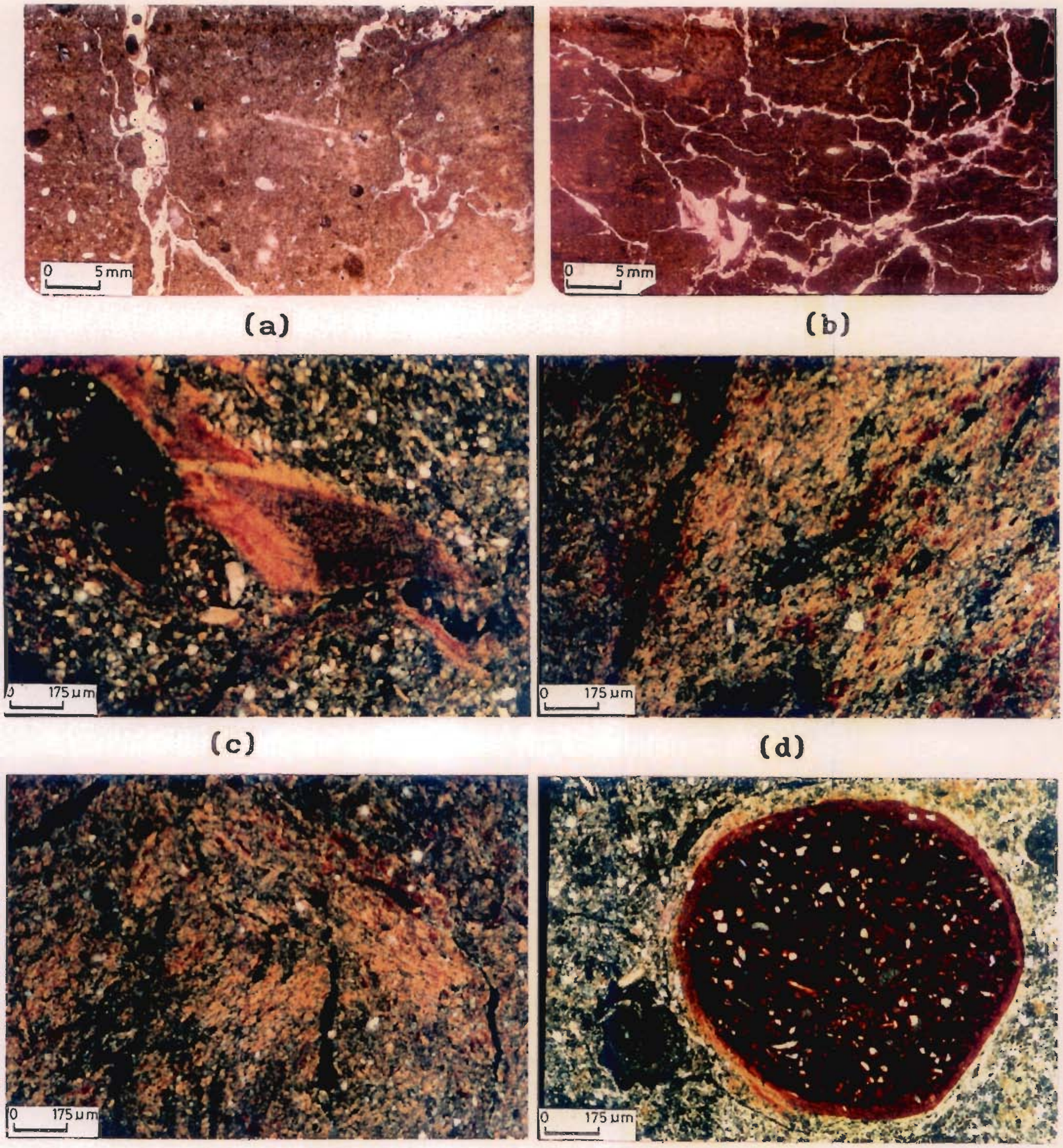


Fig.4.7. Photomicrographs of soil thin sections (Pedon S4) from the Lower Atrai Depression showing **(a)** Well developed ferruginous nodules, flood coatings (to the upper right) and weakly developed peds, B21 hor., Ord., light; **(b)** Crack structure ad aggregates of ferrugious material B21 hor., Ord. light; **(c)** Flood coating consisting of clay, fine silt and organic matter infills a void (enlargement of the upper right part of **(a)**, C hor., XPL; **(d)** Strongly developed unistrial b-fabric and an elongated planar void, B21 hor., XPL; **(e)** Strongly developed cross striated b-fabric and many planar voids, B21 hor., XPL and **(f)** Well developed ferruginous nodule with sharp boundary, C hor., XPL.

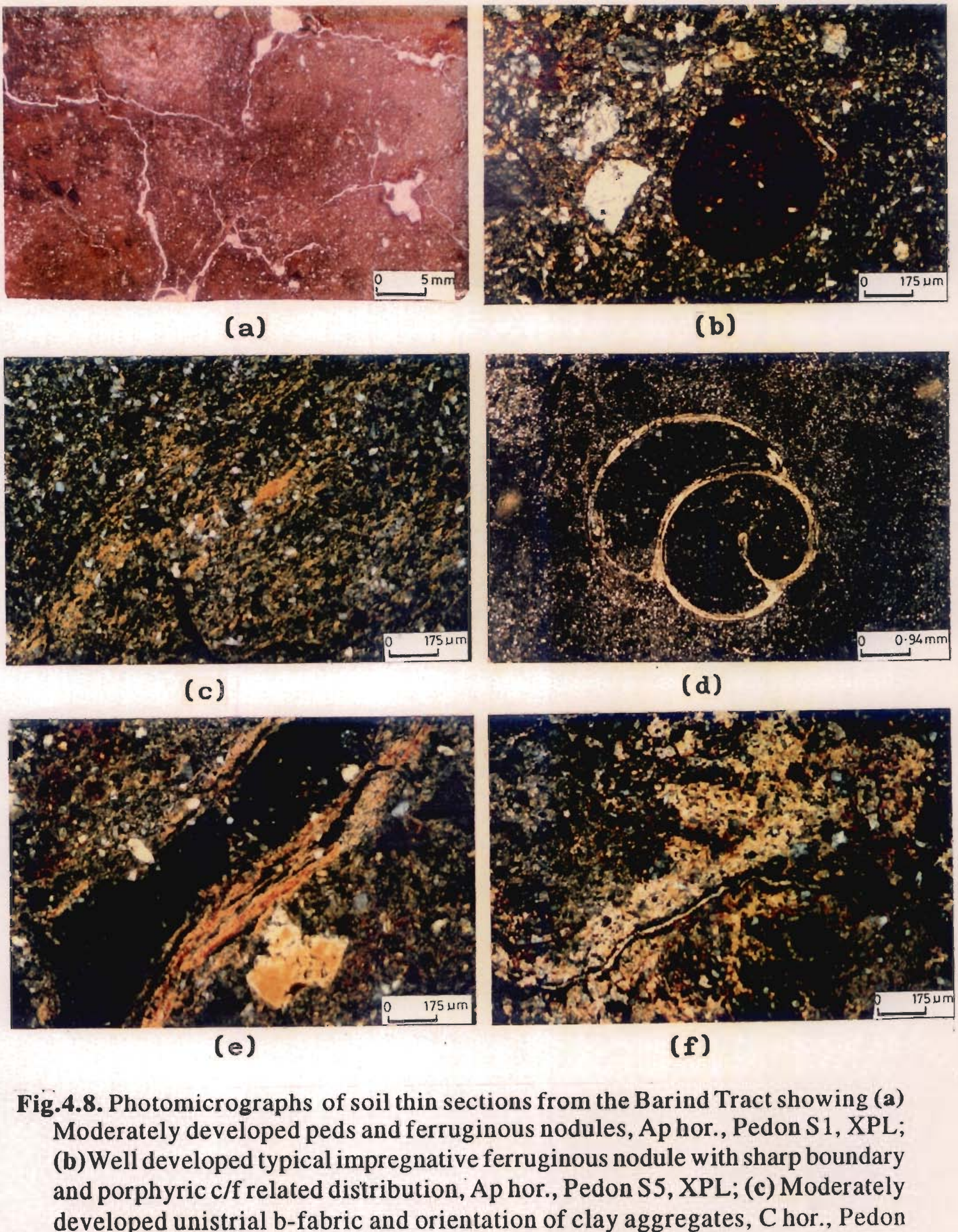


Fig.4.8. Photomicrographs of soil thin sections from the Barind Tract showing **(a)** Moderately developed peds and ferruginous nodules, Ap hor., Pedon S1, XPL; **(b)** Well developed typical impregnative ferruginous nodule with sharp boundary and porphyric c/f related distribution, Ap hor., Pedon S5, XPL; **(c)** Moderately developed unistrial b-fabric and orientation of clay aggregates, C hor., Pedon S2, XPL; **(d)** A gastropod shell (4.3 mm in length and 3.9 mm in width), B3 hor., Pedon S6, XPL; **(e)** Microlaminated clay coating along a planar void, Ap hor., Pedon S6; XPL and **(f)** Microcrystalline calcite (calcitan) along a planar void, Calcrete of stage III with overprints of ferruginous material, C hor., Pedon S2, XPL.

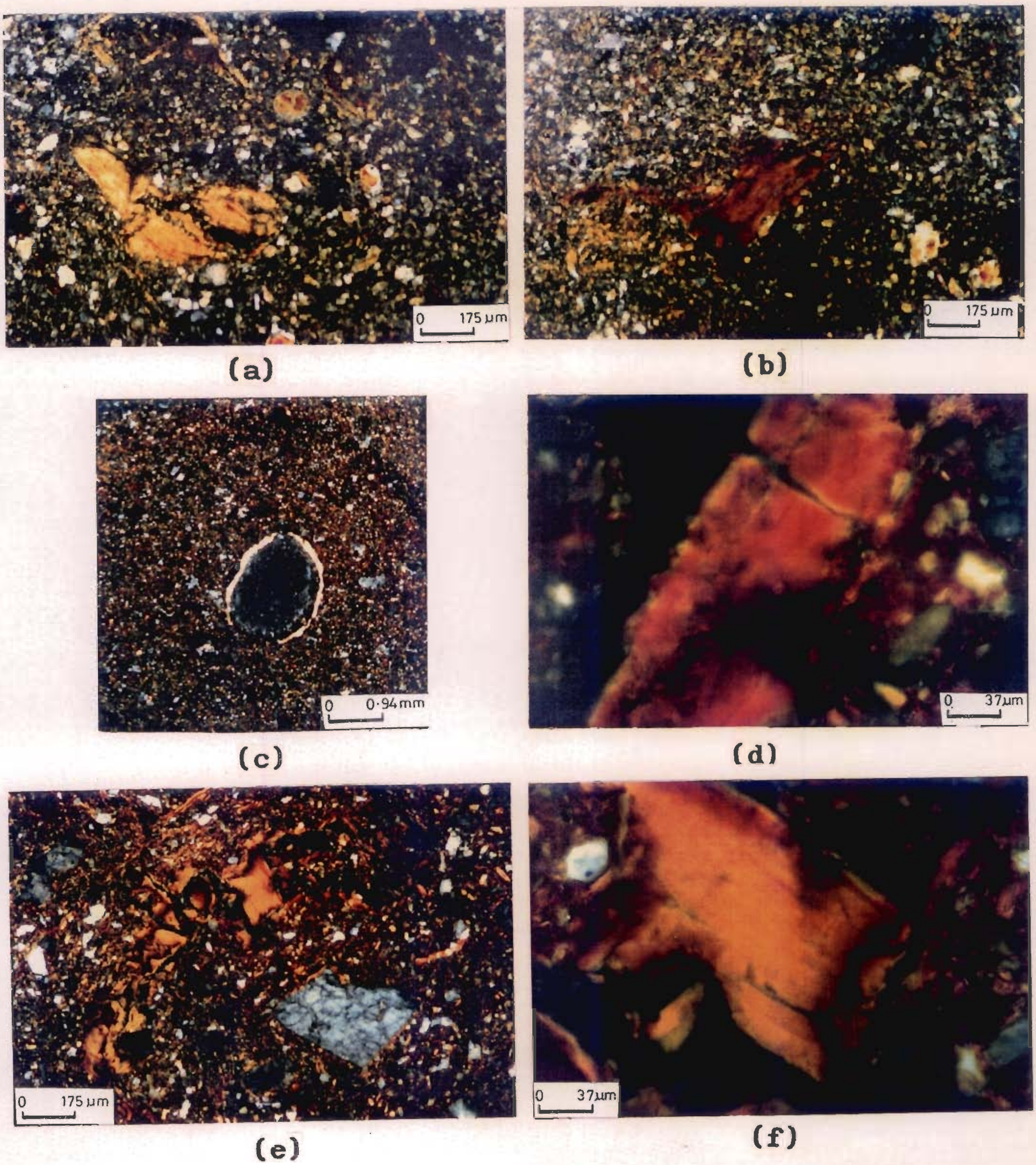


Fig.4.9. Photomicrographs of soil thin sections from the Madhupur Tract showing **(a)** A thick argillan/hypocoating of limpid clay (~240 µm) along a void marked by pedoturbation, B23 hor., Pedon T6, XPL; **(b)** A large papule (500 µm in length and 200 µm in width), C hor., pedon T6, XPL; **(c)** A shell of mollusca (2.25 mm in length and 1.7 mm in width), B21t hor., Pedon T7, XPL; **(d)** A thick argillan/hypocoating (130-150 µm) of limpid clay, B22t hor., Pedon T7, XPL; **(e)** Many thick argillans (50-175 µm) and papules mostly along a planar void marked by pedoturbation, B22t hor., Pedon T7, XPL and **(f)** A thick argillan (160-175 µm), enlargement of upper middle part of (e).

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
ii) T7/5, 100-200cm, B24	Strong, subangular blocky peds	Planar	Pellicular grain	30/70, Open porphyric	Many thick argillans (50-250μm)	-do-	-do-	Intense red colouration of finer material
iii) T6/1, 0-10cm, Ap	Apedal	Simple packing	-do-	80/20, Chitonic and porphyric	Zones of Fe-oxides	-do-	Moderate to strong	Impregnative and aggregate nodule
iv) T6/3, 10-42cm, B21	-do-	Elliptical and Planar	Massive and pellicular grain	30/70, Porphyric	Few hypocoatings of impure clay	Strong, Unist-, rial, parallel and cross striated	Strong	Few impregnative nodules
Lalmai Hills								
i) T12/5, 65-165cm, B24	Apedal	Elliptical and subrounded	Pellicular grain	50/50, chitonic	Many argillans (50-100 μm)	Undifferentiated	Moderate to strong	Intense red colouration of finer material
ii) T12/7, 200-250cm, C	-do-	Simple packing	-do-	70/30, gefuric and chitonic	Few argillans	-do-	Strong	Aggregate noduli

blocky peds. Pellicular grain microstructures are observed. The voids are mostly planar. The c/f ratio is 30/70 and the c/f related distribution is open porphyric. Very few grains of orthoclase and muscovite are observed. Virtually only quartz grains constitute the coarse fraction of the groundmass. Intense red colouration of the micromass and aggregates of iron oxides are also noticed. The micromass is characterized by undifferentiated b-fabrics. Many thick (100 - 250 µm) argillans are observed mainly on the ped sufaces/the walls of the planar voids. Papules are also seen. Argillans occupy about 3-4% of the thin sections and therefore, these soil horizons are termed argillic (Bt) horizons following McKeague (1983).

According to Duchaufour (1977) sesquioxide rich soils undergo three phases of weathering and with increasing degree of weathering they are fersiallitisation, ferrugination and ferrallitisation. Micromorphological and clay mineralogical (Chapter 3) studies suggest that these 'red soils' have reached the phase of ferrugination and the brown/red mottled soils developed on the level landscape of this unit and the Barind Tract (section 4.3.9) have reached the phase of fersiallitisation. Some of the important micromorphological characters of these soils such as many thick argillans (50-240µm), papules, porphyric related distribution and a shell of mollusca are presented in Fig.4.9.

4.3.11 Micromorphological characters of the Lalmai Hill Soils

Two thin sections from this upland have been described (Table 4.1 and Appendix V). Some of the diagnostic features of these soils are shown in Fig.4.10. The soils are apedal and show pellicular grain microstructures. The voids are elliptical and subrounded. The c/f ratio ranges from 70/30 to 50/50 and the c/f related distribution from gefuric to chitonic. Degree of alteration of biotite is strong. The micromass is characterized by undifferentiated b-fabrics. The coarse fraction of the groundmass consists almost entirely of quartz grains. The diagnostic characteristics of these soils are the presence of many moderately thick argillans (50-100 μm) on the quartz grains which occupy about 2-3% of the thin section. Intense red colouration of the micromass is also observed. The other observed features are papules and aggregate nodules of iron oxides. Micromorphological investigations suggest that these soils resemble those of the Madhupur Tract 'red soils' (section 4.3.10) except that these show slightly lower degree of development, which may be attributed to sandy parent materials of the soils. These soils possess argillic (Bt) horizons like Madhupur Tract 'red soils' and have undergone ferrugination phase of weathering.

4.4 MICROPROBE ANALYSIS

The present study includes microprobe analysis of the weathered biotites, Fe-Mn nodules, hypocoatings and argillans observed in the soil thin sections. The objective was to determine the major elemental composition and to suggest the processes of alteration and formation of the examined features.

(a) Weathering of biotite

The weathering of biotite and its transformation to expanding layers have been studied by several workers (Sarma, 1976; Fanning and Keramidas, 1977; Jackson, 1970; Ismail, 1970; Eswaran and Bin, 1978 and Bisdom et al., 1982). Oxidation of Fe^{2+} to Fe^{3+} in the biotite disrupts the electrostatic neutrality of the crystal and brings about collapse of the lattice. The transformation of biotite to vermiculite is primarily due to the weathering of biotite by oxidation (Birkeland, 1984). The rate of oxidation in the soils depend mainly on the rate of release of free iron. The depth and intensity of oxidation increase with increasing

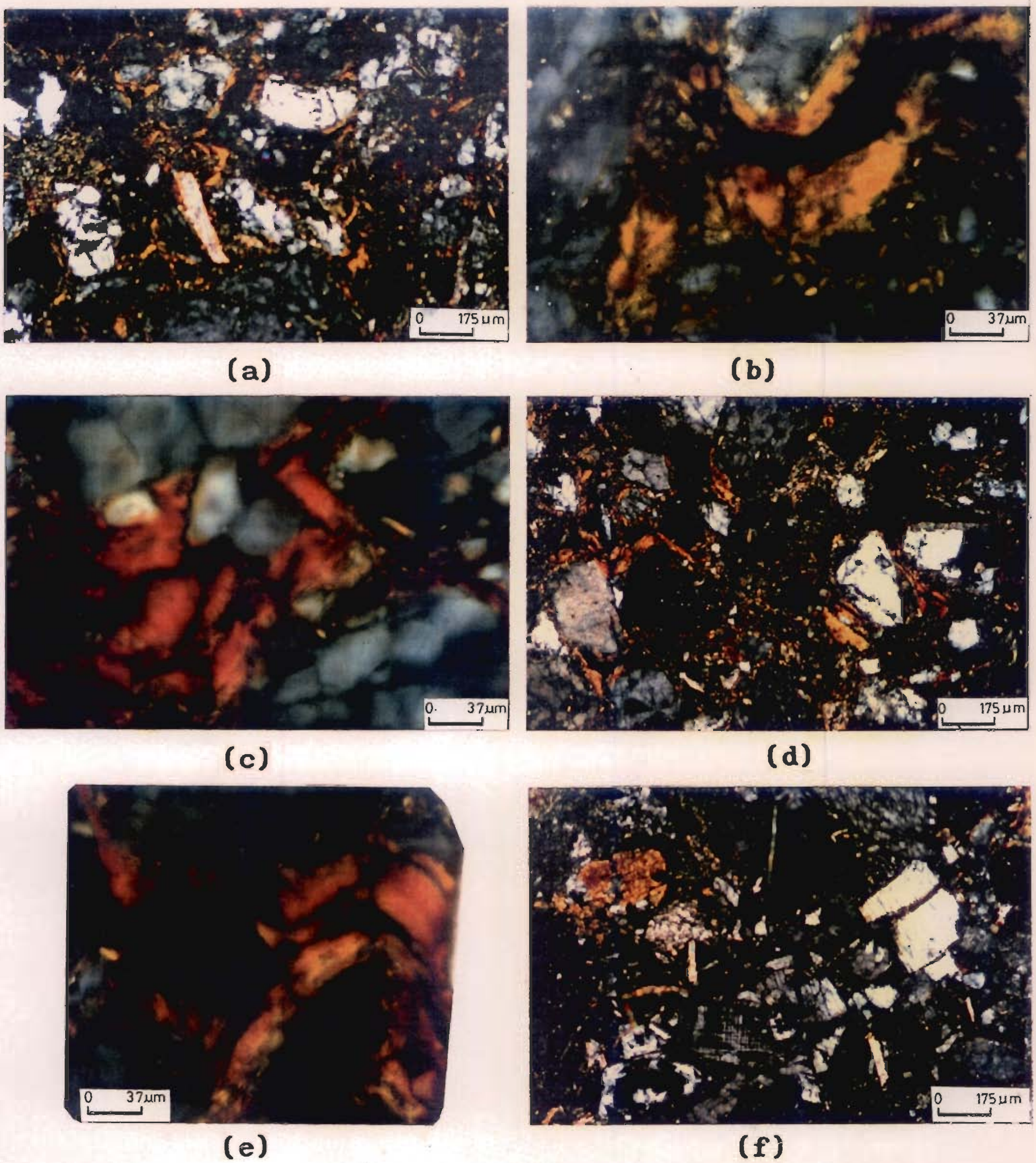


Fig.4.10. Photomicrographs of soil thin sections (Pedon T12) from the Lalmai Hills showing **(a)** Many argillans (30-60 µm) on voids and quartz grains, B3t hor., XPL; **(b)** A thick argillan (50-60 µm) along a void and partly on quartz grain, B3t hor., XPL; **(c)** Many argillans embedded in the intergranular spaces of quartz grains, B3t hor., XPL; **(d)** Many argillans (40-80 µm) on voids and quartz grains, B3t hor., XPL; **(e)** A thick argillan (70-80 µm), enlargement of **(d)**from the middle right part, C2 hor., XPL and **(f)** Weakly altered muscovite and feldspar grains, C hor., XPL.

age of the soil.

Keeping the above points in view, the major elemental compositions of the weathered biotites from soil thin sections were determined by microprobe analysis at the University Scientific Instrumentation Centre, University of Roorkee, Roorkee for the Lalmai Hill and Moribund Ganges Deltaic plain soils. The obtained data (Table 4.2) were compared with standard composition of biotite from granite given by Deer et al. (1966). The average chemical composition of the weathered biotites from the Lalmai Hill soils suggests a substantial increase in SiO_2 and Al_2O_3 contents and almost a total depletion of iron and potassium, whereas biotite composition from Moribund Ganges Deltaic Plain indicates a substantial increase in SiO_2 and decrease in Fe_2O_3 contents accompanied by almost total depletion of potassium.

The chemical analysis of the weathered biotites from the study area supports the concept that on weathering biotite loses potassium (Dennison et al., 1929). Under the present hot and humid weathering condition biotite easily collapses by rapid weathering and releases various elements to the environment and these elements may subsequently reconstitutes to form some pedogenic clay minerals in some parts of the study area. For example, some proportion of total kaolinite present in the Lalmai Hill soils (usually higher amounts, ≃ 40%) may be due to intense alteration of biotites as suggested by higher contents of Al_2O_3 in the weathered biotites (see Table 4.2).

A great loss of iron from weathered biotite accounts for the formation of diffused mottles and impregnative nodules in the soils of the Moribund Ganges Deltaic Plain by hydromorphism and also for intense red colouration of the finer matrix in the soils of the Lalmai Hills by redistribution of free iron accumulated by hydromorphism (second cycle of weathering under well drained condition).

(b) Fe-Mn concretions/nodules

Secondary iron and manganese compounds occur in soils in several forms such as concretions, nodules, pans, coatings and mottles and they are used as diagnostic indicators of soil hydromorphism (Bogdanov and Voropayera, 1969 and Soil Survey Staff, 1975). Many workers have indicated higher concentration of Fe and Mn in the concretions than in the soil matrix (Taylor et al., 1964; Polteva and Sokolova, 1967; Gallaher et al., 1973 and Sidhu et al., 1977).

In the present context the total major elemental composition of Fe-Mn nodules from 3 soil-geomorphic units of the study area were determined from soil thin sections by microprobe analysis (Table 4.3). It is observed that the enrichment of Fe_2O_3 in the Fe-nodules from Moribund Ganges Deltaic Plain and Old Brahmaputra Plain soils are 18.26% and 42.46% respectively. The concentration of MnO in the Mn-nodules is 29.35% in the Old Brahmaputra Plain soils. The Fe-nodules from the Barind Tract soils show enrichment of alkali and alkaline earth metals in association with free iron. From the study, it seems that the Barind soils have undergone higher degree of pedogenesis and depleted alkali and alkaline earth metals which on reprecipitation formed nodules in association with clay and free iron. The variation in concentration of Fe_2O_3 in the nodules from the Old Brahmaputra plain and the Moribund Ganges Deltaic Plain soils is attributed to their variation in the degree of pedogenesis. Fe-Mn nodules suggest strong hydromorphism of soils in some poorly drained parts of the study area.

Table 4.2 : Chemical composition of Weathered biotite, Fe-Mn nodules and individual hypocoatings/argillans

Soil-geomorphic units	Code No.	Sample	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	MnO (%)	CaO (%)	K_2O (%)	Na_2O (%)	TiO_2 (%)
					Biotite						
LH	T12/5	Av.of 10 pts.	56.56	33.50	2.47	2.51	0.06	0.80	1.42	2.07	0.56
MGDP	T3/4	-do-	64.06	11.60	16.31	1.82	0.04	3.45	0.37	1.09	1.18
Standard	Biotite		37.17	14.60	30.60	4.23	0.06	0.17	8.25	0.15	3.14
					Fe-Mn Concretions						
MGDP	T3/4	Av.of 5pts	48.82	19.14	18.26	2.74	1.11	4.7	3.12	1.40	0.52
OBP	S9/3/1	-do-	41.12	17.74	4.52	1.20	29.35	2.24	1.70	1.53	0.60
-do-	S9/3/2	-do-	32.50	15.12	42.46	2.26	0.20	1.39	3.68	1.05	1.06
BT	S2/3/1	-do-	23.45	30.98	0.00	10.23	0.00	17.70	4.57	12.91	0.00
-do-	S2/3/2	-do-	19.16	11.63	10.17	0.62	1.78	9.69	21.65	21.50	3.38
					Hypocoatings and Argillans						
SD	S13/6/1	Hypoc-oating	80.17	6.20	5.23	2.06	0.37	3.45	1.05	0.84	0.43
-do-	S13/6/2	-do-	24.60	8.45	22.94	2.32	0.00	17.79	1.89	18.17	0.63
-do-	S13/6/3	-do-	67.99	9.58	8.54	2.22	0.35	6.13	1.67	2.03	0.81
LH	T12/5/1	Argill-an	64.01	14.02	6.08	2.05	0.06	7.55	1.18	4.55	0.45
-do-	T12/5/2	-do-	46.24	29.94	18.06	0.81	0.42	1.39	0.58	1.11	1.42
MT	T7/5/1	-do-	50.90	36.49	5.84	1.10	0.04	0.88	2.83	0.92	0.75
MGDP	T3/4/1	Hypoc-oating	26.35	21.35	1.67	14.88	0.49	25.60	1.37	6.29	0.00
-do-	T3/4/2	-do-	50.91	20.18	5.48	4.29	0.03	10.06	5.43	2.90	0.64
-do-	T3/4/3	-do-	72.15	14.81	3.15	1.28	0.01	1.61	1.84	2.44	2.64
-do-	T3/4/4	-do-	56.95	23.68	6.54	4.62	1.08	2.29	3.01	0.43	0.69
Kaolinite			45.80	39.55	0.75	0.14	-	0.41	0.03	-	-
Illite			56.91	18.50	5.25	2.07	-	1.59	5.10	0.43	0.81
Montmorillonite			51.14	19.76	0.83	3.22	-	1.62	0.04	0.11	-
Vermiculite			34.04	15.37	8.01	22.58	-	-	-	-	-

LH - Lalmai Hills, MGDP - Moribund Ganges Daltaic Plain
OBP- Old Brahmaputra Plain, BT - Barind Tract,
SD - Sylhet Depression, MT - Madhupur Tract.

(c) **Composition of individual hypocoatings and argillans**

The total major elemental composition of hypocoatings and argillans from four soil-geomorphic units of the study area were determined from soil thin sections by microprobe analysis (Table 4.2). The data were compared with known compositions of kaolinite, illite, montmorillonite and vermiculite given by Deer et al. (1966). From these chemical data it seems that hypocoatings from the Sylhet Depression soils consist mainly of amorphous silica, iron hydroxides and illite as suggested by higher contents of SiO_2 and Fe_2O_3 and lower contents of Al_2O_3 and K_2O. The argillans from the Lalmai Hills and Madhupur Tract soils consist of kaolinite and illite in association with iron as suggested by higher amount of Al_2O_3 and Fe_2O_3 in association with moderate amount of SiO_2. The hypocoatings from the Moribund Ganges Deltaic Plain soils comprise mainly amorphous silica, illite and vermiculite as suggested by higher amount of MgO, moderate to higher amount of SiO_2 and moderate amount of Al_2O_3. Some hypocoatings from the Barind Tract and Moribund Ganges Deltaic Plain contain about 10 to 15% MgO and 18 to 26% CaO indicating the formation of calcretes. The observations made by Microprobe Analysis are consistent with other studies (see Brinkman et al., 1973).

4.5 RESUME

Micromorphological investigation of soils shows systematic variation in soil characters from the least developed soils of group I to the most developed soils of group V as ranked earlier. The various micromorphological features gradually become more distinct and abundant with increasing degree of pedogenesis. These features are related to grade of pedality, roughness of voids, abundance and thicknesses of argillans, occurrence of hypocoatings of impure clay (c.f. diffusion cutans of Brewer, 1964), c/f ratio and c/f related distribution, development of b-fabrics, alteration of biotite, abundance and forms of sesquioxidic nodules and nature of calcretes. Some of the diagnostic features such as the grade of pedality, abundance and thicknesses of the argillans, the degree of b-fabric developments (e.g. unistrial, parallel and cross striated) and the degree of alteration of biotite mineral are suggestive of the varying degree of soil development in the study area. Also, many soil-forming processes have been operating in the study area since the Late Pleistocene period. As a result, various types of soils with varying degrees of development are found to occur over the area. Broadly speaking, these soils as ranked earlier into five groups have developed on three different types of geomorphic surfaces and therefore, they are divided into three major kinds of soils viz. Fluvio-deltaic plain soils, palaeofluvio-deltaic upland soils and Depression soils as discussed below.

(a) Fluvio-deltaic plain soils

These soils occupy about 65% of the study area. Since the Mid-Holocene period they have been developing under humid condition on the alluvial and deltaic plains of the Ganges-Brahmaputra-Meghna river system. These soils also include the Tista Fan and Old Tista Plain soils. Some of the soil-forming processes which gave rise to a varying degree of soil development in the alluvial and deltaic plains of the study area are summarized below.

(i) Initial stage: At this stage soils are not much developed and it may be called an immature stage of development. Sedimentary structures such as lamination, cross-bedding etc. are still visible (Fig.4.1a,b) and easily weatherable biotite mineral remains almost fresh.

(ii) Soil structures: After ripening and homogenization of soil mass, soil structures (peds) develop due to shrinking and swelling effects. The varying grade of pedality is associated with different degree of soil development (Figs. 4.3a; 4.5a,c; 4.6.a; 4.7a and 4.8.a).

(iii) Flood coatings: Development of soil structures facilitates the movement of clay, fine silt and organic matter through cracks and their redeposition in the B or C horizons give rise to flood coatings (Figs.4.6.b and 4.7.a,c). These features when examined under microscope show lack of orientation (birefringence) of translocated clay. The term "gleyans" has been proposed for these features by Brammer (1971).

(iv) Acidification of topsoils: It is observed that pH values in the upper horizons are 1 or 2 degrees lower than the subsoil during dry season in most part of the study area (Appendix II). This is attributed to initial stage of Ferrolysis (Brinkman, 1970) that facilitates removal of cations from the upper horizons.

(v) Hydromorphism : Soil thin section studies show segregations of iron hydroxides, Fe-Mn nodules, diffused mottles of iron oxides, ferriargillans and hypocoatings of ferruginous materials (Figs.4.1.f; 4.2.a,e,f; 4.3.a,e; 4.4.b; 4.5.e; 4.6.e; 4.7.f and 4.8.b). All these features suggest repeated cycles of oxidation and reduction of iron-rich minerals (e.g. biotite) resulting in release of free iron and its translocation and redeposition in pores on reoxidation. This process of soil formation has been designated as 'hydromorphism of soils' by Duchaufour (1977) which occur at many parts of the study area.

(vi) Translocation of fine clay (<.2μm): It is observed that translocation of fine clay is related to degree of soil development. The least developed soils of group I contain no argillans. The soils of group II show rare occurrences of thin argillans (30-60 μm), whereas the soils of group III contain a few thick argillans (50-150 μm) (Figs.4.1.e; 4.3.c and 4.4.c).

(vii) Translocation of organic matter: Thin section studies show that except Ap horizons, translocation of organic matter has not occurred in the subsoils of the study area.

(viii) Effects of microtopography: The alluvial and deltaic plains of the study area are criss-crossed by innumerable backswamps and ridges. The degree of soil development is found to be relatively higher in the backswamps than in the ridges due to greater amount of soil moisture, organic matter and finer particles (clay) in the former.

(ix) Carbonate nodules: In the younger soils the dissolution and leaching of calcium carbonate from the upper horizons lead to redeposition of the same in the subsoils as segregated forms. But, in the older soils the redeposited calcium carbonate forms moderately developed carbonate nodules in the B or C horizons (Figs. 4.3.f and 4.6.f). These pedofeatures may be termed micritic calcretes of stage I (cf. Birkeland, 1984).

(x) Buried soils: The investigation of five composite profiles show that a higher degree of pedogenesis has occurred in the buried soils than in the surficial soils due to relatively longer period of pedogenesis in the former under the same type of weathering/pedogenic environment since the Mid-Holocene period. The buried soils are characterized by strong development unistrial, cross and parallel striated b-fabrics (Fig. 4.3.e).

(b) Palaeofluvio-deltaic plain soils

These soils comprise about 25% of the study area and occupy upland areas representing palaeofluvio-deltaic plains of the Late Pleistocene age. The upland soils bear the imprints of former pedogenic processes and they may be designated as relict soils. In general, the upland soils passed through three phases of pedogenesis soils as described below.

(i) Alternating dry and wet phase : At an earlier stage of pedogenesis in the Late Pleistocene period the climatic condition was different than at present. At this phase alternating dry and wet periods probably promoted a widespread translocation of fine clay (<.2μm) from the upper horizons and its redeposition in the B horizons in the form of thick argillans (50 - 250 μm) that occupy 2-3% of the thin sections (Figs.4.9.a,d,e,f). The argillans underwent in-situ modification by pedoturbation. These soils are also characterized by very strong alteration of muscovite, occurrence of very few altered grains of biotite and absence of feldspar grains (Figs.4.9a,b,). The coarse fraction of the groundmass almost entirely comprises quartz grains and the soil mass as a whole shows intense red colouration (Figs.4.9a,b,e). All the above characteristics suggest that these soils (red relict soils) have undergone an advanced ferrugination stage of weathering/ pedogenesis as discussed by Duchaufour (1977). Also, many parts of the uplands show a moderate degree of development due to erosion of the former soil cover or poorly drained condition that prevented better development of soils (Discussed in detail in chapter 5).

(ii) Dry Phase: The dry condition in the middle stage favoured formation of calcretes of stage III (cf. Birkeland, 1984) at many parts of the uplands (Fig.4.8.f).

(iii) Wet Phase : At later stage since the Mid-Holocene period the development of soils occurred under a hot and humid condition that continued till today. The wet phase shows hydrolysis and ferrolysis of soils at many places of the uplands. These soils are characterized by segregations of iron oxides, formation of Fe-Mn nodules and hypocoatings of ferruginous materials. Overprints of ferruginous material on the calcretes are also seen (Fig. 4.8.a,b,f).

(c) Depression soils

Due to subsidence of some parts of the alluvial plains water logged conditions have been created. For example, repeated cycles of oxidation and reduction under these conditions in the Sylhet and Lower Atrai Depressions have caused strong hydromorphism of soils as marked by well developed Fe-Mn nodules, thick ferriargillans/hypocoatings and impregnations of ferruginous materials (Figs.4.7.f and 4.5.e).

Microprobe analysis of some pedofeatures suggests that higher degree of biotite alteration and greater amount of free iron/manganese in the Fe-Mn nodules are related to higher degree of weathering/ pedogenesis of the soils. The dominance of kaolinite in the argillans is observed in the most developed soils (Group V soils) of the study area. Accumulation of illite, vermiculite, iron hydroxides and silica gel is observed in the hypocoatings of relatively younger soils (Groups II and III soils).

CHAPTER 5

SUMMARY, SYNTHESIS AND CONCLUSIONS

CHAPTER 5

SUMMARY, SYNTHESIS AND CONCLUSIONS

5.1 INTRODUCTION

The Lower Ganges-Brahmaputra-Meghna river system occupies most of Bangladesh and forms one of the world's largest fluvio-deltaic plains. Major parts of these plains overlie the Bengal Basin. This basin has been tectonically active since the Eocene period (Graham et al., 1975; Curray et al., 1982 and Lindsay et al., 1991) by the development of the Himalayas on the north and Indoburman ranges on the east due to collision of the Indian, Chinese and Burmese plates. Worldwide Quaternary palaeoclimatic and sea level changes must have affected these plains, as these lie close to the coast line. Keeping these points in view, the present study is aimed to achieve the following objectives:

(i) To refine the delineation of the soil-geomorphic units using Landsat images, field checks and laboratory data.

(ii) To study the evolution of parts of Bangladesh plains through an understanding of the varying degree of soil development on the different soil-geomorphic units.

(iii)To prepare a soil chronoassociation for the study area.

(iv) To reconstruct neotectonic events in relation to the evolution of the landforms and soils and

(v) To understand the impacts of the palaeoclimatic and sea level changes on the geomorphic and pedogenic processes in the study area.

5.2 PREVIOUS WORK

Morgan and McIntire (1959) have described the morphology of the fluvio-deltaic plains of Bangladesh and parts of India. Coleman (1969) has studied the channel processes and sedimentation patterns of the Brahmaputra river. Alluvial morphology and sedimentary environments of Bangladesh plains have been briefly described by Fergusson (1863), Geddes (1960), Johnson (1975), Umitsu (1985, 1987, 1993), Oya (1977), Alam (1989), Islam (1976), Hasan (1986) and Monsur and Paepe (1992). Basic frameworks and outlines of the development of soils of Bangladesh have been provided by Brammer (1964, 1971), Brammer and Brinkman (1977), Brinkman (1970, 1977), Habibullah et al. (1971), Huizing (1971), Hussain (1974), Karim and Hossain (1957), Karim et al. (1978), Monsur and Hossain (1992), Karim (1984) and Ziysvelt (1980). These workers investigated the development of landforms and soils along two different pathways i.e. geomorphology and pedology. A little is known about (i) the correlation of the varying degree of soil development and landforms, (ii) the soil chronoassociation/soil stratigraphy and (iii) the impacts of neotectonism, palaeoclimatic and sea level changes on the evolution of landforms and soils in the study area. The present study aims at filling up this gap.

5.3 GENERAL FEATURES OF THE STUDY AREA

The study area constitutes about two-thirds of the fluvio-deltaic plains of Bangladesh (Fig.1.1). These plains are the gifts of the three major river systems, namely the Ganges, Brahmaputra and Meghna which confluence in the study area and carry huge amount of sediments (2.2 billion tons/year) to the Bay of Bengal (Coleman, 1969). The area is mostly flat and low-lying and about 20% of it is inundated by floods every year. The entire area can be broadly grouped into three major types of landforms (Table 5.1), namely (i) the fluvio-deltaic plains of the Mid-Holocene to Recent age, (ii) the palaeofluvio-deltaic uplands of the Late Pleistocene age and the depressions with water logged conditions since about the Mid-Holocene time. The fluvio-deltaic plains represent monotonous and almost level landscape. An alluvial fan called the Tista Fan is also included in this landform type. These plains are marked by innumerable levees and backswamps. The former consist of sandy material and generally lie above flood level. The latter comprise clayey material and generally undergo deep flooding. The palaefluvio-deltaic uplands generally rise to higher levels than the adjoining plains. These are partly dissected by rivers and partly marked by level topography. The depressions are low-lying areas with poorly drained conditions and they undergo deep flooding every year and accumulate mainly clayey materials. One large depression has formed due to subsidence of a part of the fluvio-deltaic plains (e.g. Sylhet Depression) and another depression has formed due to subsidence of a part of the palaeo-fluvio deltaic uplands (e.g. Lower Atrai Depression).

The various rivers flowing across these plains changed their courses from time to time and left behind some imprints of past phase of river action (e.g. palaeochannels/ox-bow lakes). Sandy layers beneath the backswamps also suggest the location of the former river. Patterns of river shifting are shown in Fig.5.1.

The various landform patterns of the study area are exhibited by the varying landsat image characters (Figs.2.2 and 2.3). The overall grey tone in B & W and red colour in FCC images represent the moist condition/vegetation cover, the intensity of which is directly related to the amount of moisture/density of vegetation cover. The active channels appear as dark grey tone in B&W and dark blue colour in FCC images. The black lines/patches represent stagnant water bodies (e.g. backswamps and low-lying depressions). The light grey tone/light yellow colour may represent sand bodies and upland areas (e.g. the Barind Tract, Madhupur Tract and Lalmai Hills) due to their higher reflectances. The mosaic of the various tones and colours indicate complex patterns of landscape. The overall landsat image characters of the various soil-geomorphic units are briefly described in Table 5.2.

The study area possesses a tropical monsoon climate characterized by excess rainfall over evaporation. The mean annual temperature is 25.5°C. The area receives 1270-5080 mm rainfall annually, 90% of which occurs during the monsoon period between mid-April and early October.

5.4 INVESTIGATION PROCEDURE

Topographic maps, Landsat B&W TM images of bands 3 & 4, FCC images and field checks were used to identify twelve geomorphic units in the study area. As the subsequent field morphology and laboratory investigations showed that, with minor exceptions, the soils on these geomorphic units were fairly uniform and their properties varied within a narrow range, these have been designated as the soil-geomorphic units (Fig.2.1). Field work was carried out along three traverses ('R', 'S'

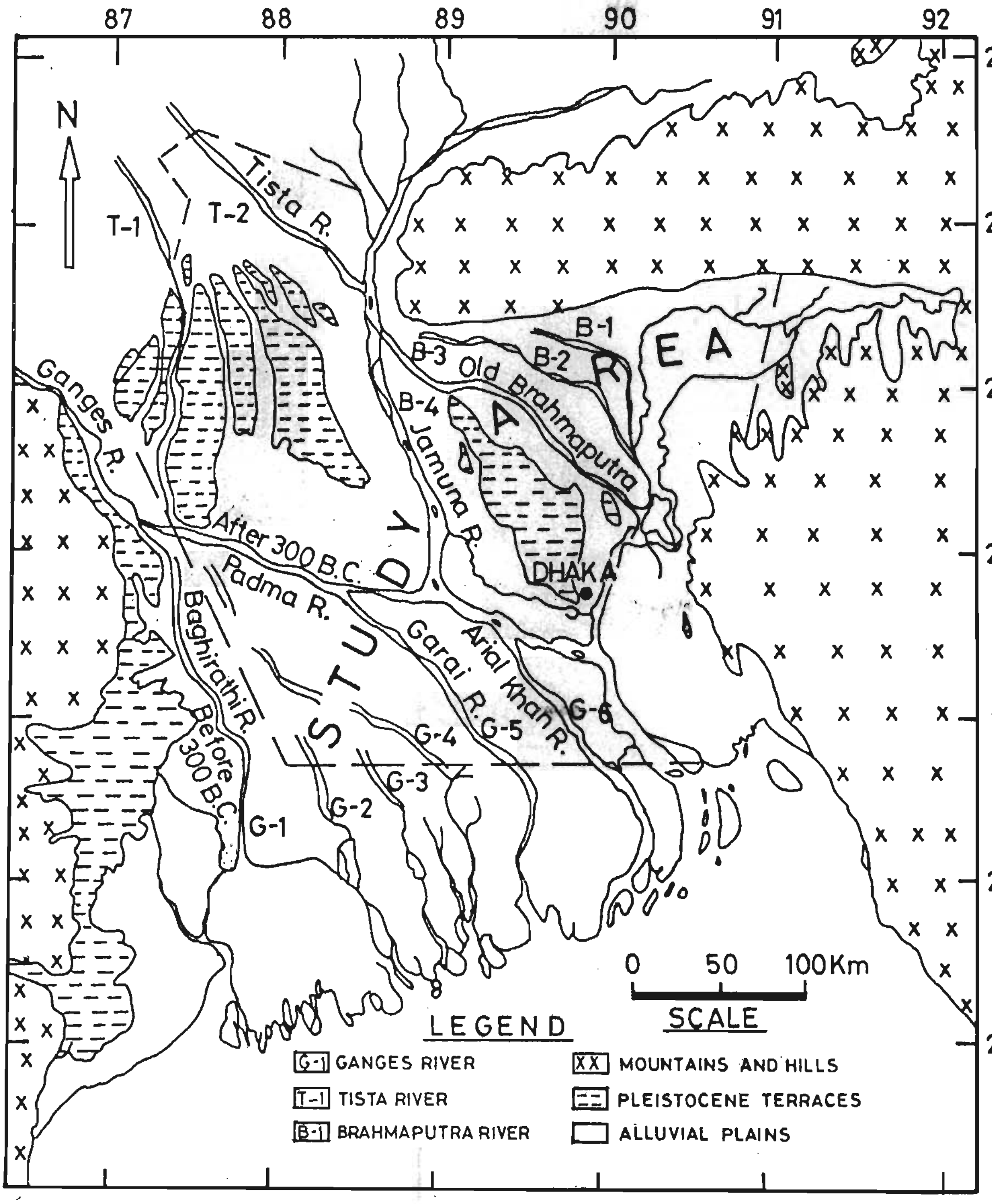


FIG. 5-1. EASTERLY SHIFTINGS OF MOST OF THE RIVERS IN THE BENGAL PLAINS (MODIFIED AFTER COLEMAN, 1969 AND UMITSU, 1985)

and 'T') in order to cover maximum number of soil-geomorphic units. The units not covered by these traverses were studied separately. A total of 45 pedons (including five composite pedons) have been investigated in the field. Master horizons and subhorizons were studied in the field and the various properties of soil such as colour, mottling, structure, texture, consistence, calcite content, sesquioxidic nodules etc. were recorded following Soil Survey Staff (1975). The thickness of each horizon/subhorizon was also recorded for each pedon.

Of the 45 pedons, 30 were selected for detailed laboratory analyses. The grain size distributions for the various soil samples were determined following the method of Galehouse (1971). The fraction <2 μm (clay) has been used to assess the vertical and spatial variation of clay minerals by x-ray diffraction analysis. The clay minerals were identified using the scheme of Wilson (1987) and their semi-quantitative estimation was carried out following primarily the procedure of Schultz (1964). Total elemental composition of the nine major elements was determined using the two solution method of Shapiro (1975) on Atomic Absorption Spectrometer and Inductively Coupled Plasma Spectrometer. Free iron contents in the soil profiles were determined using the method of Mehra and Jackson (1960). For micromorphological studies, 150 undisturbed (in-situ) soil samples were collected in metal boxes. The samples were impregnated with crystic resin and large (60x40 mm) thin sections were prepared according to the procedure described by Jongerius and Heintzberger (1963) and Miedema et al. (1974). Of 150 soil thin sections, 40 were described in detail (Appendix V) following mostly the terminology of Bullock et al. (1985). Also, major elemental analysis of some pedofeatures was carried out by Microprobe analysis.

5.5 MAJOR SOIL-GEOORPHIC UNITS

Within the three major landforms described earlier, using remote sensing techniques, detailed field work and laboratory analyses twelve soil-geomorphic units have been identified (Table 5.1). Remote sensed (Landsat image) characters, physiography, drainage patterns and soils of the soil-geomorphic units are given in Table 5.2. All these units are grouped into five members of a soil chronoassociation. The members are designated as QGB1 to QGB5, with QGB5 being the oldest member (Tables 5.2 and 5.3).

Table 5.1: Major landform types and soil-geomorphic units of the study area

Major landform types	Soil-geomorphic units
(a) Fluvio-deltaic plains (cover 65% of the study area)	(i) Brahmaputra Floodplain (ii) Young Ganges Deltaic Plain (iii) Tista Fan (iv) Old Tista Plain (v) Moribund Ganges Deltaic Plain (vi) Old Brahmaputra Plain (vii) Old Meghna Deltaic
(b) Palaeofluvio-deltaic uplands (cover 25% of the study area)	(viii) Barind Tract (ix) Madhupur Tract (x) Lalmai Hills
(c) Depressions (cover 10% of the study area)	(xi) Sylhet Depression and (xii) Lower Atrai Depression

The Young Ganges Deltaic Plain has been incorporated in the present study mainly on the basis of remote sensing techniques and its description is based on the work of Brammer (1971). The Brahmaputra Floodplain is a very young floodplain formed by the Jamuna river after the shifting of the Old Brahmaputra into the Jamuna channel. The Tista

Fan and Old Tista Plain are genetically related and have been formed by the north-south flowing rivers like the Mahananda, Purnabhaba, Atrai, Tista and Karatoya which debouching from the Himalayas have formed Tista Fan at foothills and Old Tista Plain downslope of the fan. The Tista Fan and Old Tista Plain fall under the domain of the "Tista Mega Fan". The Old Brahmaputra Plain, Sylhet Depression and Old Meghna Deltaic Plain are also genetically related and have been constructed by the combined Old Brahmaputra and Old Meghna river system. A part of the region had undergone subsidence, now called the Sylhet Depression. The Barind and the Madhupur Tracts represent the palaeofluvio-deltaic plain formed by the former Ganges-Brahmaputra river system of the Late Pleistocene period. This plain, subsequently, underwent uplift/tilting (e.g. Barind and Madhupur Tracts) and also subsidence as marked by a depression called the Lower Atrai Depression. The Lalmai Hills represent the Pliocene fluvio-deltaic plain which had undergone uplift at much later stage.

Table 5.2 : Remote sensed (Landsat image) characters, physiography, drainage patterns and soils of the various soil-geomorphic units included in the chronoassociation members (QGB1-QGB5)

Soil-geomorphic units (1)	Remote sensed (Landsat image) characters (2)	Physiography and drainage patterns (3)	Soils (4)
QGB1(<1500 Yrs.B.P.)			
(i) Brahmaputra Floodplain	Grey to dark grey tone in B&W and blue and red colours in FCC images.	Very recent meander floodplain of the Brahmaputra with an area 3500 km^2 and slope of 7.4 cm/km. Only a few rivers flow through this unit. Moderately to poorly drained landscape.	Poorly developed silt loam soils

Table 5.2 contd..

(1)	(2)	(3)	(4)
(ii)Young Ganges Deltaic Plain	Gray tone with dark grey patches in B&W images and red and bluish white colours in FCC images.	Nearly level smooth plain undergoes annual flooding and sedimentation. Area-6000 km^2 and slope-3 cm/km. Moderately to poorly drained landscape with a medium textured drainage.	Poorly to moderately developed silt loam soils.
QGB2(2500-3000 Yrs.B.P.)			
(iii) Tista Fan	Light grey tone with dark grey patches in B&W images and radiating patterns of light blue, bluish and bright red colours in FCC images.	Alluvial fan at the foothills of the Himalayas. Area 10,000 km^2 and slope-39 cm/km. Moderately well drained landscape.	Permeable silt loam and Black Terai soils (moderately developed)
(iv) Old Tista Plain	More or less similar to those of the Tista Fan	Floodplain of N-S flowing rivers that cross the downslope of the Tista Fan. Area-4000km^2 and slope-9.8 cm/km. Poorly to moderately drained.	Mainly silt loam with patches of silty clay loam soils.
(v)Moribund Ganges Deltaic Plain	Uniform grey tone in B&W images and red colours with mottles in FCC images	Old Deltaic Plain of Ganges. Area - 9000km^2 and slope - 9.6 cm/km. Moderately drained plain and medium textured drainage pattern.	Calcareous silty loam and silty clay loam soils.
(QGB3 (3000-4000 Yrs. B.P.)			
(vi)Old Brahmaputra Plain	Light grey tone with dark grey patches in B&W images and blue and red colours in FCC images.	Almost level plain of the old Brahmaputra. Area - 7000 km^2 and slope - 8.8 cm/km. Moderately to poorly drained plain with a few rivers.	Silt loam to silty clay loam soils

Table 5.2 contd..

(1)	(2)	(3)	(4)
(vii) Sylhet Depression	Overall dark grey tone in B&W images and red colour in FCC images.	Low-lying depression, very poorly drained and deeply flooded annually. Area - 5000 km^2 and slope - 3.8 cm/km. Fine textured drainage.	Fine textured soils.
(viii) Old Meghna Deltaic Plain	Grey tone with dark grey patches in B&W images and blue and red colours in FCC images	Almost level deltaic plain. Area - 5500 km^2 and slope 4.5 cm/km. Moderately to well drained.	Mainly silt loam soils.
QGB4 (5000-6000 yrs. B.P.)			
(ix)Lower Atrai Depression	Light to dark grey tone in B&W images & bright red with deep blue patches in FCC images.	Low-lying depression, very poorly drained and deeply flooded annually. Area - 2500 km^2 and slope--4.1 cm/km. Fine textured drainage.	Fine textured soils.
QGB5 (>15000 yrs. B.P.)			
(x) Barind Tract	Very light grey tone with grey mottles in B&W images and very light yellow colour with light red mottles in FCC images.	Mostly level moderately drained upland. Area-9000 km^2 and slope - 20.6 cm/km. Dissected into blocks by rivers.	Mainly grey soils with well developed red soils in the north-east.
(xi)Madhupur Tract	Very light grey tone with dark grey patches in B&W images and light red colour with bluish white patches in FCC images.	Closely dissected upland with red soils on the margins and edges of the upland and valleys. Grey soils also occur. Area - 4500 km^2 and slope 12.5 cm/km.	Red soils on the higher edges and grey soils on the level landscape.
(xii)Lalmai Hills	Light grey tone in B&W images and light red colour in FCC images.	Small upland area with steep gullied sides. Moderately well drained. Rises about 30 m above the adjoining Old Meghna Deltaic Plain	Mostly red soils.

5.6 SYSTEMATIC VARIATION IN SOIL CHARACTERS AMONG THE MEMBERS OF THE SOIL CHRONOASSOCIATION

Some systematic changes in the morphological, physical, chemical, clay mineralogical, microscopic and submicroscopic characteristics of soils are observed from the QGB1 to QGB5 members of the soil chronoassociation. These changes are discussed below.

5.6.1 Morphology

The soils in the study area show systematic variation in morphological characters from the least developed soils of member QGB1 to the most developed soils of member QGB5. The thicknesses of the B2 horizons and the sola (A+B) have been calculated from soil-profiles of the various soil-geomorphic units included in the soil-chronoassociation members. From QGB1 to QGB5, the thicknesses of the B2 horizons are 20 cm, 20-60 cm, 45-68 cm, 80-100 cm and 90-292 cm respectively and that of the sola are 52 cm, 60 - 100 cm, 60 - 110 cm, 100 - 150 cm and 105 - 312 cm respectively. Also, to infer the degree of soil development, following Bilzi and Ciolkosz (1977), Meixner and Singer (1981) and Harden (1982) profile development indices (PDI) were evaluated for various soil profiles from different soil-geomorphic units. This was done by assigning some points to six important morphological properties of soils (e.g. colour, texture, structure, consistence, clay films and boundaries) and normalizing them (Discussed in detail in chapter 2). It is observed that PDI values increase systematically from QGB1 to QGB5 members as 50-51, 54-67, 59-75, 84 and 142-175 respectively. The variation in the morphological features of the QGB1 to QGB5 soil chronoassociation members is diagrammatically shown in Fig. 5.2.

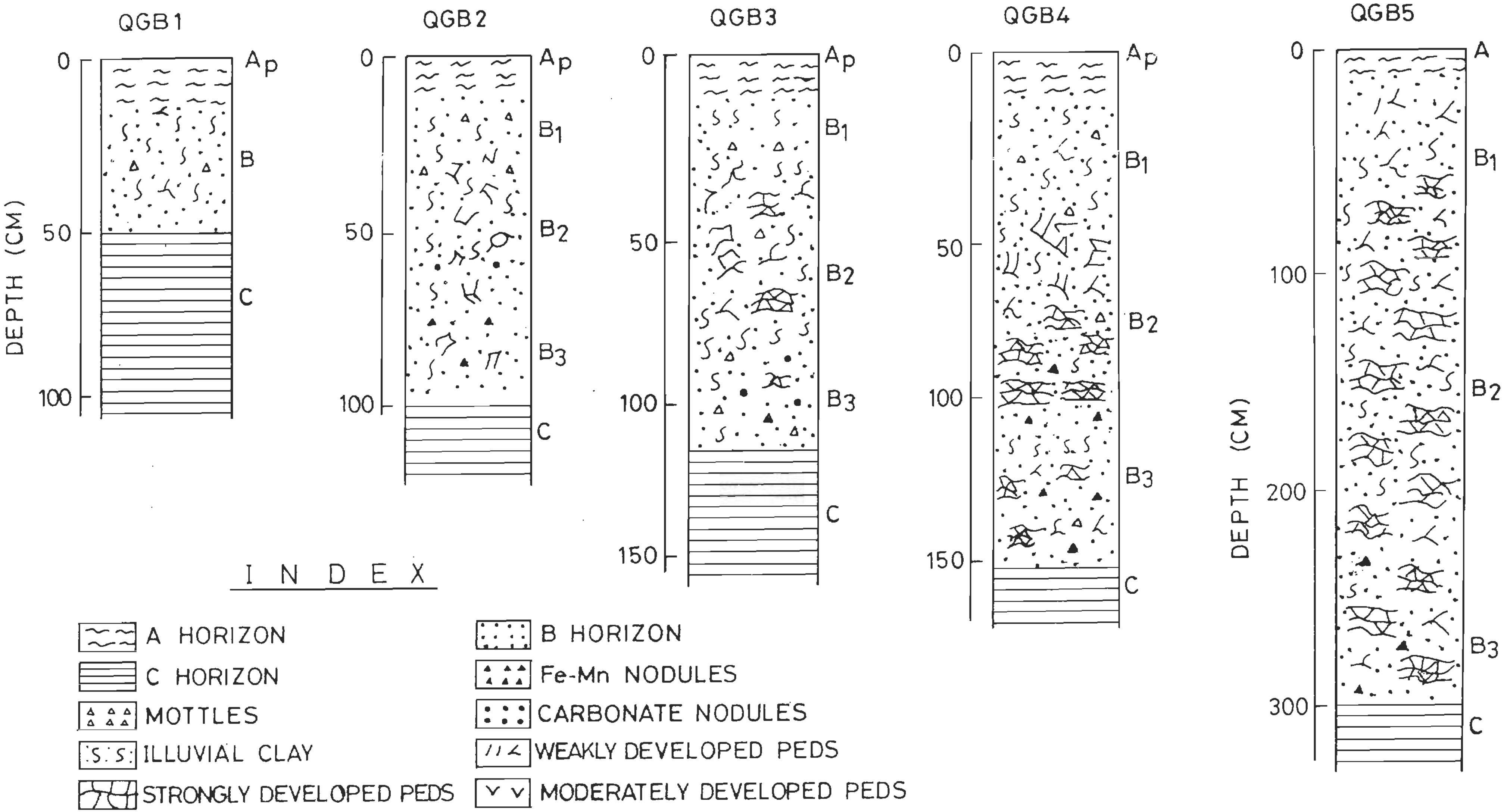


FIG.5-2. MORPHOLOGICAL FEATURES OF THE QGB1 TO QGB5 SOIL CHRONOASSOCIATION MEMBERS.

5.6.2 Textural Variation

Grain size analysis of soils from the various soil-geomorphic units indicates that most of the soils are fine to medium textured except coarse textured soils from the Lalmai Hills and proximal part of the Tista Fan. In general, soils from the uplands (QGB4 and QGB5 members) are silty clay loam to silty clay. The alluvial and deltaic plains (QGB1 to QGB3 member) are characterized by the development of silt loam soils on the ridges and silty clay loam soils on the backswamps. Grain size distribution shows an overall dominance of silt-sized particles (50-80%) suggesting the deposition of the parent sediments under low energy conditions.

Increase in pedogenic clay content in the B horizon is a useful indicator of relative ages of soils (Birkeland, 1985). The variation of total clay and pedogenic clay contents with depth for the various pedons from the different soil-geomorphic units are given in Fig.3.1. The amount of pedogenic clay increases from QGB1 to QGB5 member. The clay accumulation index as suggested by Levine and Ciolkosz (1983) has been calculated to assess the relative degree of soil development. From QGB1 QGB5, the clay accumulation indices increase as 152-179, 140-713, 392-1946, 1935 and 1385-4354 respectively. From grain size data the (sand silty)/clay ratio has been calculated for the various soil profiles following Ahmad et al. (1977). The decrease in (sand+silt)/clay from the Ap to the B horizons from QGB1 to QGB5 are 13%, 24-37%, 34-35%, 41% and 52-61% respectively.

5.6.3 Chemical composition

Total elemental analysis of soils is the most widely used way of determining the amount of chemical weathering that has taken place (Birkeland, 1984). But, absolute values of major elements are not very useful for determining relative profile development. Therefore, molar ratio SiO_2/R_2O_3 (where $R_2O_3 = Fe_2O_3 + Al_2O_3 + TiO_2$) has been used for the present study. The soils of the QGB4 member do not show any trend due to hydromorphic characters of these soils. Decrease in molar ratio SiO_2/R_2O_3 from the Ap to the B horizons for the soils of QGB2, QGB3 and QGB5 members are 7-11%, 6-15% and 23-30% respectively. This indicates a systematic increase in pedogenesis from QGB2 to QGB5. Following Arduino et al. (1984, 1986) the relative degree of soil development has been evaluated by determining $Fe_d/Fe_t \times 100$ (where, Fe_d = dithionite extractable iron and Fe_t = total iron) for the soils in the study area. Increase in $Fe_d/Fe_t \times 100$ values for the Ap to the B horizons for QGB2, QGB3 and QGB5 members are 14-18%, 17-18% and 31-41% respectively. This also implies systematic increase in pedogenesis from the QGB2 to QGB5 soils.

5.6.4 Clay mineralogy

Major clay minerals in the studied soils are illite, kaolinite, chlorite, vermiculite and montmorillonite in decreasing order of abundance. A significant proportion of mixed layer minerals like illite-chlorite, illite-vermiculite, chlorite-vermiculite, chlorite-montmorillonite and illite-kaolinite are also present. Illite is the most dominant clay mineral in all members of soil-chronoassociation followed by kaolinite. Chlorite is found to be sensitive to increasing degree of pedogenesis as seen by decreasing amount of chlorite from QGB2 to QGB4 and it is completely absent in the soils of the QGB5 member. Transformation of chlorite to vermiculite, then to montmorillonite is observed in the soils of the QGB3 member.

Transformation of biotite/chlorite to vermiculite followed by translocation of the latter in the lower horizons is observed in the soils of the Barind Tract (QGB5). Neoformation of montmorillonite by synthesis under a poorly drained condition is observed in the soils from the Moribund Ganges Deltaic plain of the QGB2 member. From QGB2 to QGB5, the amount of kaolinite increases systematically. Neoformation of kaolinite has mainly occurred through alteration of feldspars. It is probable that alteration of montmorillonite, vermiculite and illite has also contributed to the formation of kaolinite through a mixed layer mineral stage mainly in the soils of the QGB5 member (e.g. Madhupur Tract and Lalmai Hills soils).

5.6.5 Micromorphology of soils

Micromorphological study of the undisturbed soil samples from the various soil-geomorphic units reveals systematic variation with increasing degree of pedogenesis/soil development in the features related to grade of pedality, c/f ratio and c/f related distribution, plasma separation/development of b-fabrics, abundance and thicknesses of argillans, abundance and thicknesses of hypocoatings of impure clay (e.g. Diffusion cutans of Brewer, 1964), alteration of biotite, abundance and forms of sesquioxidic nodules and development of calcrete pedofeatures. The above observed features gradually become more distinct and abundant with increasing degree of pedogenesis from QGB1 to QGB5 members. Micromorphological characters of the different soil-geomorphic units are summarised in Table 5.3.

Soils of QGB1 member do not show the development of pedality. These soils are characterized by weak development of unistrial, parallel and cross- striated b-fabrics and weak alteration of biotite. **Soils of QGB2** member are characterized by weak to moderate grade of padality, moderate degree of development of unistrial, parallel and cross-striated b-fabrics, weak to moderate alteration of biotite, rare occurrences of argillans (60 - 150 μm), a few hypocoatings (50 - 300 μm) of impure clay, a few impregnative Fe-nodules, few ferriargillans (20-60 μm), many segregations of iron hydroxides and a few carbonate nodules. **Soils of the QGB3 member** show a moderate to strong grade of pedality, moderate to strong unistrial, parallel and cross-striated b-fabrics, a few thin argillans (30-40 μm), rare occurrences of thick argillans (100-150 μm), many hypocoatings (100 - 200 μm) of impure clay, strong alteration of biotites, many impregnative and aggregate Fe-nodules and very few carbonate nodules. **Soils of QGB4** member are marked by moderate to strong grade of pedality, strong development of unistrial, parallel and cross-striated b-fabrics, many hypocoatings (100 - 250 μm) of impure clay, very strong alteration of biotite and a few well developed Fe-nodules. In these soils c/f ratio varies from 40/60 to 5/95 and c/f related distribution is mainly open porphyric. **Soils of QGB5** member show moderate to very strong grade of pedality, very strong alteration of biotite, absence of weatherable primary minerals (comprise quartz and very few grains of altered biotite and feldspar), many thick argillans (50 - 250 μm) occupying 2-3% of the thin section and intense red colouration of soil matrix. The above features are observed in the 'red soils' developed on margins of the uplands. Moderately developed red mottled soils of this chronoassociation member show well developed Fe-nodules, papules, microlamination of clay and strong development of

Table 5.3 : Summary of micromorphological characters of the different soil-geomorphic units

Soil-Geomprhic units	Grade of pedality and ped types	Type of voids	Hypocoatings of impure clay	Argillans, Papules and calcretes	C/f ratio and C/f related distribution	Degree of alteration of micas	Development of b-fabrics	Occurrence of iron oxides
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Brahma-putra Floodplain	Apedal and strong (sab)	Elliptical and planar	-	-	70/40 to 30/70, monic, gefuric and porphic	Weak to moderate, unistrial, parallel and cross striated	Segregated forms	Weak to moderate
Tista Fan	Apedal to weak (sab?)	Elliptical, circular and planar	-	-	90/10 to 70/30, monic and gefuric	Weak to moderate	Moderate to strong, parallel cross, unistrial and porostriated	-
Old Tista Plain	Weak to moderate (slab)	Elliptical and planar	Few	-	60/40 to 5/95 monic, gefuric, [illegible]	Moderate strong	Moderate to strong, unist- [illegible]	Few ferrans, hypocoatings [illegible]
Old Meghna Deltaic Plain	Weak to moderate	Elliptical and subrounded	Few	Few argillans (30-40μm) and	90/10 to 40/60, monic, gefuric and porphyric	Moderate to strong	Weak, undiffer-entiated and mosaic-speckled	Impregnative and aggregate nodules
Barind Tract	Apedal	Elliptical planar and irregularly shaped	-	Few argillans, papules and microlaminated clay bands	70/30 to 30/70, porphyric, gefuric and chitoric	-do-	Undifferentiated and weak to moderate, para-llel, cross and porostriated	Well developed impregnative and nucleic nodules

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Madhupur Tract	Apedal and moderate to very strong (sab)	Planar and elliptical	Few	Many thick argillans (50-250μm) papules	80/20 to 30/70, porphyric and chitonic	Very strong	Undifferentiated and strong, unistrial, parallel and cross striated	Impregnative and aggregate nodules, intense red colouration of matrix
Lalmai Hills	Apedal	Elliptical and subrounded	-	Many thick argillans (50-150μm)	70/30 to 50/50, gefuric and chitonic	Very strong	Undifferentiated	Aggregate nodules and intense red colouration of matrix
Sylhet Depression	Apedal and moderate to strong	Planar and elliptical	Common	-	65/35 to 10/90 Porphyric	Strong	Strong, unistrial, parallel and cross striated	Impregnative and aggregate nodules, intense red colouration of matrix
Lower Atrai Depression	Moderate to strong (sab)	Elliptical Planar and irrigularly shaped	Few	-	40/60 to 5/95 Porphyric	Very strong	Moderate to strong, unistrial, cross and parallel striated	Few nodules

unistrial, parallel and cross-striated b-fabrics.

5.6.6 Microprobe analysis

Major elemental analyses of some micromorphological features (Table 4.2) were carried out from the soil thin sections by microprobe analysis. It is observed that the degree of alteration of biotite has some relationship with the formation of Fe-nodules. Higher degree of alteration of biotite is followed by greater concentration of free iron oxides in the Fe-nodules. Mn-nodules are found to occur in a poorly drained soil. The argillans from the well developed soils (red soils) of the Madhupur Tract and the Lalmai Hills consist mainly of kaolinite and some proportion of illite. The compositions of the hypocoatings and argillans from moderately developed soils of the Moribund Ganges Deltaic Plain and the Sylhet Depression show greater concentration of amorphous silica and free iron oxides in association with 2:1 clay minerals (illite, vermiculite and montmorillonite).

5.7 SOIL CHRONOASSOCIATION, PEDOGENIC PROCESSES, ROLE OF NEOTECTONICS AND IMPACTS OF PALAEOCLIMATIC AND SEA LEVEL CHANGES ON THE DEVELOPMENT OF LANDFORMS AND SOILS OF THE STUDY AREA - A SYNTHESIS

5.7.1 Soil Chronoassociation

A soil chronoassociation as defined by Mohindra et al. (1992) is a grouping of soils based on the degree of soil development in areas with varied climate and parent materials. The study area witnessed varied climate since the Late Pleistocene period and soils have developed on varying parent materials. Keeping these points in view, all the soil-geomorphic units were ranked into five groups (I to V) using the varying thicknesses of the sola and B2 horizons as well as soil development index (SD1) and profile development index (PDI) values

(Chapter 2). These groups show a systematic increase in the degree of soil development from the lower to higher ranks. Subsequently, this ranking was confirmed by the studies of the textural, chemical, clay mineralogical, micromorphological and submicroscopic properties of soils. Since these groups (I to V) reflect the varying degree of soil development, they are designated as members of a soil chronoassociation (QGB1 to QGB5, QGB5 being the oldest member) (Table 5.4). Some available radio carbon and Thermoluminescence dates were used for assigning ages to the members as discussed below.

The QGB5 member includes the soils from the upland areas. According to Brammer and Brinkman (1977) these areas underwent uplift and block-faulting in the Late Pleistocene to early Holocene period. One of the overlying oldest sedimentary deposits on a part of the tilted upland (e.g. at Basabo, Dhaka city) has a radiocarbon age of about 12780 yrs. B.P. (Monsur and Paepe, 1992). The soils on the upland areas are strongly developed as indicated by the morphological, physical, chemical, microscopic and submicroscopic characters of the soils. Taking all these points in view, an age of >15000 yrs. B.P. has been assigned to the soils of the QGB5 member. On the basis of radio carbon and Thermoluminescence dates, Alam et al. (1990) have assigned an age of Mid-Holocene to the Old Brahmaputra and Old Meghna Deltaic Plains. Brammer (1971) has carbon dated the Old Meghna Deltaic Plain as 3000 yrs. B.P. Keeping these points in view, an age of 3000 - 4000 yrs. B.P. has been assigned to QGB3 member. The soils of the QGB4 member show comparatively a higher degree of development than those of the QGB3 member. An age of 5000 - 6000 yrs. B.P. has been assigned to this member. The soils of the QGB2 member show a lower degree of soil development than those of the QGB3 member. A few carbon dates are available from the adjoining areas (Umitsu, 1993; Banerjee and Sen, 1987; Vaidyanadhan and Ghosh, 1993) which were also used, in addition to determining the degree of soil development. An age of 2500 - 3000 yrs. B.P. has been assigned to the soils of the QGB2 member. The soils of the QGB1 member show a varying degree of soil development with A/C and ABC type profiles. One carbon date (Brammer, 1971) shows that the maximum age of these soils is about 1500 yrs. B.P.. Considering the youngness of the soils an age of < 1500 yrs. B.P. has been assigned.

Table 5.4 : Soil chronoassociation for the study area

Member	Assigned ages (Yrs. B.P.)	Soil-geomorphic units included in each member
QGB1	< 1500	Brahmaputra Floodplain and Young Ganges Deltaic Plain
QGB2	2500 - 3000	Tista Fan, Old Tista Plain and Moribund Ganges Deltaic Plain
QGB3	3000 - 4000	Old Brahmaputra plain, Sylhet Depression and Old Meghna Deltaic plain
QGB4	5000 - 6000	Lower Atrai Depression
QGB5	> 15000	Barind Tract, Madhupur Tract and Lalmai Hills

5.7.2 Pedogenic processes

Pedogenic processes in the area can be best understood in terms of the three major landform types discussed below.

(a) **The alluvial and deltaic plain soils (QGB1 to QGB3 members)**

The alluvial and deltaic plain soils have developed since the Mid-Holocene period on the alluvial and deltaic plains of the Lower Ganges-Brahmaputra-Meghna system.

A systematic increase in the degree of soil development from the least developed QGB1 member to moderately developed QGB3 member may be visualized through an understanding of the following soil-forming processes:

(i) **Initial stage**: At this stage destruction of alluvial stratification, development of mottles, ripening and homogenization of soil material take place.

(ii) **Soil Structures**: After initial stage of ripening and homogenization of soil mass the development of soil structures starts, which become more prominent with increasing degree of soil development. A higher grade of pedality is generally associated with a higher degree of soil development.

(iii) **Flood coatings:** The formation of soil structure provides cracks in the soil mass. Also, pores/holes are made by plant roots and animals. Water passing through these cracks and pores may transport material from the soil surface and deposit it in the lower horizons as coatings on the sides of the cracks and pores which are called 'flood coatings' (Brammer, 1971). These 'flood coatings' consist of clay, fine silt and organic matter.

(iv) **Hydromorphism of soils**: Repeated cycles of oxidation and reduction facilitate release of iron oxides due to alteration of iron rich minerals (mainly biotite in the present case). The released iron oxides accumulate in the soil mass as various forms such as diffused mottles, Fe-nodules, ferriargillans and ferruginous hypocoatings. The abundance and degree of development of these forms generally increase with increasing degree of soil development.

(v) Effects of microtopography: To a certain extent, microtopographical variation within individual soil-geomorphic units may control degree of pedogenesis. Relatively a higher degree of pedogenesis in the backswamp soils as compared to the ridge soils is attributed to a greater amount of soil moisture, organic matter and finer particles in the former.

(vi) Translocation of fine clay: Translocation of fine clay from the upper horizons into the lower horizons under leaching environment gives rise to clay cutans/argillans on voids. The thin argillans (30 - 60μm) are observed in the younger soils and moderately thick argillans (50-125μm) are found in the older soils among QGB2 and QGB3 members.

(vii) Carbonate nodules: Dissolution and translocation of $CaCO_3$ from the upper horizons and its reprecipitation as segregated forms in the B horizons of the younger soils is a common process. On the other hand, reprecipitation of $CaCO_3$ in the form of well developed carbonate nodules is observed in the B3 and C horizons of the older soils among QGB2 and QGB3 members.

(viii) Weathering of primary minerals: Only biotite mineral shows a good trend. A higher degree of biotite alteration is associated with an increasing degree of soil development.

(ix) Buried soils: These soils with similar characteristics show a higher degree of development than those of the surficial soils developed under a hot and humid condition prevailing since the Mid-Holocene period. Investigation of five composite profiles indicate that the soils might have undergone burial due to the effects of neotectonism as discussed in section 5.7.3.

(b) The upland soils (QGB5 and QGB4 members)

The upland soils have developed on the palaeofluvio-deltaic plains since the Late Pleistocene period. These are sesquioxide rich relict soils and have passed through three major phases of pedogenesis as discussed below.

(i) Alternating dry and wet phase of Late Pleistocene time

During the earlier phase with contrasting wet and dry periods a widespread translocation of fine clay and formation of many thick argillans (50-250μm) might have occurred in the upland soils. These soils representing relict red soils are found to occur at many places on the margins of the uplands or edges of the valleys (Fig.5.3) which underwent subsequent modification as seen in the dislocation and degradation of argillans by pedoturbation (e.g. the soils of the Madhupur and Lalmai Hill Uplands). The presence of thick argillans (50 - 250 μm) (Fig.4.9), intense weathering/ pedogenesis of soils and dominance of kaolinite mineral in the soils suggest that these soils belong to ferrugination stage of Duchaufour (1977).

The greater amount of mixed layered minerals, colour hue (red mottled soils), free iron contents (Table 3.2) and micromorphological characters (Chapter 4) suggest that the soils from the Barind Upland and the level parts of the Madhupur Upland might have passed through fersiallitisation stage of Duchaufour (1977).

(ii) Dry phase at 7000 - 8000 yrs. B.P.

The upland soils also passed through a dry period of middle phase of pedogenesis. During this period a widespread calcrete formation occurred on the uplands. These calcretes (Fig. 4.8.f) represent stage III of Birkeland (1984).

(iii) Hot and humid phase since the Mid-Holocene period

Finally, at a later stage continuing till today, a hot and humid condition (wet phase) prevailed over the uplands that facilitated hydromorphism and ferrolysis of soils. Overprints of ferruginous material on the calcretes (Fig.4.8.f) in the upland soils support that dry phase was followed by a wet phase. All the above mentioned three phases of pedogenesis reflect the polygenetic characters of the upland soils. The overall pedogenic processes on the upland areas are discussed below.

The margins of the Barind Tract (northeastern part) and almost whole of the Madhupur Tract and Lalmai Hills are marked by the development of thick red soils (2-3 m). However, flat regions in the interior parts away from the margins are characterized by red/yellow mottled soils. In addition, moderately developed soils with thin solum (~ 1m) has also been observed in some areas (Mr.L.P.Singh, pers. comm.). Hydromorphic soils are also observed in the floodplains of the modern rivers cutting through the upland areas at a lower level. These features are explained as follows: (i) the lower levels in the Barind Tract represent erosional surfaces related to the uplifting episodes of the area and (ii) the soil type distribution in the upland areas can be explained by reference to catena described by Birkeland (1984). According to it, red soils develop at the crest of slope and red/yellow mottled soils in the lower part, differences being due to variation in soil drainage.

In the present area (Fig.5.3), the northeastern edges of the Barind Tract are characterized by red soils due to a good drainage and red/yellow mottled soils have developed on the flat regions of the Barind Tract due to a poor drainage. The Madhupur Tract and Lalmai Hills are areally narrow patches and the former is closely dissected. The whole of these areas are marked by good soil drainage and so almost whole of these areas are marked by red soils. In comparison to the Madhupur Tract and Lalmai Hill soils the poor developed of soils on the Barind Tract as a whole may also be affected by rapid uplift followed by erosion (Bashar, 1985) as discussed later.

Kaolinite is found to be common clay mineral in the red soils and montmorillonite is occasionally found at some localities of the Barind Tract (Appendix IV) under poorly drained conditions. This observation is consistent with the clay mineralogical variation in a soil catena described by Birkeland (1984).

(c) The depression soils (QGB3 and QGB4 members)

Both the Sylhet and Lower Atrai Depressions have well developed soils as indicated by sola thicknesses of 90-150cm and thick ferriargillans (~80 μm) suggesting an earlier phases of soil

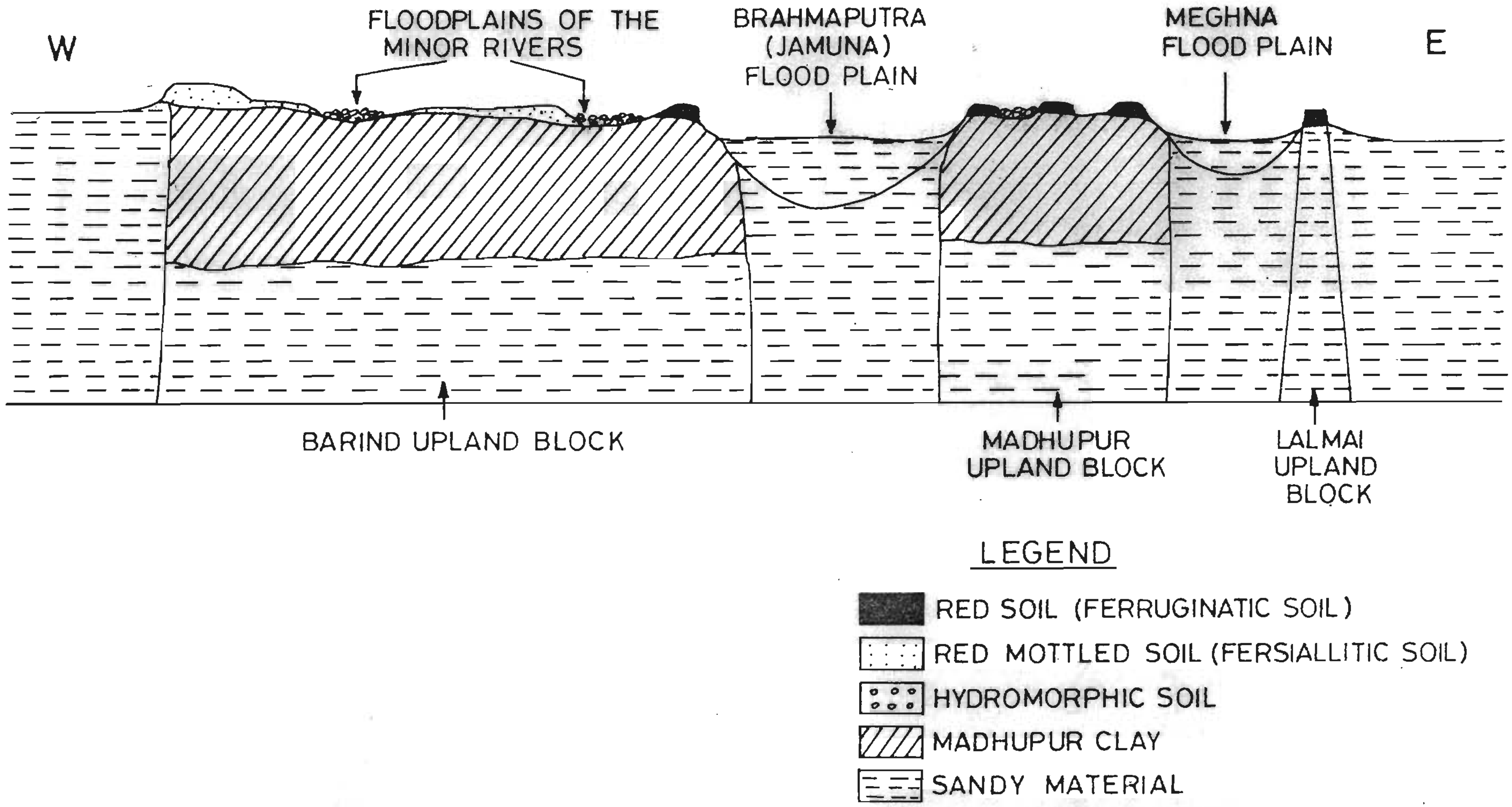


FIG. 5·3. DIAGRAMMATIC SKETCH SHOWING VARIOUS SOIL PATTERNS DEVELOPED ON THE UPLANDS OF THE STUDY AREA DUE TO VARIATION IN INTERNAL SOIL DRAINAGE. THE BARIND, MADHUPUR AND LALMAI UPLAND BLOCKS ARE SEPERATED BY ALLUVIAL SOIL /SEDIMENT OF LATER STAGE.

development. The subsidence of the area formed depressions which have been marked by repeated cycles of oxidation and reduction leading to strong hydromorphism causing general segregation of iron oxides throughout the solum, hypocoatings of ferruginous material and flood coatings.

5.7.3 Role of Neotectonics on the development of landforms and soils

(i) Introduction

The study area lies close to the northeastern Himalayas and Indoburman ranges. Tectonically this region is one of the most active areas of the world (Nandy, 1986). Seismic activity observed for the last 200 years also reflect that the region (including the study area) is active till today (Chen and Molnar, 1990 and Khandoker, 1990). This tectonic activity has a direct bearing to the development of landforms and soils in the study area.

Keeping the above points in view, the investigations of Landsat imageries (both B & W and FCC images) followed by field checks were carried out. The distribution of soils and geomorphological features helped to delineate 8 major faults (viz. Dauki Fault, Madhupur Fault, Karatoya - Banar Fault, Atrai-Dhaleswari Fault, Padma Fault, Sylhet Fault and Maldah-Kishanganj Fault), 3 weak zones (viz. Jamuna - Padma Graben, Meghna Fault zone and Ganges Deltaic Graben) and 8 tectonic blocks (viz. Tista Plain Block, Barind Upland Block, Madhupur Upland Block, Lower Atrai Block, Old Brahmaputra-Meghna Plain Block, Old Meghna Deltaic Plain Block, Lalmai Upland Block and Ganges Deltaic Plain Block) (Fig.5.4). All these tectonic elements helped to explain for the development of the various landform and soil patterns of the study area.

Firstly, a brief account of these tectonic elements is given and then, the impacts of neotectonism on the development of landforms and soils are discussed as follows:

(ii) Major Faults

Dauki Fault: It is an east-west trending major fault passing approximately along the southern margin of the Shillong Plateau (India) and northern boundary of Bangladesh. Dauki Fault has controlled the uplift of the Shillong Plateau (India) and the subsidence of the Sylhet Depression in Bangladesh (Morgan and McIntire, 1959; Murthy et al., 1969 and Desikachar, 1974).

Madhupur Fault: This is a very long tear fault (Morgan and McIntire, 1959) that forms the western scarpy limit of the Madhupur Upland and extends along NNW direction upto Sikkim (India).

Karatoya-Banar Fault: This fault delimits the northern margins of both the Barind and the Madhupur Uplands and extends along NW-SE direction upto the Himalayan foothills (Pitman, 1984).

Atrai-Dhaleswari Fault: This fault delimits the southern margins of both the Barind and the Madhupur Uplands and trends along NW-SE direction.

Padma Fault: Almost straight course of the Padma river through Ganges alluvial plain is suggestive of being controlled by a major fault. This fault has been identified by Nandy (1980) as a lineament along the river Padma.

Sylhet Fault: It delimits the northern margin of the Old Meghna Deltaic Plain and is downthrown to the northeast.

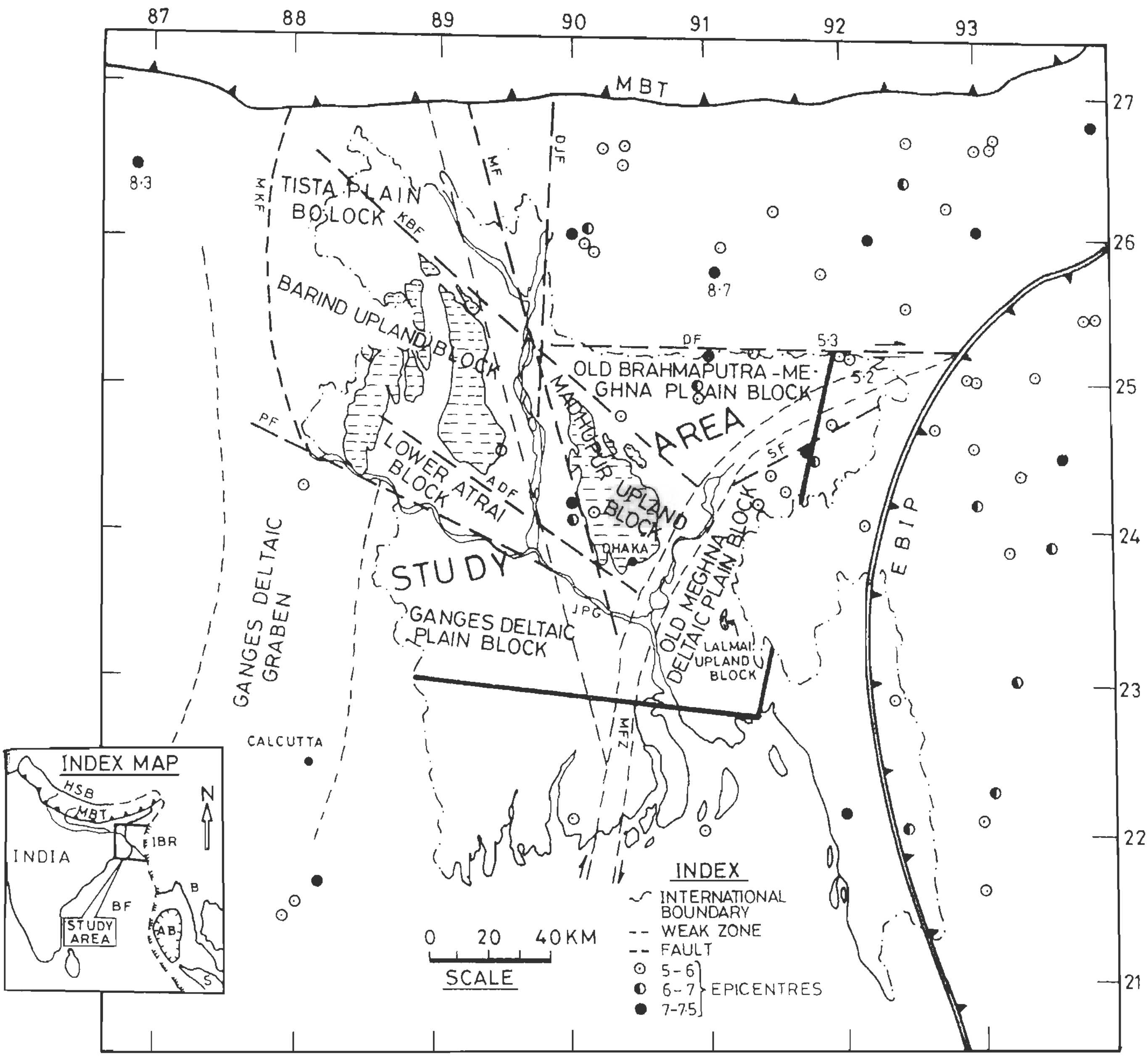


FIG.5·4. MAP SHOWING MAJOR FAULTS, TECTONIC BLOCKS AND EPICENTRES OF EARTHQUAKES FOR THE PERIOD 1762-1988 (MODIFIED AFTER KHANDOKER, 1990; MORGAN AND MCINTIRE, 1959; HOLCOMBE, 1977 AND GRAHAM ET AL., 1975). AB-ANDAMAN BASIN, ADF-ATRAI DHALESWARI FAULT, B-BURMA, BF-BENGAL FAN, DF-DAUKI FAULT, DJF-DHUBRI JAMUNA FAULT, EBIP-EASTERN BOUNDARY OF INDIAN PLATE, HSB-HIMALAYAN SUTURE BELT, IBR-INDOBURMAN RANGES, JPG-JAMUNA GRABEN, KBF-KARATOYA BANAR FAULT, MKF-MALDAH KISHANGANJ FAULT, MBT-MAIN BOUNDARY FAULT, MFZ-MEGHNA FAULT ZONE, MF-MADHUPUR FAULT, PF-PADMA FAULT, S-SUMATRA SF-SYLHET FAULT.

Maldah-Kishanganj Fault: This is a N-S trending fault. It controls the entire course of the Mahananda river which flows towards south along the western margin of the Barind Upland and joins the Ganges (Krishnan, 1982).

Dhubri - Jamuna Fault: It delimits the western margin of the Shillong plateau and extends along the Jamuna river in a N-S direction.

(iii) Weak Zones

Jamuna-Padma Graben: This weak zone follows a NW-SE trend roughly along the Jamuna-Padma river. It represents either a deep-seated major fault or a subsiding trough and is related to a sinistral sense of movement (Morgan & McIntire, 1959 and Sesoren, 1984).

Meghna Fault zone: This zone also represents either a major deep-seated fault or a subsiding trough and follows a NE-SW trend along the Meghna river. It is related to a dextral sense of movement (Sesoren, 1984).

Ganges Deltaic Graben: This weak zone is a N-S trending graben and lies in West Bengal (India). It extends from the coast to the foothills of the Darjeeling Himalaya. It has been identified by many workers (Burke and Dewey, 1973; Mukhopadhya et al., 1986 and Curray and Moore, 1974).

(iv) Tectonic blocks

Tista Plain BLock: This represents a graben (Garo-Rajmahal Gap) between the Rajmahal Hills and the Shillong Plateau. It is delineated on the west by the Maldah-Kishanganj Fault and on the east by the Dhubri-Jamuna Fault. On the north of this block lies the foothills of the Himalayas. Both the Tista Fan and Old Tista Plain overlie this tectonic block.

Barind Upland Block: It is an upthrown block rising to an elevation of about 40 m in the west. It tilts towards the southeast (Fig. 5.4).

Madhupur Upland Block: This is also an upthrown block rising to a maximum elevation of about 15m. It tilts towards the southeast (Fig.5.4).

Lower Atrai BLock: This is a downthrown block representing a subsided part of the Barind Upland and lies along the southern margin of the latter.

Old Brahmaputra-Meghna Plain Block: It is an easterly tilted block bounded on the north by the Dauki Fault, on the south by the Tista Banar Fault and on the east by the Meghna Fault zone. At the eastern part of the block lies a tectonic depression called the Sylhet Depression.

Old Meghna Deltaic Plain Block: This deltaic plain block rises about 2 m above the Meghna Floodplain and is slightly tilted towards the west.

Lalmai Upland Block: This is a small upthrown block and it rises about 25 m above the old Meghna Deltaic Plain.

Ganges Deltaic Plain Block: This block rises to an elevation of about 20 m in the northwest and 1 m in the southeast. It tilts towards the southeast and is bounded on the north by the Padma Fault, on the west by the Ganges Delta Graben and on the east by both the Jamuna-Padma Graben and the Meghna Fault zone.

(v) Neotectonism and the evolution of the landforms and soils

Tectonics seems to have played a major role in the development of landforms and soils in the study area. As discussed earlier, different tectonic blocks are bounded by faults/weak zones. Neotectonic activity along these bounding faults/weak zones controlled the patterns of movements of the blocks which in turn influenced the geomorphic and pedogenic processes in the study area. Significant phenomena caused by tectonics are as follows:

(1) **The Tista Plain Block** has accommodated a thick column of sediments since the Pleistocene time and at a later phase, the Tista Fan and Old Tista Plain were constructed on this block by the north-south flowing rivers like the Mahananda, Purnabhaba, Atrai and Karatoya. These rivers originating in the Himalayans pass through the Tista Fan and Old Tista Plain and finally join the Ganges and Brahmaputra rivers. In response to neotectonic activity, the above rivers shifted their courses and influenced the geomorphic and pedogenic processes. For example, the easterly tilting of the Tista Plain Block has influenced the migration of the Tista river towards the east (Fig.5.1) and now it flows along a fault. An age of 2500 to 3000 years has been ascribed to the soils on this block. From north to south systematic changes such as a decrease in rate of sedimentation and an increase in the degree of soil profile development are observed. This can be explained with reference to a pedofacies relationship discussed by Brown and Kraus (1987). According to them, the least developed soils form at a place where sediment accumulation is rapid, whereas the most developed soils form at a place where sediment accumulation rates are significantly less. Also, the observations made by Kumar (1991) and Srivastava (1992) show that a general decrease in sedimentation and an increase in degree of soil development occur from the Himalayan foothills towards the south due to a higher subsidence followed by an accumulation of thicker column of sediments adjacent to the Himalayan foothills.

(2) **The Barind and the Madhupur upland blocks** together with the Lower Atrai block represent a palaeofluvio-deltaic plain. This was subject to

uplift, block faulting and tilting in the Late Pleistocene period. Ferruginatic red soils (relict soils) of an earlier stage overlie major parts of the Madhupur Upland Block and only a small northeastern part of the Barind Upland Block (Fig.5.3). Mainly good internal soil drainage at the margins/edges of the uplands/valleys have promoted the development of deeply weathered red soils on the Madhupur and Lalmai Hill Uplands. Slow rate of uplift (Bashar, 1985) may also have facilitated the development of red soils on these uplands and northeastern parts of the Barind Upland. The higher rate of uplift of the Barind Tract as a whole may have favoured partial erosion of its soils. Also, in response to neotectonics, the Lower Atrai Block subsided and facilitated hydromorphism of soils under a poorly drained condition. The southern part of this block has allowed the deposition of sediments from the distributaries of the Ganges.

(3) The former floodplain of the old Brahmaputra-Meghna river system overlies **the Brahmaputra-Meghna Plain Block**. This block, in response to neotectonic instability, had tilted towards east and formed the Sylhet Depression at its eastern part as indicated by the eastward flow of the old Brahmaputra river system. The major river old Brahmaputra flows towards southeast along a fault and finally confluences with the Meghna river. This phenomenon has resulted in a moderately well drained condition in the west and a poorly drained condition in the east. The soils from the western part contain "argillans" indicating a leaching environment, whereas hydromorphic soils characterized by Fe-Mn nodules, ferruginous hypocoatings and ferriargillans (Fig.4.5.e) overlie the eastern part of the block. An age of 3000 to 4000 years has been

assigned to the soils overlying this tectonic block.

(4) An extensive deltaic plain of the Ganges overlies **the Ganges Deltaic Plain Block.** This tectonic block had undergone tilting towards the east which facilitated gradual easterly shifting of the Ganges from the N-S trending Bhagirathi-Hoogly channel (Fig.5.1). As a result, over the northwestern part of the block lie older soils than on the southeastern part. From the northwest to the southeast a tecto-pedafacies sequence (Kumar et al., in press) with ages of soils decreasing from 3000 to 800 years is found to occur on this block (Fig.5.5). The Ganges delta is prograding southward with contemporaneous decrease in rate of sedimentation in the direction of progradation. This may be explained as a pedofacies relationship (Brown and Kraus, 1987) with ages of soils decreasing from 3000 to 900 years B.P. towards the south (Fig.5.5).

(5) **The Old Meghna deltaic plain block** was a site of sedimentation till 4000 yrs. B.P. Neotectonic activities along the Meghna Fault zone, Sylhet Fault and Tripura folded zone probably caused the shifting of the Old Meghna river from this block and made it a site of pedogenesis. This block has been raised by about 2 m from the present Meghna estuarine floodplain.

(6) **The Lalmai Upland Block** being a small horst rises about 25 m above the adjoining Old Meghna Deltaic Plain. Mainly good soil drainage promoted the development of deeply weathered red soils on this block. Relatively slow rate of uplift (Bashar, 1985) may also have favoured the preservation of relict red soils at many places of the block.

(7) The influence of neotectonics on geomorphic and pedogenic processes is best documented by a very recent event of shifting of Old Brahmaputra river into the Jamuna river about 200 years ago. This may be attributed to reactivation of the Jamuna Padma graben/Madhupur Fault that influenced the migration of the Old Brahmaputra into Jamuna river now roughly following the trend of the Jamuna Padma graben. The sediments carried by the Jamuna river constructed the Brahmaputra Floodplain along the sides of the river and also buried parts of the former alluvial plains/soils.

The above discussion brings out that the neotectonism has been affecting the geomorphic and pedogenic processes significantly in the study area since the Late Pleistocene period. The spatial distribution of landforms and soils is related to neotectonics in the following manners:

(a) At a particular time in the past if a certain block subsides slightly, it becomes a waterlogged depression allowing hydromorphism of soils viz. the Lower Atrai Depression and the Sylhet Depression became low-lying areas and favoured hydromorphism of soils characterized by Fe-Mn nodules, ferruginous hypocoatings, ferriargillans and segregation of free iron oxides. Higher subsidence allowed sedimentation on the southern margin of the Lower Atrai Block.

(b) If a block is uplifted/tilted gradually, the rivers flowing over it shift away and the zone of sedimentation becomes a site of pedogenesis. Time of uplift/tilt determines the degree of pedogenesis. For example, the Madhupur and Lalmai upland blocks were subject to slow rate of

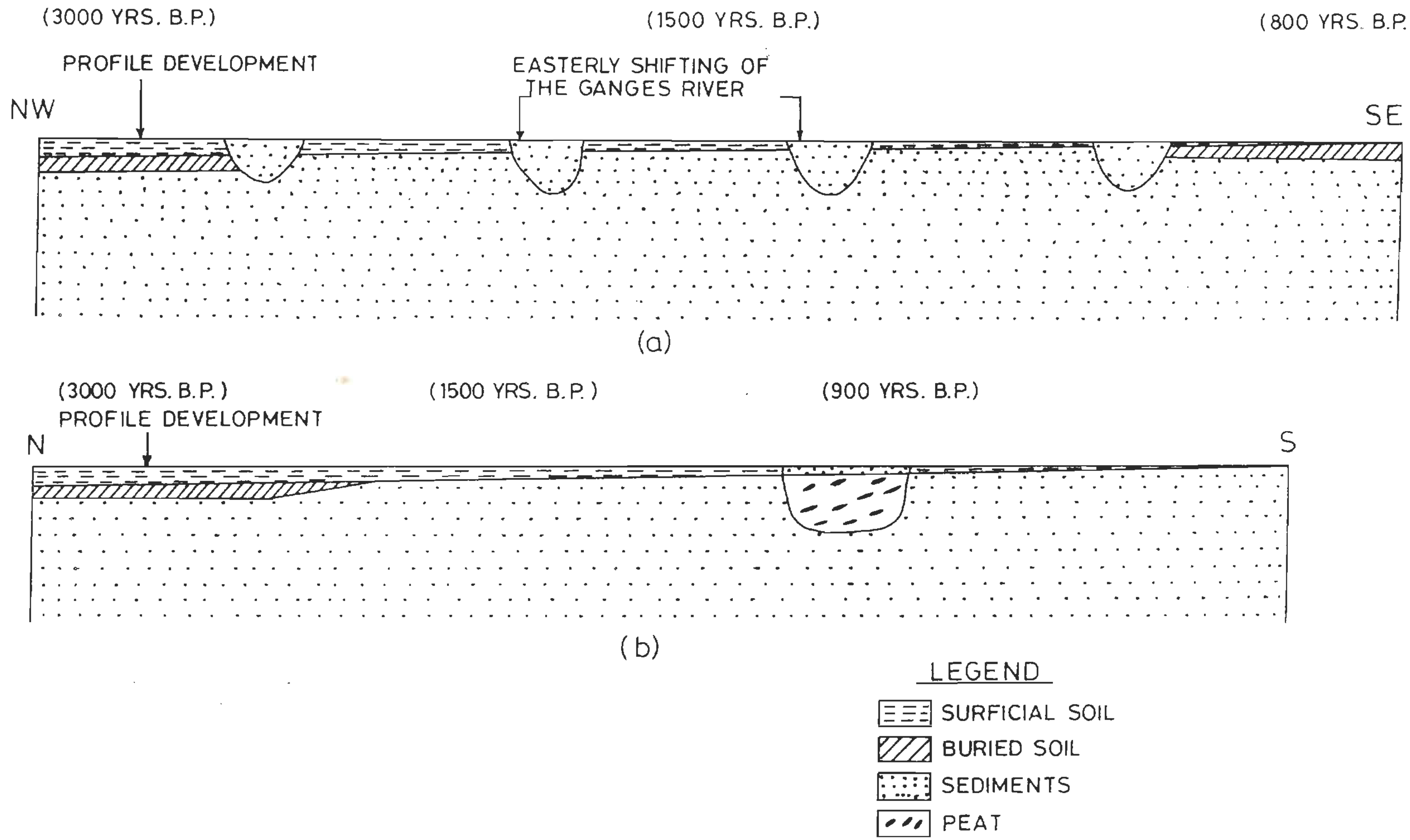


FIG. 5-5. DIAGRAMMATIC SKETCH SHOWING THE DEVELOPMENT OF (a) TECTO-PEDOFACIES RELATIONSHIP TOWARDS SOUTH-EAST AND (b) PEDOFACIES RELATIONSHIP TOWARDS THE SOUTH ON THE GANGES DELTAIC PLAIN. THE DEGREE OF SOIL DEVELOPMENT DECREASES SYSTEMATICALLY BOTH TOWARDS THE SOUTH-EAST AND SOUTH.

uplift/ tilting since the Late Pleistocene period and well developed relict red soils are preserved on these blocks. Similar way, the Old Meghna deltaic plain block underwent a slight uplift/tilting since the Mid-Holocene period and remained detached from active sedimentation as the Old Meghna river shifted its course from this block. Thus, a zone of sedimentation became a site of pedogenesis.

(c) Although mainly good drainage conditions facilitate deep weathering, rapid uplift of the tectonic block may also affect the development of soils. For example, the Barind Upland Block might have undergone erosion due to its rapid uplift/ tilting (e.g. Bashar, 1985) and except at the northeastern part, the entire upland lack 'red soils' unlike the Madhupur and the Lalmai upland areas.

(d) Due to gradual tilting of a block, the rivers flowing over the block may shift and abandon their courses successively and a pedofacies relationship may develop on the block. For example, a tecto-pedofactes occurs from northwest to southeast on the Ganges deltaic plain block with ages decreasing from 3000 to 800 years. On the other hand, a pedofacies relationship is observed both on the Tista Plain and Ganges Deltaic Plain Blocks along north-south direction in a reverse manner.

(e) The overall eastward/southeastward tilting of the Tista Plain, Ganges Deltaic Plain, Old Brahmaputra-Meghna Plain, Barind Upland and Madhupur Upland Blocks is indicated by easterly/southeasterly shifting of the Tista and Ganges rivers (Fig.5.1) and also by easterly and southeasterly subsidence of parts of the Old Brahmaputra Plain, Barind Tract and Madhupur Tract. This is attributed to the easterly subduction of the Indian plate beneath the Burmese plate. This is consistent with the observations made by other studies (Brunnscheiller, 1966; LeDain, 1984; Sengupta et al., 1990).

(f) Since the tectonic blocks are bounded by faults, movements of these blocks are accompanied by tectonic activities along the bounding faults and their times of activity can be constrained. For example, the Jamuna-Padma Graben or the Madhupur Fault reactivated about 200 years ago and allowed the Old Brahmaputra river to shift into the present Jamuna river. The floodplain on the sides of the Jamuna river testifies to its recent development.

5.7.4 Impacts of palaeoclimatic and sea level changes on the geomorphic and pedogenic processes

The palaeoclimatic and sea-level changes seem to have affected significantly the development of landforms and soils in the study area since the Late Pleistocene period. Some of these changes are discussed below.

The palaeoclimatic changes in and around the study area indicate a warm and humid climate around 40,000 years B.P. and this was followed by cold and dry climate till about 17,000 years B.P. (Vishnu-Mittre and Sharma 1984). Also, the monsoon climate passed through a very arid phase at 22,000 - 18,000 years B.P. (Cullen, 1981) when the study area witnessed a very weak SW monsoon characterized by low rainfall. During the last glacial maximum (18,000 years B.P.) the sea level fell down to - 130 m depth allowing the coastline to move over 100 km south than at present (Johnson, 1975 and Alam, 1989). During this lowered sea-level phase the upland areas of the study area as well as former geomorphic surfaces presently lying beneath the alluvial and deltaic plains of the Ganges- Brahmeputra-Meghna river system underwent erosion and entrenchment by the then rivers due to their low discharge, high sediment load and very low sea level than at present.

At later stage at about 12,500 - 10,500 years B.P. the study area passed through a very humid phase characterized by increased precipitation owing to strong SW monsoon circulation (Cullen, 1981). This was responsible for the greater amount of run-off by the Ganges-Brahmaputra system which facilitated the infillings of the former dissected valleys and sedimentation over the previous geomorphic surfaces. Then, a short period of dry phase passed over the study area which was responsible for the formation calcretes at many places at about 8000 - 7000 yrs. B.P. (Banerjee and Sen, 1987).

During the post-glacial maximum the sea-level started to rise gradually and at 6000-7000 years B.P. transgression of sea caused the coast line to move about 80 to 120 km inland than at present (Banerjee and Sen, 1987). As a result, some parts of the study area went beneath the sea. Since 6000 years B.P. the regression of sea took place. The delta building processes prograded towards south and finally reached upto the present coastline about 500 years ago.

The above discussion brings out that palaeoclimatic and sea level changes affected the geomorphic and soil-forming processes significantly in the study area. The upland soils covering 25% of the study area bear the witnesses of the palaeoclimatic changes and are marked by (i) the presence of relict red soils of Late Pleistocene time, (ii) soils of arid phase containing calcretes of state III at about 8000 - 7000 yrs. B.P. and (iii) hydromorphic soils of wet phase and valley soils on valley-infilled sediments since the Mid-Holocene time. Infillings of valleys occurred mainly in the Madhupur upland. This upland was probably influenced by the transgression of the sea. The alluvial and deltaic plains of the Ganges - Brahmaputra - Meghna system stabilized after the retreat of the sea from the deltaic system and the soil formation started with the regression of sea since 6000 years B.P. under humid climatic condition.

5.8 CONCLUSIONS

Major conclusions drawn from the present study are summarized as follows:

(1) Twelve soil-geomorphic units have been identified from the study area based on remote sensing studies (Landsat imageries), field checks, morphological investigations and laboratory analyses of soils. These units are (i) Brahmaputra Floodplain (ii) Young Ganges Deltaic Plain (iii) Tista Fan (iv) Old Tista Plain (v) Moribund Ganges Deltaic Plain (vi) Old Brahmaputra Plain (vii) Sylhet Depression (viii) Old Meghna Deltaic Plain (ix) Lower Atrai Depression (x) Barind Tract (xi) Madhupur Tract and (xii) Lalmai Hills.

(2) Using the field characteristics and laboratory data, the degree of soil development on the different soil-geomorphic units has been evaluated and is used to develop a soil chronoassociation for the study area.

(3) The soil-geomorphic units have been grouped into five members of the soil chronoassociation (QGB1 to QGB5, with QGB5 being the oldest member). The QGB1 member (< 1500 yrs. B.P.) includes the soils of the Brahmaputra Floodplain and Young Ganges Deltaic Plain. The QGB2 member (2500 to 3000 yrs. B.P.) includes the soil of the Tista Fan, Old Tista Plain and Moribund Ganges Deltaic Plain. The QGB3 member (3000 to 4000 yrs. B.P.) comprises soils of the Old Brahmaputra Plain, Sylhet Depression and Old Meghna Deltaic Plain. The soils of the Lower Atrai Depression are included in the QGB4 member (5000 to 6000 yrs. B.P.). The QGB5 member (>15000 yrs. B.P.) includes the soils of the Barind Tract, Madhupur Tract and Lalmai Hills.

(4) Major processes of soil formation recognised in the study area are physical and chemical weathering of mineral grains, translocation of fine clay (<.2 μm), impure clay, sensquioxides, oxides of alumina and silica and leaching of calcium carbonate from the upper horizons and their redeposition in the B horizons. Alteration of biotite has resulted in the transformation/neoformation of clay minerals. Chlorite has transformed to vermiculite and montmorillonite. Neoformation of kaolinite is a significant process. Synthesis of montmorillonite under a poorly drained condition may also be one of the processes.

(5) Three weathering/pedogenic phases are identified in the upland soils which covers 25% of the study area. These phases are **(a)** alternating wet and dry phase of Late Pleistocene time represented by the relict (red) soils with many thick argillans (50 - 250 μm) and argillic Bt horizons **(b)** dry phase at 8000-7000 Yrs. B.P. marked by calcretes of stage III and **(c)** wet phase since the Mid-Holocene time

marked by hydromorphism and ferrolysis of soils. On the other hand, the alluvial and deltaic plain soils of later period (since the Mid-Holocene time) cover 65% of the study area and are characterized by hydromorphism and ferrolysis of soils with minor extent of translocation of fine clay (<.2 μm) and leaching of calcium carbonate from the upper horizons and their redeposition in the B horizons. Also, the depression soils covering 10% of the study area are marked by general segregation of iron oxides throughout the profile, formation of thick ferriargillans (~80 μm) and flood coatings. These processes suggest strong hydromorphism of soils.

(6) Neotectonism affected sedimentation and pedogenesis by subsiding some areas so that they became sites of deposition; by slightly uplifting some areas to allow soil development; by strongly uplifting certain areas so that they were subject to erosion and by gently tilting other areas to facilitate the development of a pedofacies sequence.

(7) A few major faults recognized in the study area seem to be deep seated while others are unrelated to basement features. These faults have been active since the Late Pleistocene period.

(8) Many of the rivers like the Tista, Ganges, Brahmaputra and Meghna are fault-controlled.

(9) The eastward tilting of the Ganges Deltaic Plain, Tista Plain and old Brahmaputra-Meghna Plain Blocks is indicated by the easterly shifting of the Ganges and Tista rivers and easterly flow of the old Brahmaputra river. The southeasterly tilting of the Barind and Madhupur uplands is indicated by the southeasterly subduction of parts of the Barind and Madhupur uplands beneath recent sediments. All these

phenomena are attributed to the overall easterly subduction of the Indian plate beneath the Burmese plate and also to shear forces developed due to differential interaction of the Indian and Burmese plates.

(10) The areas close to the Himalayan foothills (e.g. the Tista Fan) show a pedofacies relationship with an increasing degree of soil development towards the distal part of the fan.

(11) The Ganges Deltaic Plain as a whole shows a tecto-pedofacies relationship towards the east/southeast and a pedofacies relationship from the north to south accompanied by a decreasing degree of soil development.

(12) During the last glacial maximum at about 18000 yrs. B.P. the lowering of sea level by 130 m in the Bay of Bengal caused the coast line to move over 100 km south from the present one. During this period the study area was subject to dissection by rivers due to lowering of sea level and weak SW monsoon. The monsoon climate passed through a very arid period at about 22,000-18000 yrs. B.P. and a very humid period at 12500-10500 yrs. B.P. A short period of dry climate existed at about 8000-7000 yrs. B.P. Since 6000 yrs. B.P. a warm and moist climate has been prevailing over the study area. Also, the transgression of sea at about 7000 - 6000 yrs. B.P. swept over many parts of the study area which was followed by regression of sea, progradation of the Ganges - Brahmaputra delta towards south and formation of soils.

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APPENDICES

APPENDIX - I

Soil development and profile development indices for the different soil-geomorphic units

Soil-Geomorphic unit	Profile	Hori- file	Thick- zon	SDI* ness	PDI**
(1)	(2)	(3)	(4)	(5)	(6)
	T4	Ap	0-10	6	
		B21	10-35	9	
		B22	35-55	8	51.29
Brahmaputra Floodplain		C	55-74	4	
		Bb1	74-114	9	
		Bb2	114-150	10	
		IIC	150-180	4	
	T5	Ap	0-10	7	
		B2	10-40	10.5	50.50
		B3	40-62	9	
		C1	62-72	6	
		C2	72-79	6	
	R1	Ap	0-16	9	
		A	16-42	10	
		Ap2	10-15	7	
		B	42-86	6	54.62
		C1	86-106	4	
		C2	106-115	4	
	R2	Ap1	0-13	9	
Tista Fan		Ap2	13-19	9	
		B21	19-33	14	58.94
		B22	33-49	13	
		B23	49-72	12	
		C1	72-97	6	
		C2	97-110	6	
	R3	Ap1	0-9	6.5	
		Ap2	9-15	6.5	
		B21	15-38	14	66.40
		B22	38-61	12.5	
		B3	61-88	10.5	
		C	88-110	3	
	R4	Ap	0-13	10	
		B21	13-48	15	
		B22	48-72	7.5	64.72
		C1	72.106	7	
		C2	106.130	1	

Soil-Geo-morphic units	Profile	Horizon	Thickness	SDI*	PDI*
(1)	(2)	(3)	(4)	(5)	(6)
	S7	Ap1	0-10	6	
		Ap2	10-15	10	
		B2	15-43	14.5	
Old Tista Plain		B3	43-71	9	60.02
		C	71-105	11	
		Bb1	105-142	16	
		Bb2	142-159	15	
		IIC	159-186	12	
		Bb	186-200	13.5	
		IIIC	200-230	8	
	S8	Ap	0-10	6	
		Ap2	10-15	7	
		B	15-26	9.5	
		C	26-47	6	68.63
		Bb	47-69	11	
		IIC	69-84	7.5	
		Bb1	84-103	10	
		Bb2	103-128	9	
		IIIC	128-152	4	
	T1	Ap	0-14	6	
		B1	14-41	14	
		B2	41-53	13	66.80
		C1	53-81	9	
		C2	81-98	9	
	T2	Ap	0-12	6	
		B1	12-36	10	
		B2	36-83	11	60.31
		B3	83-103	12	
		C1	103-138	8	
		C2	138-169	7	
Moribund Ganges Deltaic Plain	T3	Ap	0-11	10	
		B21	11-20	17	
		B22	20-48	18.5	
		B23	48-71	14	62.71
		C1	71-87	6	
		C2	87-134	6	
		Bb1	134-167	17	
		Bb2	167-181	9	

SDI* - Soil Development Index assessed according to Bilzi and Ciolkosz (1977) and Meixner and Singer (1981)

PDI** - Profile Development Index assessed according to Harden (1982).

(1)	(2)	(3)	(4)	(5)	(6)
	S3	Ap1	0-10	8	
		Ap2	10-17	12	
		B21	17-47	14.5	63.87
		B22	47-90	13	
		B3	90-120	11	
		C	120-140	6	
	S9	Ap1	0-9	5	
		Ap2	9-14	7	
		B21	14-36	9	
		B22	36-51	7.5	59.07
		B23	51-62	9	
Old		C1	62-74	3	
Brahma-		C2	74-82	6	
putra		Bb	82-103	12.5	
Plain		IIC	103-115	5	
	S10	Ap1	0-10	10	
		Ap2	10-16	11	
		B21	16-42	14.2	
		B22	42-58	7	61.89
		B23	58-85	10	
		B24	85-98	9.5	
		C	98-105	4	
	S11	Ap1	0-9	9	
		Ap2	9-15	11.5	
		B21	15-29	18.5	
		B22	29-42	22	69.20
		B23	42-57	24	
		C	57-83	17.5	
		Bb1	83-96	19.5	
		Bb2	96-110	19	
		Bb3	110-120	18.5	
	S12	Ap1	0-10	8	
		Ap2	10-17	10	
		B21	17-39	12.5	65.20
		B22	39-63	13.25	
		B23	63-85	13	
		B3	85-111	10.75	
		C1	111-120	10.75	
		C2	120-130	5.5	
Old	T10	Ap1	0-10	9.5	
Meghna		Ap2	10-16	9.5	
Deltaic		B2	16-45	15	74.72
Plain		B3	45-73	15	
		C	73-110	12	
	T11	Apg1	0-13	6	
		Apg2	13-20	6.5	
		B21	20-64	13.5	68.00
		B22	64-88	11.5	
		C1	88-104	8	
		C2	104-127	4	
	S1	Ap1	0-12	7	
Barind		Ap2	12-17	10	
Tract		B21	17-36	13.5	76.66
		B22	36-58	23	
		B24	58-92	21	
		C	92-105	18	
	S2	Ap	0-14	6	
		B21	14-28	15.5	
		B22	28-43	12.5	65.37
		B23	43-62	17.5	
		C	62-88	15.5	
	S5	Ap1	0-8	7	
		Ap2	8-13	12	
		B21	13-26	13.5	
		B22	26-64	16	76.97
		B23	64-90	16	
		C1	90-119	14	
		C2	119-140	11	
	S6	Ap1	0-10	6	
		Ap2	10-15	8	
		B21	15-32	12.5	
		B22	32-63	15.5	66.45
		B23	63-76	15	
		B24	76-124	13	
		B25	124-168	14	
		B26	168-202	14	
		C	202-265	7	
Madh-	T7	A	0-8	6	
upur		B21t	8-81	22	
Tract		B22t	81-102	25	
		B23t	102-180	23	175.50
		B24t	180-200	23	
		B25t	200-300	23	

(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
	T12	A	0-15	10.5							
		B21t	15-32	19.5							
Lalmai		B22t	32-48	18.5	141.88						
Hills		B23t	48-65	18.5							
		B24t	65-165	15.5							
		C1	165-200	6							
		C2	200-300	5							
	S13	Ap	0-15	8							
		B21	15-32	15.75							
		B22	32-43	16.75							
		B23	43-63	16	68.34						
		B24	63-83	14.5							
		B25	83-96	8							
		C	96-110	7							
Sylhet		Ap	0-15	7.5							
Depre-		B	15-27	10							
ssion		C	27-45	8	66.73						
	S14	Bb1	45-58	13							
		Bb2	58-77	14.75							
		Bb3	77-98	19							
		Bb4	98-110	17							
	S4	Ap1	0-9	13							
		Ap2	9-16	16							
Lower		B21	16-47	18	84.16						
Atrai		B22	47-78	18							
Depre-		B23	78-120	17.5							
ssion		B3	120-180	16.5							
		C	180-210	8							

APPENDIX - II

Particle size distribution, clay accumulation index, (sand+silt)/clay ratio and pH values of soil profiles of the various soil-geomorphic units

Depth (cm)	Hori-zons	Sand%	Silt%	Clay%	Tex-ture	Clay accumu-lation index	(sand+silt) / clay	Percent decrease of (8)from the A/c to the B hori-zon	pH
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
BRAHMAPUTRA FLOODPLAIN									
Pedon T4									
0-10	Ap	4.97	78.75	16.27	Sil		5.14		8.0
10-35	B21	0.17	86.53	13.29	Sil		6.52		8.0
35-55	B22	1.50	85.94	12.56	Sil		6.96	-	8.0
55-74	C	5.12	85.89	8.97	Sil	152	10.72		8.0
74-114	Bb1	1.30	77.54	21.16	Sil		3.72		8.0
114-150	Bb2	0.63	80.45	18.91	Sil		4.28	22.17	8.0
150-180	Cb	20.54	65.02	14.44	Sil		5.92		8.0
Pedon T5									
0-10	Ap	4.47	76.00	19.52	Sil		4.12		7.5
10-40	B	0.41	80.96	18.62	Sil		4.37		8.0
40-62	C1	2.34	81.04	16.60	Sil		5.02	-	8.0
62-72	C2	0.70	85.72	13.36	Sil		6.37		8.0
72-79	C3	2.94	80.34	16.69	Sil		4.99		8.0
79-90	C4	4.71	80.29	14.99	Sil	179	5.67		8.0
90-108	C5	3.33	83.23	13.43	Sil		6.44		8.0
108-120	C6	3.06	83.89	13.04	Sil		6.66		8.0
TISTA FAN									
Pedon R1									
0-16	Ap	48.01	34.96	17.01	Lm		4.88		4.5
16-42	A1	62.52	16.28	21.12	Salm		3.72		4.5
42-86	B	73.93	10.72	15.33	Salm	235	5.52		5.0
86-106	C1	85.50	6.14	8.35	Salm		10.97		5.0
106-115	C2	83.85	6.10	10.03	Salm		8.99		5.0

Sil = Silt loam, Sicl = Silty clay loam, Sic = Silty clay, Lm = Loam, Salm = Sandy loam, Sd = Sand, Clm = Clay loam, C = clay.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
				Pedon R2					
0-13	Ap1	6.22	66.04	27.73	Sil		2.60		6.0
13-19	Ap2	1.08	66.04	32.87	Sicl		2.03		7.0
19-33	B21	6.78	58.64	34.57	Sicl	140	1.89	27.30	8.0
33-49	C	3.39	72.00	24.59	Sil		3.06		8.0
49-72	Bb1	8.19	56.49	35.31	Sicl		1.83		8.0
72-97	Bb2	7.02	64.81	28.15	Sicl	400	2.55		8.0
97-110	Cb	21.91	54.93	23.14	Sil		3.32		8.0
				Pedon R3					
0-9	Ap1g	16.48	64.11	19.40	Sil		4.15		5.5
9-15	Ap2g	6.82	73.04	20.12	Sil		3.96		8.0
15-38	B21	14.59	65.46	19.93	Sil		4.01	-	8.0
38-61	B23	4.86	73.81	21.32	Sil	458	3.68		8.0
61-88	B3	13.90	74.51	11.58	Sil		7.63		8.0
88-110	C	36.14	52.76	11.08	Sil		8.08		8.0
				Pedon R4					
0-13	Ap	35.90	47.65	16.44	Lm		5.08		5.5
13-48	B21	16.91	59.70	23.37	Sil		3.28		5.5
48-72	B22	16.78	59.26	23.95	Sil	418	3.17	36.61	6.0
72-106	C1	10.13	78.43	11.43	Sil		7.75		6.0
106-130	C2	89.00	4.01	6.97	Sd		13.34		7.5
				OLD TISTA PLAIN					
				Pedon S7					
0-10	Ap1	9.12	71.36	19.51	Sil		4.12		6.0
10-15	Ap2	4.71	74.44	20.84	Sil		3.79	18.68	8.0
15-43	B21	3.44	68.73	27.81	Sil	578	2.59		8.0
43-71	B3	1.28	79.18	19.53	Sil		4.11		8.0
71-105	C	1.62	85.02	13.34	Sil		6.49		8.0
105-142	Bb*	3.14	64.64	32.20	Sicl	1018	2.10		8.0
142-159	Bb	0.90	58.89	40.19	Sicl		1.48		8.0
159-186	Cb	5.44	78.70	15.84	Sil		5.31		8.0
186-200	Bb	10.81	42.00	47.18	Sicl	424	1.12		8.0
200-230	C6	50.36	32.88	16.75	Sil		4.96		8.0

Bb* = Buried B horizon

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
				Pedon S8					
0-10	Ap1	14.57	62.30	23.12	Sil		3.32		7.0
10-15	Ap2	9.51	65.38	25.10	Sil		2.98		8.0
15-26	B	12.10	67.83	20.05	Sil	44	3.99		8.0
26-47	C	34.46	49.45	16.08	Lm		5.24		8.0
47-69	Bb	4.12	71.93	23.93	Sil	336	3.17	-	8.0
69-84	Cb	4.47	86.87	8.64	Silt		10.57		8.0
84-103	Bb	13.73	68.79	17.47	Sil		4.72		8.0
103-128	Bb	14.93	64.06	20.99	Sil	138	3.76		8.0
128-152	Cb	55.69	27.96	16.33	Salm		5.11		8.0
			MORIBUND GANGES DELTAIC PLAIN						
				Pedon T1					
0-14	Ap	18	72	10	Sil		9		7.0
14-41	B1	19	66	15	Sil		5.66		8.0
41-53	B2	18	67	15	Sil	273	5.66	37.11	8.0
53-81	C1	20.5	70	9.5	Sil		9.52		8.0
81-98	C2	21	71	8	Sil		11.5		8.0
				Pedon T2					
0-12	Ap	34.29	26.50	39.19	Sil		1.55		7.0
12-36	B1	19.70	72.92	7.36	Sil		12.58		8.0
36-83	B2	20.69	68.45	10.35	Sil	526	8.21		8.0
83-103	B3	18.72	61.22	20.05	Sil		3.99		8.0
103-138	C1	23.17	70.65	6.17	Sil		15.20		8.0
138-169	C2	13.20	73.55	13.23	Sil		6.55		8.5
				Pedon T3					
0-11	Ap	3.5	71.5	25	Sil		3.00		4.5
11-20	B1	2.9	67.5	29.6	Sicl		2.37		5.5
20-48	B22	4.2	64.1	31.7	Sicl	713	2.15	21	5.5
48.71	B23	7.1	65.1	27.8	Sil		2.59		8.0
71.87	C1	10.5	69.2	20.3	Sil		3.92		8.0
87-134	C2	12.1	69.9	18.0	Sil		4.55		8.0
134-167	Bb1	4.5	62.8	32.8	Sicl	582	2.05	44.4	8.0
167-181	Bb2	6.9	68.2	24.9	Sil		3.01		8.0

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Pedon S3									
0-10	Ap1	3.57	74.16	22.26	Sil		3.49		8.0
10-17	B21	2.77	69.56	27.66	Sil		2.59		8.0
17-47	B22	7.19	70.52	22.28	Sil	375	3.48		8.0
47-90	B23	12.14	73.56	14.29	Sil		5.99	-	8.0
90-120	B3	10.98	73.06	15.95	Sil		5.26		8.0
120-140	C	27.90	57.63	14.45	Sil		5.91		8.0
OLD BRAHMAPUTRA PLAIN									
Pedon S9									
0-9	Ap1	27.53	63.97	8.49	Sil		10.77		6.0
9-14	Ap2	6.00	78.31	15.68	Sil		5.37		6.5
14-36	B21	12.77	74.03	13.19	Sil		6.58		7.5
36-51	B22	44.81	48.69	6.50	Lm	435	14.38		7.5
51-62	B3	21.88	71.03	7.08	Sil		13.12	-	7.5
62-74	C1	70.94	23.77	5.28	SaLm		17.93		7.5
74-82	C2	43.75	51.93	4.33	Lm		22.09		7.0
82-103	Bb	7.21	77.97	14.82	Sil		5.74		8.0
103-115	Cb	60.24	34.62	5.17	Salm		18.34		8.0
Pedon S10									
0-10	Ap1	10.55	67.88	22.24	Sil		3.52		6.5
10-16	Ap2	5.39	80.65	13.94	Sil		6.17		6.5
16-42	B21	25.37	57.32	17.30	Sil	588	4.78	22.52	7.5
42-58	C	46.57	45.61	7.80	Lm		11.81		7.0
58-85	Bb1	17.32	68.43	14.24	Sil		6.02	-	7.5
85-98	Bb2	12.82	70.21	16.95	Sil		4.90		7.0
98-105	Bb3	20.79	61.98	17.22	Sil		4.80		8.0
Pedon S11									
0-9	Ap1	21.71	56.33	21.95	Sil		3.55		6.0
9-15	Ap2	12.65	58.61	28.72	Sil		2.48		6.0
15-29	B21	10.84	63.11	26.04	Sil		2.83		7.0
29-42	B22	14.20	58.13	27.65	Sil	758	2.61	28.57	7.5
42-57	B23	33.10	45.80	21.09	Lm		3.74	-	7.5
57-83	C	37.98	46.90	15.11	Lm		5.60		7.5
83-96	Bb1	4.34	69.32	26.32	Sil		2.79		8.0
96-110	Bb2	9.24	65.15	25.59	Sil		2.90		8.0
110-120	Bb3	14.65	64.33	21.00	Sil		3.76		8.0

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
				Pedon S12					
0-10	Ap1	11.77	78.18	10.03	Sil		8.96		6.5
10-17	Ap2	11.30	71.99	16.69	Sil		4.99		6.5
17-39	B21	20.72	67.82	11.45	Sil		7.74		7.5
39-63	B22	15.52	58.95	25.52	Sil	821	2.91	37.72	7.5
63-85	B23	12.72	68.25	19.02	Sil		4.25		7.5
85-111	B31	13.20	63.49	23.30	Sil		3.29		7.5
111-120	B32	25.32	51.89	22.77	Sil		3.39		8.0
120-130	C	32.49	54.86	12.59	Sil		6.93		8.0
				Pedon T8					
0-15	A	4.75	59.75	35.49	Sicl		1.81		7.0
15-60	B	0.06	54.03	45.91	Sic		1.17		8.0
60-90	C1	4.68	80.85	14.46	Sil	-	5.91	-	8.0
90-140	C2	0.57	85.01	14.41	Sil		5.93		8.0
140-170	C3	4.99	78.33	14.66	Sil		5.68		8.0
170-200	C4	1.88	87.21	10.89	Sil		8.18		8.0
				SYLHET DEPRESSION					
				Pedon S13					
0-15	Ap	1.14	81.94	16.91	Sil		4.91		6.5
15-32	B21	2.83	57.48	39.67	Sicl		1.52		6.5
32-43	B22	3.48	70.10	26.40	Sil		2.78		7.0
43-63	B23	4.46	61.99	33.54	Sicl	1946	1.98	54.66	7.5
63-83	B24	0.94	70.67	28.38	Sil		2.52		8.0
83-96	B25	1.08	68.92	29.99	Sil		2.33		8.0
96-110	C1	0.27	91.63	8.09	Sil		11.36		8.0
110-115	C2	0.23	85.03	14.72	Sil		5.79		8.0
				Pedon S14					
0-15	Ap	65.60	15.94	18.44	Salm		4.42		6.5
15-27	B1	29.67	53.35	16.97	Sil		4.89	30.54	6.5
27-45	B	40.38	47.18	12.43	Lm	55	7.04		6.5
45-58	C	14.16	54.77	31.06	Sicl	+	2.21		5.5
58-77	Bb	20.01	44.68	35.30	Sicl	1786	1.83	-	6.0
77-98	Cb	10.05	43.94	46.00	Sic		1.17		6.5
98-110	Bb	8.49	45.22	46.28	Sic		1.16		6.5

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)

OLD MEGHNA DELTAIC PLAIN

Pedon T9

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
0-10	Ap1	1.08	81.97	16.94	Sil		4.90		6.5
10-15	Ap2	0.18	82.10	17.71	Sil		4.64		8.0
15-54	B21	0.67	79.86	19.45	Sil	392	4.14	32.05	8.0
54-89	B22	0.50	80.92	18.56	Sil		4.38		8.0
89-115	C	4.38	81.87	13.74	Sil		6.27	–	8.0

Pedon T10

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
0-10	Ap1	0.74	79.63	19.62	Sil		4.09		7.0
10-16	Ap2	0.22	75.52	24.24	Sil		3.12		8.0
16-45	B21	1.69	54.10	44.20	Sic	1266	1.26	35.56	8.0
45-73	B3	0.52	79.55	19.92	Sil		4.01		8.0
73-110	C	1.29	89.50	9.20	Silt		9.80		8.0

Pedon T11

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
0-13	Ap1g	5.36	84.57	10.06	Silt		8.93		7.0
13-20	Ap2g	6.50	59.49	34.00	Sicl		1.94		8.0
20-64	B21	7.61	69.98	22.40	Sil	705	3.46	35.38	8.0
64-88	B22	3.94	84.98	11.06	Silt		8.08		8.0
88-104	C1	4.63	85.39	9.97	Silt		9.02	-	8.0
104-127	C2	1.42	90.36	8.21	Silt		11.70		8.0

LOWER ATRAI DEPRESSION

Pedon S4

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
0-9	Ap1	0.47	67.97	31.55	Sicl		2.16		6.5
9-16	Ap2	0.97	58.24	40.78	Sicl		1.45		8.0
16-47	B21	0.95	44.17	54.87	Sic		0.82		8.0
47-78	B22	2.88	49.75	47.36	Sic	1935	1.19	40.84	8.0
78-120	B23	5.77	63.59	30.62	Sicl		2.26		8.0
120-180	B3	5.84	62.88	31.27	Sicl		2.19		8.0
180-210	C	6.07	67.13	26.79	Sil		2.73		8.0

BARIND TRACT

Pedon S1

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
0-12	Ap1	5.08	68.12	26.79	Sil		2.73		6.5
12-17	Ap2	3.69	78.45	17.85	Sil		4.60		8.0
17-36	B21	4.71	66.85	28.43	Sil		2.51		8.0
36-58	B22	3.11	70.43	26.45	Sil	1528	2.78	52.46	8.0
58-92	B3	7.81	48.16	44.02	Sic		1.27		8.0
92-105	C	7.46	53.81	38.71	Sicl		1.58		8.0

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
				Pedon S2					
0-14	Ap	6.24	68.49	25.25	Sil		2.95		7.5
14-28	B21	2.50	53.95	43.46	Sic		1.30		8.0
28-43	B22	5.63	71.38	22.98	Sil	700	3.35	27.62	8.0
43-62	B3	4.12	55.47	40.40	Sic		1.47		8.0
62-88	C	3.23	67.58	29.17	Sicl		2.42	-	8.0
				Pedon S5					
0-8	Ap1	9.55	74.80	15.64	Sil		5.39		5.5
8-13	Ap2	9.62	65.61	24.76	Sil		3.04		6.5
13-26	B21	11.90	51.74	36.35	Sicl		1.75		8.0
26-64	B22	7.09	67.07	25.82	Sil	1702	2.87	40.20	8.0
64-90	B3	10.89	63.86	25.23	Sil		2.96		8.0
90-119	C1	10.41	61.47	28.10	Sil		2.55		8.0
119-140	B2	15.59	48.02	36.38	Sil		1.74		8.0
				Pedon S6					
0-10	Ap1	12.73	62.81	24.45	Sil		3.08		5.5
10-15	Ap2	9.89	66.47	23.63	Sil		3.23		6.5
15-32	B21	14.60	67.12	18.27	Sil		4.47		8.0
32-63	B22	17.35	56.87	25.76	Sil		2.88		7.0
63-76	B3	15.09	52.42	32.47	Sicl	1955	2.07	-	7.0
76-124	C1	20.91	55.38	23.69	Sil		3.22		8.0
124-168	C2	12.66	51.24	36.09	Sicl		1.77		8.0
168-202	C3	12.16	48.69	39.14	Sicl		1.55		8.0
202-265	C4	28.48	52.04	19.46	Sil		4.13		8.0
				MADHUPUR TRACT					
				Pedon T6					
0-10	Ap1	6.38	69.66	23.95	Sil		3.17		5.5
10-18	Ap2	5.12	64.96	29.91	Sil		2.34		5.5
18-42	B21	10.58	67.49	21.92	Sil	-	3.56	-	6.0
42-52	B22	9.96	64.73	25.30	Sil		2.95		6.0
52-110	B23	8.18	69.07	22.73	Sil		3.39	-	6.5
110-140	C	4.07	76.33	19.58	Sil		4.10		6.5

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
				Pedon T7					
0-8	A	21.80	50.02	28.16	Sicl		2.55		6.1
8-81	B21	12.67	33.66	53.65	C		0.86		5.2
81-102	B22	12.91	36.76	50.31	C		0.98		5.2
102-180	B23	10.88	40.71	48.40	Sic	4354	1.06	58.04	5.5
180-200	B24	16.44	32.95	50.59	C		0.97		5.5
200-300	B25	13.01	46.85	40.13	Sic		1.49		5.5
				LALMAI HLLLS					
				Pedon T12					
0-15	A	63.86	28.29	7.83	Salm		11.76		4.5
15-32	B21	51.72	40.17	8.09	Salm		11.35		5.0
32-48	B22	62.32	26.48	11.18	Salm	1385	7.94	30.61	5.0
48-65	B23	65.68	21.80	12.51	Salm		6.99		5.0
65-165	B3	65.91	20.49	13.58	Salm		6.36		5.0
165-200	C	75.22	21.40	3.36	Salm		28.75		5.5

APPENDIX - III

Variation of Major Oxides and Molar Ratio with Depth in the Various Soil-Geomorphic Units

Depth	Horizon	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	MnO	Na_2O	K_2O	Molar ratio $SiO_2/R_2O_3^*$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
TISTA FAN											
Pedon R1											
0-16	Ap	69.26	18.46	5.02	0.79	0.12	0.64	0.09	1.23	1.93	5.18
16-42	A	69.54	18.39	5.48	0.81	0.07	0.70	0.09	1.11	2.03	5.15
42-86	B	68.00	19.89	5.52	0.82	0.19	0.67	0.10	1.40	2.26	4.71
86-106	C1	69.81	18.39	5.41	0.83	0.38	0.61	0.11	1.70	2.25	5.18
106-115	C2	70.39	18.41	5.03	0.80	0.50	0.61	0.12	1.85	2.16	5.27
Pedon R4											
0-13	Ap	68.10	18.24	5.97	0.78	0.51	1.20	0.16	1.50	2.22	5.01
13-48	B21	66.21	19.21	6.37	0.89	0.52	1.34	0.18	1.40	2.29	4.60
48-72	B22	65.32	19.52	7.44	0.91	0.53	1.83	0.15	1.36	2.67	4.35
72-106	C1	67.12	18.10	7.24	0.84	0.40	1.83	0.13	1.49	2.83	4.78
106-130	C2	68.41	17.21	4.66	0.85	0.40	0.60	0.11	1.43	1.89	5.45
OLD TISTA PLAIN											
Pedon S7											
0-10	Ap1	64.32	20.21	6.54	0.75	0.52	1.29	0.12	1.27	2.37	4.30
10-15	Ap2	64.21	20.45	6.57	0.78	0.34	1.30	0.12	1.30	2.32	4.25
15-43	B21	62.51	22.32	7.69	0.85	0.20	1.69	0.15	1.01	2.64	3.74
43-71	B3	64.61	20.10	7.78	0.81	0.18	1.71	0.15	1.07	2.93	4.20
71-105	C	65.51	19.89	7.50	0.82	0.20	1.70	0.15	1.17	3.02	4.32
105-142	Bb1	60.00	23.23	7.85	0.84	0.10	1.60	0.16	0.86	2.67	3.47
142-159	Bb2	59.00	23.12	7.31	0.85	0.15	1.61	0.16	0.90	2.49	3.46
159-186	Cb	64.91	18.59	7.53	0.78	0.32	1.77	0.14	1.19	3.08	4.51
186-200	Bb	58.00	24.45	7.57	0.87	0.21	1.59	0.14	0.96	2.33	3.23
200-230	Cb	65.21	19.12	6.71	0.75	0.14	1.45	0.14	1.50	1.99	4.54

$$R_2O_3^* = Al_2O_3 + Fe_2O_3 + TiO_2$$

MORIBUND GANGES DELTAIC PLAIN

Pedon T1

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
0-14	Ap	68.23	16.52	6.77	0.89	1.02	1.44	0.09	1.03	2.37	5.27
14-41	B1	67.54	16.95	7.28	0.81	1.54	1.60	0.08	0.88	2.27	5.06
41-53	B2	66.32	17.59	6.54	0.79	4.05	1.36	0.05	0.80	1.35	4.94
53-81	C1	65.51	16.97	6.72	0.82	3.84	1.81	0.07	1.01	2.08	5.22
81-98	C2	62.20	15.25	6.41	0.91	8.07	2.07	0.08	1.07	2.04	5.14
Pedon T3											
0-11	Ap	68.10	17.10	6.43	0.81	0.23	1.46	0.06	0.74	2.48	5.19
11-20	B1	67.50	18.42	6.62	0.85	0.50	1.34	0.05	0.67	1.99	4.82
20-48	B22	66.10	18.56	7.15	0.89	0.50	1.45	0.05	0.72	2.52	4.62
48-71	B23	65.51	18.91	7.50	0.90	0.51	1.56	0.12	0.74	2.60	4.47
71-87	C1	67.92	17.00	6.48	0.91	0.66	1.29	0.10	1.04	2.07	5.45
87-134	C2	66.25	15.90	6.88	0.82	3.35	1.77	0.09	0.84	2.24	5.27
134-167	Bb1	65.21	18.42	8.10	0.91	0.57	1.72	0.80	0.43	2.45	4.46
167-181	Bb2	65.10	18.62	6.05	0.91	0.85	0.84	0.05	0.88	2.09	4.66
Pedon S3											
0-10	Ap1	67.10	17.23	7.80	0.81	1.13	1.91	0.16	0.64	2.19	4.89
10-17	Ap2	66.00	17.49	7.83	0.85	2.18	2.07	0.16	0.57	2.28	4.75
17-47	B21	65.52	18.89	7.14	0.89	1.27	1.45	0.12	0.69	2.05	4.52
47-90	B22	65.61	19.10	7.02	0.91	0.46	0.88	0.12	0.98	1.92	4.49
90-120	B3	66.00	19.32	7.17	0.95	0.44	1.22	0.13	1.87	2.12	4.46
120-140	C	67.70	17.42	6.53	0.85	0.63	1.08	0.13	0.99	1.91	5.06
OLD BRAHMAPUTRA PLAIN											
Pedon S9											
0-9	Ap1	69.23	15.61	5.91	0.81	1.52	1.26	0.05	1.56	1.89	5.75
9-14	Ap2	69.10	15.92	6.46	0.85	1.39	1.44	0.09	1.41	1.93	5.55
14-36	B21	67.23	17.21	7.12	0.99	1.28	1.67	0.08	1.52	2.01	4.98
36-51	B22	66.00	17.31	6.27	0.89	1.70	1.42	0.08	1.66	1.98	4.98
51-62	B3	66.21	17.40	6.58	0.92	1.83	1.50	0.07	1.65	1.97	4.93
62-74	C1	69.42	15.61	5.88	0.93	2.71	1.31	0.07	1.80	1.70	5.73
74-82	C2	66.43	17.91	6.60	0.85	1.87	1.49	0.11	1.68	1.89	4.85
82-103	Bb	66.00	17.21	7.09	0.96	0.98	1.72	0.09	1.21	2.10	4.87
103-115	Cb	66.10	17.91	7.15	0.87	0.99	1.73	0.09	1.32	2.28	4.72

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
					Pedon - S12						
0-10	Ap1	68.50	16.00	5.76	0.73	0.96	1.15	0.05	1.40	2.01	5.57
10-17	Ap2	67.10	16.20	6.47	0.81	0.88	1.42	0.08	1.50	2.25	5.32
17-39	B21	66.20	17.00	6.10	0.92	1.30	1.30	0.06	1.36	1.89	5.09
39-63	B22	65.50	17.21	6.13	0.92	0.86	1.29	0.05	1.23	1.94	4.98
63-85	B23	65.50	17.00	6.68	0.95	0.86	1.54	0.06	1.27	2.31	4.96
85-111	B31	66.20	16.95	6.91	0.94	0.69	1.25	0.04	1.01	1.89	4.98
111-120	B32	68.00	16.10	6.39	0.84	1.02	1.40	0.05	1.22	1.95	5.43
120-130	C	68.10	16.15	6.23	0.91	1.23	1.36	0.06	1.35	1.92	5.43
					SYLHET DEPRESSION						
					Pedon S13						
0-15	Ap	67.12	18.32	6.45	0.87	0.29	1.11	0.04	0.83	1.82	4.80
15-32	B21	66.10	18.21	7.10	0.81	0.12	1.08	0.06	0.76	1.88	4.72
32-43	B22	65.91	19.10	6.85	0.91	0.30	1.17	0.06	0.76	1.97	4.54
43-63	B23	65.81	19.34	7.44	0.95	0.33	1.34	0.07	0.82	2.06	4.41
63-83	B24	65.91	19.40	7.60	0.92	0.36	1.38	0.12	0.86	2.23	4.38
83-96	B25	67.00	18.10	7.80	0.89	0.53	1.48	0.05	0.97	2.25	4.69
96-110	C1	67.10	17.10	8.44	0.85	0.73	1.68	0.11	1.10	2.29	4.83
110-115	C2	67.21	16.50	7.80	0.81	1.01	1.86	0.08	1.45	2.34	5.03
					Pedon T9						
0-10	Ap1	69.50	16.20	5.51	0.81	0.60	0.94	0.08	1.25	1.94	5.68
10-15	Ap2	69.10	16.81	5.95	0.85	0.58	1.04	0.08	1.31	1.98	5.40
15-54	B21	67.50	17.95	6.49	0.89	1.44	1.09	0.11	1.27	2.08	4.93
54-89	B22	67.30	17.10	6.94	0.91	0.50	1.04	0.14	1.13	1.85	5.08
89-115	C	69.78	15.95	7.24	0.90	0.71	1.51	0.15	1.33	2.24	5.45
					OLD MEGHNA DELTAIC PLAIN						
					Pedon T11						
0-13	Ap1g	69.25	16.28	5.83	0.96	0.98	1.01	0.04	1.41	1.66	5.53
13-20	Ap2g	69.59	16.32	5.27	0.89	0.60	1.00	0.05	1.28	1.68	5.50
20-64	B21	67.25	17.58	7.50	0.91	0.61	1.30	0.08	1.30	0.83	4.70
64-88	B22	67.59	18.58	7.50	0.85	0.72	1.47	0.11	1.34	1.96	4.62
88-104	C1	69.61	15.85	6.54	0.89	0.88	1.27	0.07	1.45	1.84	5.58
104-127	C2	70.25	15.32	6.98	0.92	0.28	1.44	0.14	1.42	1.99	5.69

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
					LOWER ATRAI DEPRESSION						
					Pedon S4						
0-9	Ap1	62.00	20.21	7.91	0.81	0.28	1.44	0.10	0.51	2.27	4.00
9-16	Ap2	61.21	20.41	8.00	0.82	0.33	1.55	0.12	0.48	2.37	3.91
16-47	B21	59.47	21.21	8.00	0.85	0.43	1.71	0.12	0.42	2.37	3.68
47-78	B22	59.10	21.34	8.21	0.89	0.36	1.63	0.12	0.47	2.35	3.62
78-120	B23	60.00	21.41	7.33	0.91	0.03	0.94	0.12	0.52	2.05	3.73
120-180	B3	61.21	20.32	7.96	0.92	0.04	0.80	0.11	0.47	1.99	4.08
180-210	C	61.84	20.32	6.67	0.95	0.05	0.72	0.09	0.40	1.88	4.07
					BARIND TRACT						
					Pedon S1						
0-12	Ap1	67.50	20.20	4.81	0.82	0.07	0.42	0.08	0.55	1.43	4.71
12-17	Ap2	67.10	20.51	4.97	0.85	-	0.35	0.07	0.46	1.50	4.59
17-36	B21	65.50	21.51	5.63	0.89	-	0.43	0.06	0.34	1.60	4.23
36-58	B22	66.21	22.69	6.23	0.91	-	0.48	0.04	0.31	1.64	4.03
58-92	B3	66.00	21.32	6.87	0.94	-	0.57	0.12	0.34	1.75	4.16
92-105	C	67.00	20.46	6.50	0.90	0.08	0.65	0.16	0.37	1.82	4.41
					Pedon S6						
0-10	Ap1	64.21	20.21	5.60	0.79	-	0.30	0.08	0.52	1.59	4.39
10-15	Ap2	65.00	20.42	6.09	0.80	-	0.29	0.08	0.50	1.46	4.35
15-32	B21	64.00	21.31	6.61	0.81	-	0.29	0.08	0.44	1.51	4.08
32-63	B22	64.12	22.12	6.89	0.82	-	0.44	0.22	0.32	1.75	3.94
63-76	B3	64.53	22.42	7.96	0.85	-	0.46	0.08	0.26	1.48	3.83
76-124	C1	65.10	21.00	8.12	0.80	-	0.62	0.18	0.38	1.72	4.06
124-168	C2	65.20	20.58	7.62	0.81	0.08	0.77	0.13	0.49	1.72	4.18
168-202	C3	65.31	20.61	7.93	0.82	0.05	0.73	0.16	0.54	1.78	4.15
202-265	C4	66.00	20.32	8.24	0.83	0.05	0.64	0.27	0.54	1.62	4.20
					MADHUPUR TRACT						
					Pedon T6						
0-10	Ap1	68.19	18.12	6.44	0.81	-	0.28	0.21	0.18	1.25	4.97
10-18	Ap2	61.00	23.21	7.89	0.82	-	0.36	0.17	0.13	1.44	3.53
18-42	B21	60.21	23.31	8.41	0.85	-	0.42	0.15	0.13	1.44	3.43
42-52	B22	60.51	24.00	8.18	0.89	-	0.37	0.14	0.13	1.44	3.38
52-110	B23	61.21	24.10	8.42	0.87	-	0.36	0.16	0.42	1.56	3.39
110-140	C	61.52	22.10	8.28	0.89	-	0.35	0.12	0.13	1.45	3.66

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
					Pedon T7						
0-8	A	68.19	18.12	6.44	0.81	-	0.28	0.21	0.18	1.25	4.97
8-81	A21	61.00	23.21	7.89	0.82	-	0.36	0.17	0.13	1.44	3.53
81-102	B22	60.21	23.31	8.41	0.85	-	0.42	0.15	0.13	1.44	3.43
102-180	B23	60.51	24.00	8.18	0.89	-	0.37	0.14	0.13	1.44	3.38
180-200	B24	61.21	24.10	8.42	0.87	-	0.36	0.16	0.42	1.56	3.39
200-300	B25	61.52	22.10	8.28	0.89	-	0.35	0.12	0.13	1.45	3.36
					LALMAI HILLS						
					Pedon T12						
0-15	A	70.25	18.23	6.51	0.82	-	0.22	0.11	0.17	0.71	5.08
15-32	B21	65.29	20.10	7.71	0.85	-	0.21	0.03	0.12	1.16	4.18
32-48	B22	63.10	22.20	7.68	0.86	-	0.20	0.05	0.12	1.23	3.79
48-65	B23	64.91	22.59	7.02	0.89	-	0.21	0.08	0.15	1.26	3.90
65-165	B24	65.52	20.92	6.97	0.91	-	0.21	0.04	0.15	1.26	4.19
165-200	C	69.20	18.00	6.97	0.95	-	0.23	0.08	0.24	1.52	4.96

APPENDIX - IV

Clay mineral variation with depth in the various soil-geomorphic units

Soil-geo-morphic units	Pedon	Hori-zon	Depth (cm)	Kaol-inite (%)	Chlo-rite (%)	Vermi-culite (%)	Mont moril-lonite (%)	Mixed layer minerals (%)	Illite (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
TISTA FAN	R1	Ap	0-16	7.67	15.33	-	-	27.00	50.00
		A1	16-42	8.18	20.48	-	-	8.93	62.41
		B2	42-86	10.05	15.41	-	-	7.25	67.61
		B3	86-106	10.41	31.24	-	-	8.98	49.37
		C	106-115	10.48	21.00	-	-	9.76	58.76
	R4	Ap	0-13	8.68	13.00	-	-	20.00	58.32
		B21	13-48	9.60	18.00	-	-	9.23	63.17
		B22	48-72	10.98	20.00	-	-	10.21	58.81
		C1	72-106	8.62	14.00	-	-	11.81	65.57
		C2	106-120	7.12	13.00	-	-	10.52	69.36
OLD TISTA PLAIN	S8	Ap1	0-10	29.88	7.00	-	-	5.75	57.38
		Ap2	10-15	25.31	8.98	-	-	8.85	56.86
		B	15-26	17.85	8.15	-	-	34.00	40.00
		C	26-47	8.09	12.12	-	-	38.62	41.17
		Bb	47-69	18.23	8.28	-	-	25.54	47.95
		Cb	69-84	9.69	5.33	-	-	32.09	52.89
		Bb1	84-103	10.00	4.92	-	-	27.17	48.91
		Bb2	103-128	19.70	5.88	-	-	19.30	55.12
		Cb	128-152	18.81	5.61	-	-	11.70	63.88
MORIBUND GANGES DELTAIC PLAIN	T3	Ap	0-11	10.47	7.71	-	-	30.92	50.90
		B1	11-20	19.75	6.91	-	8.63	4.05	60.66
		B22	20-48	14.37	4.63	-	7.86	19.73	53.40
		B23	48-71	10.76	5.37	-	6.77	16.89	60.21
		C1	71-87	13.20	4.80	-	-	15.78	66.22
		C2	87-134	15.22	4.00	-	-	15.92	64.86
		Bb1	134-167	7.38	4.92	-	7.27	36.99	43.44
		Bb2	167-181	17.32	2.95	-	5.12	11.28	63.33
OLD BRAH-MAPUTRA PLAIN	S10	Ap1	0-10	37.80	9.07	-	-	21.60	31.60
		Ap2	10-16	23.97	6.15	-	-	20.78	49.10
		B21	16-42	21.25	6.68	-	-	30.90	41.17
		B22	42-58	23.17	7.41	-	-	24.01	45.41
		B23	58-85	27.00	4.43	-	-	24.89	43.66
		B24	85-98	23.88	6.82	-	-	31.08	38.22
		C	98-105	21.68	6.77	-	-	24.40	47.15

b = buried horizon

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
OLD MEGHNA DELTAIC PLAIN	T11	Ap1	0-13	41.79	11.66	-	-	8.22	38.33
		Ap2	13-20	48.00	9.50	-	-	3.26	39.24
		B2	20-64	45.19	9.61	-	-	0.01	45.19
		B3	64-88	24.67	-	6.50	3.8	18.03	47.00
		C1	88-104	29.62	5.92	-	-	30.20	34.26
		C2	104-127	33.08	-	8.23	4.5	25.11	29.16
BARIND TRACT	S6	Ap1	0-10	11.90	-	4.66	-	22.69	60.75
		Ap2	10-15	19.00	-	3.33	-	28.67	49.00
		B21	15-32	21.27	-	3.33	-	34.27	41.13
		B22	32-63	20.85	-	5.71	-	20.68	52.76
		B31	63-76	19.82	-	2.66	-	32.81	44.71
		B32	76-124	18.19	-	-	7.36	22.82	51.63
		B33	124-168	18.90	-	-	10.21	22.23	48.66
		C1	168-202	20.34	-	8.00	-	30.21	41.45
		C2	202-265	20.32	-	16.00	-	10.02	53.66
MADHUPUR TRACT	T7	A	0-8	32.26	-	-	-	12.91	54.83
		B21	8-81	25.19	-	-	-	32.47	42.34
		B22	81-102	31.51	-	-	-	10.67	57.82
		B23	102-180	26.65	-	-	-	28.32	45.03
		B24	180-200	31.70	-	-	-	10.30	58.05
		B25	200-300	34.18	-	-	-	10.48	55.34
LALMAI HILLS	T12	A	0-15	34.02	-	-	-	9.18	56.80
		B21	15-32	37.55	-	-	-	13.15	49.30
		B22	32-48	45.89	-	-	-	0.01	54.10
		B23	48-65	42.46	-	-	-	3.84	53.70
		B3	65-165	43.52	-	-	-	1.49	54.99
		C	165-200	43.99	-	-	-	7.48	48.53

APPENDIX V

DESCRIPTION OF TYPICAL SOIL THIN SECTIONS FROM THE DIFFERENT SOIL-GEOMORPHIC UNITS

1. BRAHMAPUTRA FLOODPLAIN

No. of sections described : 2

(i) Code No. T4/2

Location : Dhala, Singair Upazila, Manikganj district

Horizon: B21 Depth : 10 - 35 cm

Physiography : Summit of a ridge

Flooding : 0.3 - 0.6 m, 1 - 2 months

Microstructures

Apedal soil material with single grain and bridged grain microstructures. Simple packing voids and few vughs occupy 10-15% area of the section.

Basic mineral components

c/f limit at 20 μm; ratio of 70 : 30

a) Coarse single mineral grain

50% grains are quartz which range from 30-150 μm. The other 50% grains are highly altered biotite and moderately altered muscovite (100 - 200 μm in length). Few grains of feldspars are also present.

b) Fine fraction

Very fine micaceous particles (<20 μm) and some clay aggregates constitute the micromass.

Groundmass

The c/f related distribution is monic and gefuric. The b-faric is stipple-speckled.

Textural Pedofeatures

Segregated masses of finer material (<20 μm) and iron oxides are randomly distributed. Some of them occur as elongated zones. A hypocoating of carbonaceous material along a void is also present.

(ii) Code No. T4/5

Location : Dhala, Singair Upazila, Manikganj district

Horizon : Bb1* Depth: 74 - 114 cm

Physiography: Summit of a ridge

Flooding : 0.3 - 0.6 m, 1 - 2 months

Microstructures

Well developed subangular blocky peds (2-4 mm) occupy 30 - 40% area of the section. They are bounded almost on all sides by planar voids. Irregularly shaped, elliptical and planar voids occupy 25 - 30% area of the section.

Basic mineral components

c/f limit at 20 μm; ratio of 30:70

a) Coarse single mineral grain

70% grains are quartz (20-70 μm). The rest are moderately altered muscovite and highly altered biotite minerals (125-250 μm).

b) Fine fraction

It consists of very fine particles (<20 μm) of micas and quartz.

Groundmass

The c/f related distribution is open porphyric. The micromass shows moderately developed unistrial, cross striated and parallel striated b-fabrics.

Textural Pedofeatures

Many aggregates of finer material are randomly distributed. Some of them are larger and elongated. Some of the voids are infilled by organic matter and heavy minerals like tourmaline and garnet.

2. TISTA FAN

No. of thin sections described: 4

(i) Code No. R4/3

Location : Mithapukur Upazila, Rangpur district

Horizon : B22 Depth : 48 - 72 cm

Bb1* - buried B1 horizon

Physiography: Upper part of the ridge

Flooding: Above flood level

Microstructure

Apedal soil material with dominantly single grain and compact grain structures. A few unoriented randomly distributed circular and elliptical voids with smooth walls and few irregularities range from 400 μm to 1 mm in diameter and occupy about 5% area of the thin sections. Walls of some voids are twisted due to differential forces caused by alternate swelling and drying.

Basic mineral components

c/f limit at 20 μm; ratio of 90:10

a) Course single mineral grain (> 20 μm)

About 70 - 80% of the grains are elongated, moderately sorted, weakly altered muscovites and moderately altered biotites. They range in size from 100 to 200 μm. The rest 20-30% grains are euhedral quartz of 30-60 μm size.

b) Fine fraction

Randomly distributed nonlaminated impure clay and fine silt-size particles are embedded in the s-matrix.

Groundmass

The c/f related distribution is mainly monic and the b-fabric of the micromass is moderately developed with mosaic-speckled, parallel striated and cross striated fabric units.

Textural Pedofeatures

About 10% area of the section contain randomly distributed aggregates of impure clay. No voids have clay coatings and no accumulation of iron hydroxides has taken place.

(ii) Code No. R3/5

Location : Vill. - Tampat, Rangpur Sadar

Horizon : B3 Depth : 61 - 88 cm

Physiography: Middle part of the ridge

Flooding : 0.5 m, 3 - 4 months

Microstructure

Apedal soil material with single grain and bridged grain structures. Few randomly distributed planar voids occupy less than 5% area of the section.

Basic mineral components

c/f limit at 20 μm; ratio of 80 : 20

a) Course single mineral grain (>20 μm)

About 75% of the mineral grains are elongated, moderately sorted and moderately altered biotite and muscovite ranging upto 250 μm in size. About 20% anhedral quartz grains with undulating surfaces range upto 250 μm in diameter. Less than 5% are heavy minerals (mainly tourmaline and hypersthene) and opaque grains which range from 150-200 μm in diameter.

b) Fine fraction

Nonlaminated and unoriented aggregates of impure clay with fine silt-sized micro-contrasted particles are embedded in the groundmass and occupy about 20% area of the section.

Groundmass

The c/f related distribution is monic and gefuric. The micromass is characterized by well developed parallel striated and cross striated b-fabrics.

Pedofeatures

a) Textural

About 20% area of the section is occupied by impure clay aggregates and at some places they show patterns of flowage due to movement of the finer material.

b) Amorphous

A few diffused mottles and big elliptical geodic nodules (1.4 mm in size) of iron hydroxides are present.

(iii) Code No. R2/4

Location : Vill. - Tampat, Rangpur Sadar

Horizon : B22 Depth : 33 - 49 cm

Physiography : Lower part of the backswamp

Flooding: 0.6 m, 4 - 5 months

Microstructure

Apedal soil material with single grain, bridged grain and intergrain microaggregate structures. Unoriented randomly distributed circular and elliptical voids with smooth walls and few irregularities range from 125 μm to 1 mm in diameter and occupy about 10% area of the section.

Basic mineral components

c/f limit at 20 μm ; ratio of 70 : 30

a) Coarse single mineral grain (> 20μm)

About 70% of the grains are elongate, moderately sorted and moerately altered biotite and muscovite minerals. The rest 30% grains are anhedral quartz with undulating surfaces. Less than 1% grains are tourmaline.

b) Fine fraction

Nonlaminated and unoriented aggregates of impure clay with micro-contrasted silt, quartz, and heavy mineral particles upto 60 μm in diameter are embedded in the groundmass. Impure clay also occur as coatings around voids.

Groundmass

The c/f related distribution is monic and gefuric. The micromass is characterized by moderately to strongly developed mosaic-speckled and locally porostriated, unistrial and cross striated b-fabrics.

Pedofeatures

a) Textural

About 30% area of the section comprises randomly distributed impure clay aggregates upto 500 µm in size. A few voids have hypocoatings of impure clay (50-300 µm). Very few voids are loosely infilled by soil fragments.

b) Amorphous

A number of black micronodules are randomly distributed.

(iv) Code No. R2/5

Location : Vill. - Tampat, Ranpur Sadar

Horizon : B23 Depth : 49 - 72 cm

Physiography : Lower part of the backswamp

Flooding : 0.6 m, 4 - 5 months

Microstructure

Very weakly developed peds with single grain and bridged grain microstructures. Unoriented randomly distributed circular and elliptical voids with smooth walls and few irregularities range from 125 to 175 µm in diameter and occupy about 5 - 8% area of the section.

Basic mineral components

c/f limit at 20 µm; ratio of 80:20

a) Coarse single mineral grain (>20 µm)

About 80% of the grains are elongate, moderately to well sorted and weakly to moderately altered biotite and muscovite minerals ranging upto 250 µm in length. The rest 20% of the grains are anhedral quartz with undulating surfaces and they range upto 125 µm in diameter. A few grains of tourmaline and opaque minerals also occur.

b) Fine fraction

Nonlaminated and randomly distributed aggregates of clay with micro-contransted silt-size particles are embedded in the groundmass. The aggregates are oriented along a plane and sometimes, form layers of 600 - 700 µm thickness.

Groundmass

The c/f related distribution is monic and gefuric. The micromass shows moderately developed mosaic - speckled, unistrial, cross striated b-fabrics and well-developed porostriated b-fabrics.

Pedofeatures

a) Textural

The section comprises about 20% randomly distributed clay aggregates. A few voids have illuviated clay coatings (argillans) (40-50μm). Some voids are loosely infilled with soil fragments.

b) Amorphous

A number of opaque (black) grains are randomly distributed.

c) Excrement

A few voids are loosely infilled by excrements and they are randomly distributed.

d) Fabric

Slickensided faces had involved in the rearrangement of micromass (clay) giving rise to porostriated b-fabric parallel to the surfaces of the fissures.

3. OLD TISTA PLAIN

No. of thin sections described : 3

(i) Code No. S7/1

Location: Sabgram Union, Bogra Sadar

Horizon : Ap   Depth : 0 - 10 cm

Physiography: Between a ridge and a backswamp

Flooding : 0.3 m, 3-4 months

Microstructure

Apedal soil material shows single and bridged grain microstructures. Some simple packing voids of 50 - 100 μm diameters occupy about 20% area of the section.

Basic mineral grains

c/f limit at 20 μm; ratio of 60:40

a) Course single mineral grain (>20μm)

About 50% of the mineral grains are anhedral quartz with undulating surfaces and they range from 30 - 80 μm. The rest 50% grains are moderately altered elongate biotite and muscovite minerals which range from 100 - 150 μm in length. The mineral grains are moderately sorted.

b) Fine fraction

Nonlaminated, unoriented and randomly distributed aggregates of clay and very fine silt-size micaceous particles (<10 μm) are embedded in the groundmass and they occupy about 40% area of the section.

Groundmass

The c/f related distribution is monic and gefuric. The micromass shows very weakly developed b-fabrics.

Textural Pedofeatures

Coatings around voids are absent. The finer fractions are embedded in the groundmass without showing any distinct sign of plasma (fine material) concentration/plasma separations.

(ii) Code No. S7/3

Location : Sabgram Union, Bogra sadar

Horizon : B2 Depth : 15 - 43

Physiography: Between a ridge and a backswamp,

Flooding: 0.3 m, 3 - 4 months

Microstructure

Dominantly apedal soil material contains weakly developed peds at some parts of the section. The section shows bridged and pellicular grain microstructures. Some elliptical and planar voids occupy less than 10% area of the thin section.

Basic mineral components

c/f limit at 20 μm; ratio of 30:70

a) Coarse single mineral grain (>20 μm)

About 80% of the grains are elongated moderately to highly altered, poorly to moderately sorted biotite and muscovite minerals which range in length from 125 - 250 μm. The rest 20% anhedral quartz grains with undulating surfaces range in size mainly from 20 - 50 μm. A few of them range from 50 - 100 μm. Many randomly distributed tourmaline and opaque grains range from 60 - 200 μm in size.

b) Nonlaminated and unoriented impure aggregates of clay are embedded in the groundmass and they occupy 15 - 20% area of the section.

Groundmass

The c/f related distributed is gefuric and chitonic. The b-fabric of the micromass shows moderately developed parallel striated, cross striated and porostriated fabric units.

Pedofeatures

About 70% area of the section comprises randomly distributed clay aggregates and very fine silt-size micaceous materials (< 10μm). A few voids have 15 - 20 μm thick coatings of impure clay. Along a planar void, very fine micaceous materials (< 10 μm) have oriented to give rise to skew plane cutans (Brewer, 1964) by differential movement of finer particles as a result of alternate wetting and drying. The planar void is also partly infilled by coarse grains and iron nodules.

(iii) Code No. S7/6

Location : Sabgram Union, Bogra Sadar

Horizon : Bb2* Depth: 105 - 142 cm

Physiography : Between a ridge and a backswamp,

Flooding : 0.3 m, 3-4 months

Microstructure

Weakly to moderately developed and angular to subangular blocky peds with undulating irregular ped faces are partially accomodated and incompletely separated by planar voids; size range of peds is considerable (500 μm-5 mm). The section mainly shows massive structure. Interaggregate pores consist mainly of planar voids having widths of 30-250 μm. Intraggregate pores consist of randomly distributed elliptical voids. Estimated porosity is 20 - 25%.

Bb2* - buried B2 horizon

Basic mineral components

c/f limit at 20 μm; ratio of 5:95

a) Coarse single mineral grain (>20 μm)

A few anhderal quartz grains with undulating surfaces range from 20 - 30 μm. A few tourmaline and opaque grains are also present.

b) Fine fraction

Strongly oriented and strongly altered micromass of clay-size and very fine silt-size particles (<10 μm) occupy about 80% area of the section.

Groundmass

The c/f related distribution is mainly porphyric. The micromass shows strongly developed unistrial and cross striated b- fabrics.

Textural Pedofeatures

A no. of randomly distributed elliptical voids have coatings of iron hydroxides with thickness ranging upto 50 μm. Few planar voids (ped faces) have coatings of iron hydroxides upto 20 μm thickness. Some ferrans around elliptical and planar voids also occur. Iron hydroxides are also found as impregnative forms/modules.

4. MORIBUND GANGES DELTAIC PLAIN

No. of thin sections described : 6

(i) **Code No. T3/1**

Location : Fulbari, Mirpur Upazila, Kushtia district

Horizon : Ap Depth: 0 - 11 cm

Physiography: Centre of a backswamp

Flooding: 1-1.5 m, 5-6 months

Microstructure

Apedal soil material mainly with massive structure. At some parts of the section, pellicular grain structure occurs. The voids have no definite shapes and their walls are not smooth. They range from 250 μm - 2 mm in size. Estimated porosity is about 20%.

Basic mineral components

c/f limit at 20 μm; ratio of 40:60

a) Coarse single mineral grain

About 80% of the grains are anhedral quartz with undulating surfaces. They range from 30 - 300 μm in size. Many bigger grains (200 - 300 μm) of quartz are randomly distributed in the section. About 20% elongated grains of 125 - 250 μm sizes are muscovite. Biotite is highly altered and thus, unidentifiable.

b) Fine fraction

Nonlaminated impure clay and very fine micaceous particles (< 10μm) are embedded in the groundmass.

Groundmass

The c/f related distribution is porphyric (mainly single spaced) and there is no development of b-fabrics in the micromass.

Textural Pedofeatures

Randomly distributed segregationis of iron hydroxides are clealy visible but they do not form nodules. A fragment of pedolict is also seen.

(ii) **Code No. T3/3**

Location : Fulbari, Mirpur Upazila, Kushtia district

Horizon : B22 Depth: 20 - 48 cm

Physiography : Centre of a backswamp,

Flooding : 1-1.5 m, 5-6 months

Microstructure

Moderately to strongly developed, angular to subangular, blocky and accomodated peds range from 800 μm to 3 mm in size and occupy about 25% area of the section. Some well developed peds are separated by short and long planar voids on all sides. The elliptical voids with undulating and irregular surfaces range from 100 - 700 μm in size. Randomly distributed planar voids are common and a few of them have clay coatings. Estimated porosity is 20%.

Basic mineral components

c/f limit at 20 μm; the ratio of 25:75

a) Coarse single mineral grain (>20 μ)

Except very few grains of moderately weathered muscovite, highly altered biotite and tourmaline, all other grains are anhedral quartz with undulating surfaces and they range from 20 - 100 μm in size. Two grains of quartz are 250 μm in size.

b) Fine fraction

The c/f related distribution is porphyric (both single and double spaced). The micromass has weakly developed parallel striated b-fabrics.

Textural pedofeatures

Segregations of iron hydroxides are clearly seen but they do not form nodules. A pedorelict feature (500 μm) and impregnative Fe-Mn nodules (1-5 mm) are also visible. Many clay coatings with silt-size micro-contrasted particles are present. Their thicknesses range from 50 - 125 μm. Around a subrounded void a microlaminated coating of clay and very fine silt-size particles is observed.

(iii) Code No. T3/7

Location: Fulbari, Mirpur Upazila, Kushtia district

Horizon : Bb2 Depth: 134-167 cm

Physiography: Centre of a backswamp

Flooding: 1 - 1.5 m, 5 - 6 months

Microstructure

Moderately to strongly developed, angular to subangular blocky and accomodated peds range from 200 μm to 5 mm in size and occupy 40 - 50% area of the section. Some well developed peds are separated by short and long planar voids on all sides. Elliptical and subrounded voids range from 100 - 500 μm in diameter. Some planar and channel voids are present. One channel void is found infilled with soil material and aggregates of iron hydroxides.

<u>Basic mineral grain</u>

c/f limit at 20 μm; the ratio of 3:97.

Apart from few grains of tourmaline, garnet and quartz the entire groundmass is composed of finer fractions (<10 μm).

Groundmass

The c/f related distribution is open perphyric. Mainly unistrial b-fabric occurs and it is strongly developed.

Textural Pedofeatures

Segregations of iron hydroxides are very common but without any nodules/concretions. The groundmass consists almost entirely of clay-size and very fine silt-size (<10 μm) particles. A thin coating (≈ 50 μm) of impure clay around a void is visible. Many grains of zircon, tourmaline and sphene occur together in the channel voids.

(iv) Code No. T1/3

Location: Dighirpara, Meherpur Sadar

Horizon : B2 Depth : 41-53 cm

Physiography : Almost level ridge

Flooding: Above flood level.

Microstructure

Apedal soil material with pellicular grain structure. The eplliptical and subrounded voids range from 75 - 250 μm in diameter. Few planar voids also occur. Estimated porosity is 25 - 30%.

Basic mineral components

c/f limit at 20 μm; the ratio of 50:50

a) Coarse single mineral grain (>20 μm)

Except a few grains of micas, feldspars and heavy minerals, the coarse fraction consists almost entirely of quart grains ranging from 30 - 250 μm in size of which very fine grains (30 - 100 μm) dominate.

b) Fine fraction

Unoriented randomly distributed micromass consisting of impure clay aggregates and very fine silt-size particles (<10 μm) are embedded in the s-matrix.

Groundmass

The c/f related distribution is chitonic. The b-fabric is undifferentiated.

Textural Pedofeatures

A few illuviation clay cutans around voids and grains ranging from 30 - 60 μm in thicknesses are randomly distributed. Around some voids coatings of dusty clay and impure clay with micro-contrasted particles range upto 250 μm in thickness. The coatings of dusty clay are thinnerr than that of impure clay.

(v) Code No. T2/3

Location : Fulbari, Mirpur Upazila Kushtia

Horizon : B2 Depth : 36 - 83 cm

Physiography : Top of a ridge

Flooding : Above flood level.

Microstructure

Apedal soil material shows bridged grain structure. The elliptical and subrounded voids with undulating surfaces are randomly distributed. They range from 75 - 300 µm in diameter.

Basic mineral components

c/f limit at 20 µm; the ratio of 65:35.

a) Coarse single mineral grains

The groundmass is moderately sorted. Except a few grains of micas and heavy minerals the coarse fraction consists almost entirely of anhedral quartz grains with undulating and irregular surfaces. They range frrom 30 - 150 µm in size.

b) Fine fraction

Unoriented randomly distributed clay aggregates and very fine silt-size particles are embedded in the s-matrix.

Groundmass

The c/f related distribution is gefuric and chitonic. The b-fabric is undifferentiated.

Textural Pedofeatures

A few cutans of dusty clay range upto 40 µm in thickness. Some aggregates of calcite give rise to nodular forms. A calcite nodule of 300 µm diameter contains inclusion of micro-contrrasted biotite and quartz particles. A pedofeature of 1 mm length and 60 - 70 µm width probably represents a fragment of gastropod shell.

(vi) **Code No. S3/4**

Location : Shippur, Puthia Upazila, Rajshahi

Horizon : B22 Depth: 47 - 90 cm

Physiography: Lower part of a ridge

Flooding: 0.5 - 1 m, 1 month

Microstructure

Strongly developed angular to subangular blocky and accomodated peds range from 500 µm - 5 mm in size and occupy about 50% area of the section. The peds are separated by short and long planar voids on most sides. Some voids are planar and others are circular. Estimated porosity is 20%.

Basic mineral components

c/f limit at 20 µm; ratio of 10:90

a) Coarse single mineral grain

95% grains are anhedral quartz ranging upto 60 µm in size. The rest 5% grains are muscovite and heavy minerals.

b) Fine fraction

Clay aggregates and very fine silt-size macaceous (<10 µm) particles inter mixed with amorphous iron hydroxides are embedded in the groundmass.

Groundmass

The c/f related distribution is open porphyric. The micromass possesses moderately developed parallel striated and cross striated b-fabrics.

Textural Pedofeatures

Many hypocoatings are randomly distributed. A thick hypocoating (125-200 µm) around an elliptical void is observed. Many pedorelict features with their sharp boundaries and Lamellar fabrics are clearly visible throughout the thin section.

5. **OLD BRAHMAPUTRA PLAIN**

No. of thin sections described : 6

(i) **Code No. S9/4**

Location : Kismat, Mymensing Sardarr

Horizon : B22 Depth : 36 - 51 cm

Physiography: Upper part of a nearly level ridge

Flooding : 10 - 15 cm / 4-5 days

Microstructure

Apedal soil material with compact grain structure. A few elliptical voids are randomly distributed and they occupy 10 - 15% area of the section.

Basic mineral components

c/f limit at 20 µm; ratio of 80:20

a) Coarse single mineral grain

About 80% of the mineral grains are elongate moderately to well sorted and poorly altered biotite and muscovite minerals and they range mainly from 30 - 75 µm in size. The rest 20% anhedral quartz grains range from 20 - 50 µm in size. Few grains of hypersthene and many opaque grains are also present and they range from 30 - 125 µm in size.

b) **Fine fraction**

Aggregates of impure clay and very fine silt-size micaceous materials are interspersed with the groundmass and they occupy 15 - 20% area of the section.

Groundmass

The c/f related distribution is monic. The micromass is characterized by moderately to well developed parallel striated and cross striated b-fabrics.

Textural Pedofeatures

An argillan with thickness of 100 - 150 µm occurs around a void and it is characterized by continous fabric as indicated by its strong black extinction lines. Some patches of plasma concentration are interspersed with the groundmass. Two elongated zones of clay accumulation may represent flood coatings. No segregations of iron hydroxides are seen.

(ii) **Code No. S9/5**

Location : Kismat, Mymensingh Sadar

Horizon : C Depth : 51-62 cm

Physiography: Upper part of a nearly level ridge

Flooding : 10 - 15 cm/4 - 5 days

Microstructure

Apedal soil material with single grain and compact grain microstructures. Some simple packing voids are randomly distributed and range in size from 50 µm to 2 mm. Estimated porosity is 10 - 15%.

Basic mineral components

c/f limit at 20 µm; ratio of 80:20

a) Coarse single mineral grins (>20 µm)

About 70% of the mineral grains are elongated, well sorted and poorly altered biotite and muscovite which range from 60 - 150 µm in size. The rest 30% are anhedrral quartz grains with undulating surfaces and they range from 25 - 50 µm in size., A few opaque grains also occur.

b) Fine fraction (<20 µm)

The fine fraction constitutes randomly distributed clay aggregates and very fine silt-size micaceous particles.

Groundmass

The c/f related distribution is monic. The coarse fraction shows parallel orientation due to organisation of micas.

Textural Pedofeatures

Few hypocoatings of iron hydroxides around voids are visible. Plasma separation is poor.

(iii) Code No. S9/8

Location: Kismat, Mymensingh Sadar

Horizon : Bb2 Depth: 82 - 103 cm

Physiography: Upper part of a nearly level ridge

Flooding : 10 - 15 cm / 4-5 days

Microstructures

Weakly developed peds. Some voids have irregular shapes but elliptical voids dominate. They range from 60 µm to 2 mm in length. Estimated porosity is 15 - 20%.

Basic mineral components

c/f limit at 20 µm; ratio of 20:80

a) Coarse single mineral grain

Quartz grains of 20 - 60 µm size are randomly distributed. Highly altered micas range from 20 - 70 µm in size.

b) Fine fraction

Very fine silt-size micaceous particles (<20 µm) dominate in the fine fraction. Some patches of plasma (fine material) concentrations are interspersed with the fine fraction.

Groundmass

The c/f related distribution is open porphyric. The micromass is characterized by moderately developed unistrial and parallel striated b-fabrics.

Textural Pedofeatures

Many hypocoatings of iron hydroxides around voids are randomly distributed. These coatings range from 100 - 300 µm in thickness. Some ferruginous impregnative and aggregate nodules are also found.

(iv) **Code No. S12/4**

Location: Ramgopalpur, Gauripur Upazila, Mymensingh district

Horizon : B22 Depth: 39 - 63 cm

Physiography: Margin of a backswamp

Flooding: 1.2 - 1.5 m, 4-5 months.

Microstructures

Weakly developed peds and chitonic and massive structures. Elliptical voids are randomly distributed and they range from 100 - 400 μm in diameter. Estimated porosity is 20 - 25%.

Basic mineral components

c/f limit at 20 μm; ratio of 25:75

a) Coarse single mineral grain (> 20 μm)

About 70% grains are anhedral quartz with undulating surfaces and they range from 30 - 125 μm in size. The rest 30% grains are moderately to highly altered biotite and muscovite minerals which range from 50 - 200 μm in length.

b) Fine fraction

Very fine silt-size micaceous particles (<5 μm) are embedded in the groundmass. A few patches of clay aggregates are randomly distributed.

Groundmass

The c/f related distribution is double spaced to open porphyric. The micromass possesses weakly developed parallel striated and cross striated b-fabrics.

Textural Pedofeatures

Few coatings around voids are randomly distributed and they range from 70 - 150 μm in thickness.

(v) **Code No. S12/8**

Location: Ramgopalpur, Gauripur Upazila, Mymensingh district

Horizon : C Depth : 120 - 130

Physiography : Margin of a backswamp

Flooding: 1.2 - 1.5 m, 4-5 months.

Microstructures

Apedal soil material with bridged grain and pellicular grain microstructures. Elliptical and planar voids are randomly distributed. The elliptical voids range from 100 µm to 1 mm in diameter and the planar voids are upto 3 mm in length and 500 µm in width. Estimated porosity is about 20%.

Basic mineral components

c/f limit at 20 µm; the ratio of 40:60

a) Coarse single mineral grain (>20 µm)

About 70% grains are anhedral quartz with undulating and irregular surfaces and they range from 25 - 150 µm in size. The rest 30% grains are moderately to strongly altered biotite and muscovite. Few grains of plagioclase and heavy minerals also occur.

b) Fine fraction

Very fine silt-size micaceous particles are embedded in the groundmass. A few aggregates of clay are interspersed with the micromass.

Groundmass

The c/f related distribution is chitonic, gefuric and porphyric. The micromass shows weakly to moderately developed unistrial, parallel striated and cross striated b-fabrics.

Textural Pedofeatures

Many hypocoatings around voids are present and they range from 70 - 150 µm in thickness. A few hypocoatings around planar voids also occur in the groundmass. The coatings consist of impure clay and very fine micaceous particles (2-5 µm). Micro-contrasted particles of quartz are interspersed with the coatings.

(vi) Code No. S11/8

Location : Ramagopalpur, Gauripur Upazila, Mymensingh district

Horizon : Bb2 Depth : 96 - 110 cm

Physiography: Lower part of a backswamp

Flooding: 1.2 - 1.5 m, 5 - 6 months.

Microstructures

Weakly to moderately developed subangular blocky peds. Some voids with irregular shapes occupy 10 - 15% area of the section and they range from 100 - 200 µm in diameter.

Basic mineral component

c/f ratio at 20 µm; ratio of 10:90

a) Course single mineral grain

Most of the grains are quartz which range from 20 - 30 µm in size. The rest are highly altered micas of 30 - 70 µm sizes.

b) Fine fraction

The fine fraction consists mainly of very fine silt-size (<20 µm) micaceous and quartz particles. The rest are randomly distributed clay aggregates.

Groundmass

The micromass shows moderately to strongly developed unistrial and cross-striated b-fabrics.

Textural Pedofeatures

A few elliptical and planar voids are coated with impure clay and very fine silt-size (<5 µm) micaceous particles. Many ferruginous impregnative and aggregate nodules are interspersed with the micromass.

6. **SYLHET DEPRESSION**

(i) **Code No. S13/3**

Location: Rajagati, Nandail Upazila, Mymensingh district

Horizon : B22 Depth: 32 - 43 cm

Physiography: Margin of a backswamp

Flooding : 2-3 m, 4 - 5 months

Microstructures

Moderately developed angular to subangular blocky and partially accomodated peds range from 1 - 5 mm in size and occupy 15 - 20% area of the section. The elliptical voids with undulating and irregular surfaces range from 100 µm - 1 mm in diameter. Few planar voids also occur.

Basic mineral components

c/f limit at 20 µm; ratio of 15:85

a) Coarse single mineral grain (>20 µm)

Most of the grains are quartz ranging from 30 - 100 µm in size. A few grains of highly altered micas and tourmaline also occur.

b) Fine fraction

The micromass cnsists of very fine silt-size (<5 μm) micaceuos particles and clay aggregates.

Groundmass

The c/f related distribution is open porphyric. The micromass possesses well developed parallel striated and cross stiated b-fabrics.

Textural Pedofeatures

Many randomly distributed hypocoatings around elliptical and planar voids occur which range from 50 - 250 μm is thickness. The hypocoatings are composed of clay minerals and very fine silt-size (<5 μm) micaceous particles and may be termed as diffusion cutans (Brewer, 1964). A few skew plane cutans (Brewer, 1964) with thickness upto 500 μm are observed. Patches of iron hydroxides occur as segregations and impregnations throughout the micro-mass.

(ii) Code No S13/8

Location: Rajgati, Nandail Upazila, Mymansingh district

Horizon : C Depth : 110 - 130

Physiography: Margin of a backswamp

Flooding : 2 - 3 m, 4 - 5 months

Microstructures

Apedal soil material with massive structure. Mostly elliptical and some sub rounded voids are randomly distributed. The elliptical voids are 100 μm - 2 mm in length whereas the sub rounded voids range from 75 - 150 μm in diameter. Estimated porosity is 15 - 20%.

Basic mineral components

c/f limit at 20 μm; ratio of 10:90

a) Course single mineral grain

The coarse fraction consists mainly of quartz (30 - 100 μm) grains and subordinately of highly altered micas (50 - 100 μm).

b) Fine fraction

The micromass consists dominantly of micaceous particles (<5 μm) and a few patches of clay aggregates.

Groundmass

The c/f related distribution is open porphyric. The micromass shows well developed unistrial and cross striated b-fabrics.

Textural Pedofeatures

Many rusty patches of iron hydroxides occur as impregnations. Few skew plane cutans (Brewer, 1964) also occur. Around a big elliptical void (2-3 mm long) a hypocoating of iron hydroxide is observed.

(iii) Code No. S14/3

Location: Raytuli, Itna Upazila, Kishorganj district

Horizon : B1 Depth : 27 - 45 cm

Physiography : Nearly level ridge

Flooding : 1 - 2 m, 4 - 5 months

Microstructures

Apedal soil material with massive structure. Some voids with irregular shapes and undulating surfaces range from 100 - 250 μm in diameter and they occupy 10 - 15% area of the section.

Basic mineral components

c/f limit at 20 μm; ratio of 65:35

a) Coarse single mineral grain

80% of the grains are anhedral quartz with undulating surfaces adn they range from 30 - 150 μm in size. The rest of the grains are highly altered biotite and weakly altered muscovite minerals and they range from 100 - 200 μm in length.

b) Fine fraction

Very fine silt-size particles (< 10 μm) are interspersed with the groundmass.

Groundmass

c/f related distribution is single spaced porphyric. Weakly developed parallel striated b-fabrics are present.

Textural Pedofeatures

Few impregnations of iron hydroxides are randomly distributed. They usually occur nearer to the voids.

(iv) Code No. S14/6

Location : Raytuli, Itna Upazila, Kishorganj district

Horizon : B23 Depth : 77 - 98 cm

Physiography: Nearly level ridge

Flooding : 1 - 2 m, 4 - 5 months

Microstructures

Moderately to strongly developed angular to subangular blocky peds range from 3 - 5 mm in size and occupy about 15 - 20% area of the section. Some of the voids are elliptical and others are irregular in shape. They range from 300 µm - 4 mm in length. Estimated porosity is 25 - 30%.

Basic mineral components

c/f limit at 20 µm; ratio of 25 : 75

a) Coarse single mineral grain

90% grains are anhedral quartz with undulating surfaces. They range from 30 - 100 µm in size. The rest of the grains are weakly altered elongate muscovite (100 - 200 µm) and highly altered biotite (100 - 150 µm) minerals.

b) Fine fraction

Very fine silt-size (<5 µm) micaceous particles and a few patches of clay aggregates constitute 75% of the groundmass.

Groundmass

c/f related distribution is open porphyric. The micromass is characterised by strongly developed unistrial, cross striated, parallel striated and porostriated b-fabrics.

Textural Pedofeatures

Some aggregates of iron hydroxides have impregnated the matrix and occasionally they have formed impregnative and aggregate nodules. Elongated zones of plasma (fine material) concentrations are observed. They usually occur nearer to the around voids. Few skew plane cutans (Brewer, 1964) are also seen.

7. OLD MEGHNA DELTAIC PLAIN

No. of thin sections described : 4.

(i) Code No. T11/1

Location: Baghmara, Laksham Upazila, Comilla district

Horizon: Apg Depth : 0 - 13 cm

Physiography; Nearly level ridge

Flooding : 0.3 m, 15 - 20 days

Microstructures

Apedal soil material with single grain microstructure. A few simple packing voids ranging from 200 - 250 μm in diameter occupy about 10 - 15% area of the section.

Basic mineral components

c/f limit at 20 μm; ratio of 90:10

a) Coarse single mineral grain

60% of the grains are anhedral quartz with undulating surfaces and they range from 30 - 70 μm in size. The rest 40% grains are weakly to moderately altered biotite and muscovite minerals which range in length from 100 - 200 μm. All the grains are moderately to well sorted.

b) Fine fraction

Elongated zones and patches of plasma (fine material) concentration are interpersed with the groundmass. They consist of very fine micaceous particles (<5μm) and clay aggregates.

Groundmass

The c/f related distribution is monic. The micromass has undifferentiated b-fabrics except parallel orientation of coarse-grained micas.

Textural Pedofeatures

A few papules are present. Accumulation of iron hydroxides around voids are observed.

(ii) Code No. T11/3

Location : Baghmara, Laksham Upazila, Comilla district

Horizon : B21 Depth : 20 - 64

Physiography: Nearly level ridge

Flooding : 0.3 m, 15 - 20 days

Microstructures

Moderately developed peds with single grain and bridged grain structures. Elliptical and subrounded voids with undulating surfaces occupy about 20% area of the section. The voids range from 125 μm - 1 mm in length.

Basic mineral components

c/f limit at 20 μm; ratio of 40:60

a) Coarse single mineral grain

70% of the grains are anhedral quartz with rough surfaces and they range in size from 30 - 125 μm. The rest of the grains are highly altered biotite and moderately altered muscovite minerals which range from 100 - 200 μm in length. Few grains of plagioclase are also visible.

b) Fine fraction

It consists of clay aggregates and very fine micaceous particles (<10 μm).

Groundmass

The c/f related distribution ranges from gefuric and single spaced porphyric. The micromass shows moderately developed mosaic speckled b-fabrics.

Textural Pedofeatures

Elongated zones and patches of clay aggregates are embedded in the groundmass. A few weakly developed hypocoatings around voids are present. Some impregnative nodules of iron oxides or manganese oxides are also noted.

(iii) Code No. T9/3

Location: Suchipara, Shahrasti Upazila, Chandpur district

Horizon : B21 Depth: 15 - 54 cm

Physiography: Margin of a backswamp

Flooding: 1.5 - 2 m, 5 - 6 months

Microstructures

Moderately developed peds with bridged grain and pellicular grain microstructures. Some elliptical voids have undulating surfaces. They range in diameter from 300 μm - 1 mm. Estimated porosity is 15 - 20%.

Basic mineral components

c/f limit at 20 μm; ratio of 70:30

a) Coarse single mineral grain

60% grains are anhedral quartz with undulating surfaces and they range from 20 - 70 μm in size. The rest of the grains are highly altered biotite and few unaltered muscovite minerals. They range from 60 - 150 μm in length.

b) Fine fraction

Very fine micaceous particle (<20 μm) and clay aggregates are embedded in the groundmass.

Groundmass

The c/f related distribution is monic and gefuric. The b-fabric is very weakly developed.

Textural Pedofeatures

Some elongated zones and patches of clay aggregates are interpersed with the groundmass. A few illuviated clay coatings (argillans) (70-80 μm) are present. Impregnative and aggregate nodules of iron hydroxides are also noted.

(iv) Code No. T9/5

Location: Suchipara, Shahrasti, Upazila, Chandpur district

Horizon : C Depth: 89 - 115 cm

Physiography: Margin of a backswamp

Flooding : 1.5 - 2m, 5 - 6 months

Microstructures

Apedal soil material with bridged grain micro-structure. Elongated elliptical voids with irregular surfaces range from 500μm - 2mm in length and occupy 10 - 15% of the section.

Basic mineral components

c/f limit at 20 μm; ratio of 75:25

a) Coarse single mineral grain

60% grains are anhedral quartz with undulating surfaces. They range from 20 - 100 μm in size. The rest of the grains are mainly moderately altered biotite and some unaltered muscovite minerals. They range from 60 - 200 μm in length.

b) Fine fraction

Very fine micaceous particles (<10 μm) and some clay aggregates are interspersed with the groundmass.

Groundmass

The c/f related distribution is monic. The groundmass has undifferential b-fabrics except parallel orientation of micas.

Textural Pedofeatures

Some patches of clay aggregates are randomly distributed. A few weakly developed hypocoatings around voids are noted. A skew plane cutan (Brewer, 1964) and a no. of impregnative and aggregate nodules of iron hydroxides are also present.

8. LOWER ATRAI DEPRESSION

No. of thin sections described : 2

i) Code No. S4/2

Location : Halti beel, Rai Singapur, Natore Sadar

Horizon : Ap2 Depth : 9-16 cm

Physiography : Margin of a backswamp

Flooding : 3 - 4 m, 5 - 6 months

Microstructure

Apedal soil material with massive structure. Unoriented randomly distributed elliptical voids with widths of 300 µm and lengths of 600 µm occur and some of them are of 2 mm sizes. Round - shaped and planar voids are also present. Some voids mainly big ones have distorted and irregular walls as a result of alternate wetting and drying. Total estimated porosity is 20%.

Basic mineral components

c/f limit at 20 µm; ratio of 40:60

a) Coarse single mineral grain

About 60% grains are anhedral quartz with undulating surfaces and they range from 20 - 60 µm in size. The rest of the grains are highly altered biotite and muscovite minerals which have almost lost their optical properties.

b) Fine fraction

Nonlaminated randomly distributed impure clay and very fine micaceous particles (<10 µm) are embedded in the groundmass.

Groundmass

The c/f related distribution is mainly single spaced porphyric. The weakly developed parallel striated b-fabrics are localized in the section.

Textural Pedofeatures

Hypocoatings around some voids are present. There are no accumulations of iron hydroxides in the section.

(iii) Code No. S4/4

Location : Halti beel, Rai Singapur, Natore Sadar

Horizon : B22 Depth: 47 - 78 cm

Physiography : Margin of a backswamp,

Flooding : 3-4 m, 5-6 months

Microstructure

Moderately to strongly developed angular and subangular blocky peds ranging from 5 mm to 7 mm in size occupy about 25 - 30% area of the section. Some of the peds are separated by short and long planar voids on all sides, some on most sides and some on few sides. The planar voids are, in general, long. The intrapedal voids are elliptical in shape with undulating and irregular surfaces and range from 250 μm to 2 mm in size. Total estimated porosity is 15 - 20%.

Basic mineral grains

c/f limit at 20 μm; the ratio of 5:95

a) Coarse single mineral grain

A few grains of anhedral quartz of 20 - 50 μm sizes are randomly distributed in the thin section. The micas are strongly altered and not identifiable by optical properties.

b) Fine fraction

Most of the section comprises unoriented randomly distributed impure clay aggregates and very fine silt - size (<5 μm) micaceous particles.

Groundmass

The c/f related distribution is porphyric. The micromass possesses strongly developed unistrial, parallel striated and cross striated b-fabrics.

Textural pedofeatures

Segregations of iron hydroxides intermixed with clay are clearly visible throughout the section and in few cases, weakly developed iron nodules are found. Some skew/craze planes have disturbed the micromass due to alternate wetting and drying and they have varying widths. No illuviation clay coatigs, hypocoatigs and ferrans are observed. Barring a few grains of quartz, the entire section comprises impure clay and very fine silt-size (< 5 μm) micaceous particles.

9. BARIND TRACT

No. of sections described : 4

(i) Code No. S6/1

Location : Narahatta, Kahalu upazila, Bogra district

Horizon : Ap1 Depth: 0 - 10 cm

Physiography: Nearly level upland

Flooding : 0.3m, 3 - 5 months

Microstructures

Apedal soil material shows pellicular grain microstructre. Randomly distributed elliptical voids range from 60 µm - 1 mm in length. Many planar voids criss-cross the section. Two channel voids are also seen. Estimated porosity is 20 - 25%.

Basic mineral components

c/f limit at 20 µm; the ratio of 30:70

a) Coarse single mineral grain

Coarse fraction constitutes entirely anhedral quartz grains except few grains of muscovite, microcline and plagioclase. The quartz grains range from 30 - 500 µm in size.

b) Fine fraction

It consists of clay aggregates and very fine micaceous particles (<10µm).

Groundmass

The c/f related distribution is porphyric. The micromass has moderately developed parallel striated, cross striated and porostriated b-fabrics.

Textural Pedofeatures

Many illuviation cutans (argillans) ranging from 60 - 125 µm in thickness occur mainly around round-shaped and planar voids. A microlaminated coating (125 µm thick) with micro-contrasted particles is seen along a channel void. Many impregnative and few nucleic nodules of iron oxides are also seen. A skew plane cutan (Brewer, 1964) and the segregations of iron oxides are clearly visible.

(ii) Code No. S6/8

Location : Narahatta, Kahalu Upazila, Bogra district

Horizon : C Depth : 168-202 cm

Physiography: Nearly level upland

Flooding : 0.3 m, 3 - 5 months

Microstructures

Apedal soil material with pellicular grain microstructure. Some voids with irregular shapes and others resembling to elliptical voids occupy about 20% area of the section and they range from 1 - 3 mm in length.

Basic mineral components

c/f limit at 20 μm; ratio of 70:30

a) Coarse single mineral grain

90% of the grains are quartz which range from 30 - 500 μm in size. The rest 10% grains are altered muscovite ranging from 50 - 150 μm in length. Few grains of feldspars are also present.

b) Fine fraction

The fine fraction consists of very fine micaceous and quartz particles (<20 μm) and clay aggregates.

Groundmass

The c/f related distribution is porphyric. The b-fabric is undifferentiated.

Textural Pedofeatures

A few nucleic nodules of iron oxides (500 μm - 2 mm in diameter) and segregated iron oxides are seen. One large size papule (500 μm x 450 μm) and few of smaller sizes are also seen. The papules represent disrupted argillans.

(iii) **Code No. S2/3**

Location : Sharoil, Godagari Upazila, Rajshahi district

Horizon : B22 Depth : 28 - 43 cm

Physiography : Nearly level upland

Flooding: Above flood level

Microstructures

Apedal soil material with bridged grain microstructure. Irregular voids occupy about 10 - 15% area of the section.

Basic mineral components

c/f limit at 20 µm; ratio of 50:50

a) Coarse single mineral grain

95% of the grains are anhedral quartz ranging from 20 - 200 µm in size but some of them are of larger sizes (300 - 500 µm). Few large grains may be polycrystalline quartz. Except quartz the other grains are muscovite ranging from 100 - 250 µm in length.

b) Fine fraction

Very fine micaceous and quartz particles (<20 µm) and aggregates of clay and iron oxides constitute the fine fraction.

Groundmass

The c/f related distributed is gefuric and poprphyric. The b-fabric is undifferentiated.

Textural Pedofeatures

Some oriented clay aggregates (resembling to papules) are embedded in the groundmass. A few coatings of clay occur around voids and grains. Six nucleic nodules with moderately smooth boundaries and few aggregate nodules of iron oxides are seen.

(iv) Code No. S1/6

Location: Sharoil, Godgari Upazila, Rajshahi district

Horizon : C Depth: 92 - 105 cm

Physiography: Nearly level upland

Flooding: Above flood level.

Microstructures

Well developed angular to subangular blocky peds range from 1.5 - 4 mm in size and occupy about 15 - 20% area of the section. The groundmass shows pellicular grain microstructure. Elliptical and irregular voids occupy 10 - 15% area of the section. The elliptical and subrounded voids range from 200 - 500 µm in diameter.

Basic mineral components

c/f limit at 20 µm; ratio of 60:40

a) Coarse single mineral grain

95% of the grains are quartz with a size range of 30 - 150 µm. Some of them range from 200 - 300 µm. The rest of the grains are moderately altered muscovite (100 - 150 µm in length), and few grains of feldspars.

b) Fine fraction

Very fine micaceous and quartz particles (<20 μm) and clay aggregates constitute the fine fraction.

Groudmass

The c/f related distribution is chitonic. The b-fabric is weakly developed.

Textural Pedofeatures

A few nucleic nodules with smooth boundaries and many impregnative nodules of iron oxides are randomly distributed. The nucleic nodules range from 4 - 8 mm in diameter.

10. MADHUPUR TRACT

No. of thin sections described : 4

(i) Code No. T7/2

Location : Sripur cotton seed farm, Sripur Upazila, Gazipur district

Horizon : B21 Depth: 8 - 81

Physiography: Nearly level upland terrace

Flooding : Above flood level

Microstructures

Moderately to strongly developed subangular blocky peds range from 500 μm - 5 mm in size and occupy about 30% area of the section. The groundmass has pellicular grain structure. Voids are mostly planar. Estimated porosity is 20%.

Basic mineral components

c/f limit at 20 μm; ratio of 30:70

a) Coarse single mineral grain

Coarse grains are entirely quartz particles except few grains of muscovite, tourmaline and opaque minerals. 50% of the grains range from 30 μm - 70 μm and the other 50% range from 150 - 300 μm in size. The larger grains have corroded/pitted surfaces and irregular boundaries. A few larger grains may be polycrystalline quartz.

b) Fine fraction

It consists mostly of clay aggregates having intense red colouration by iron oxides.

Groundmass

The c/f related distribution is open porphyric. The b-fabric is undifferentiated.

Textural Pedofeatures

Some aggregates of iron oxides and few papules of disrupted clay cutans (argillans) are seen.

(ii) Code No. T7/5

Location: Sripur cotton seed farm, Sripur Upazila, Gazipur district

Horizon: B24 Depth: 180 - 200 cm

Physiography: Nearly level upland terrace

Flooding: Above flood level

Microstructures

Well developed subangular blocky peds range in size from 250 µm - 3 mm and occupy about 50% area of the section. The voids are mostly planar. The groundmass shows pellicular grain structure. Estimated porosity is 20 - 25%.

Basic mineral components

c/f limit at 20 µm; ratio of 30 : 70

a) Coarse single mineral grain

The grains are mostly anhedral quartz with corroded surfaces and irregular boundaries. 30% of the grains are 250 µm in size and 60% are 20 - 125 µm in size. A few grains range from 250 - 500 µm in size. Few larger grains may be pollycrystalline quartz. Few grains of tourmaline, orthoclase and muscovite are also seen.

Groundmass

The c/f related distribution is open porphyric. The b-fabric is undifferentiated.

Textural Pedofeatures

Many illuviation clay cutans (argillans) mainly along planar voids and some around grains are present. They range from 50 - 250 µm in thickness and occupy 6 - 7% area of the section. The cutans (argillans) have continuous fabrics as indicated by black extinction lines. Some of the cutans have been displaced and deshaped by pedoturbation. The finer materials possess intense red colouratio by iron oxides.

(iii) Code No. T6/1

Location: Mouchak, Kaliakoire Upazila, Gazipur district

Horizon: Ap Depth : 0 - 10 cm

Physiography: Margin of a valley

Flooding: 0.5 - 1.5 m, 15 - 20 days

Microstructures

Apedal soil material with pellicular grain microstructure. Some simple packing voids occupy 5 - 10% area of the section.

Basic mineral components

c/f limit at 20 µm; ratio of 80:20

a) Coarse single mineral grain

90% of the grains are anhedral quartz ranging in size from 30 - 400 µm. The large grains (200 - 400 µm) of quartz have pitted/ corroded surfaces. Few larger grains are polycrystalline in nature. The rest 10% are moderately altered muscovite ranging from 75 - 125 µm in length. Few grains of orthoclase are also present.

b) Fine fraction

It consists of very fine micaceous particles (<5 µm) and clay aggregates.

Groundmass

The c/f related distribution is chitonic and porphyric. The b-fabric is undifferentiated.

Textural Pedofeatures

Impregnative and aggregate nodules of iron oxides are noted. At some parts of the section iron oxides occur as elongated zones. Organic tissue residues and particles of charcoal are also present.

(iv) Code No. T6/3

Location: Mouchak, Kaliakorie Upazila, Gazipur district

Horizon: B21 Depth 18 - 42 cm

Physiography: Margin of a valley

Flooding: 0.5 - 1.5 m, 15 - 20 days

Microstructures

Apedal soil material contains elliptical voids which range from 400 µm - 1 mm in length. Few planar voids are noted. Pellicular grain as well as massive structures are present. Estimated porosity is 15 - 20%.

Basic mineral components

c/f limit at 20 μm; ratio of 30 : 70

a) Coarse single mineral grain

80% grains are quartz ranging in size from 30 - 200 μm. The rest 20% are highly altered biotite and moderately altered muscovite ranging from 125 - 500 μm in length.

b) Fine fraction

In consists mainly of very fine micaceous particles (<20 μm).

Groundmass

The c/f related distribution is porphyric. Well developed unistrial, parallel striated and cross striated b-fabrics are observed.

Textural Pedofeatures

The segregation of iron oxides are clearly seen. The finer aggregates of iron oxides are intermixed with the groundmass. Few impregnative modules and hypocoatings are also seen.

11. LALMAI HILLS

No. of thin sections described: 2

(1) Code No. T12/5

Location : Baradharmapur, Comilla Sadar

Horizon : B24 Depth: 65 - 165 cm

Phyisography: Summit of Lalmai hills

Flooding : Above flood level

Microstructures

Apedal soil material shows pellicular grain microstructure. Elliptical and subrounded voids with undulating and irregular boundaries range from 200 - 300 μm in diameter. Estimated porosity is 20 - 25%.

Basic mineral components

c/f limit at 20 μm; the ratio of 50:50

a) Coarse single mineral grain

About 90% grains are quartz with undulating surfaces and they range from 30 μm - 1 mm in size. Apart from four or five grains of orthoclase and plagioclase, the rest of the grains are moderately altered muscovite and highly altered biotite. The biotite grains sometimes, show exfoliation features.

b) Fine Fraction

It constitutes clay aggregates and very fine micaceous and quartz particles (<10 μm).

Groundmass

The c/f related distributed is chitonic. The b-fabric is undifferentiated.

Textural Pedofeatures

Cutans (argillans) of limpid clay (50-100 μm) occur around quartz grains and voids. Some of them have been displaced by pedoturbation and sometimes, occur in intergranular spaces. As a whole, the clay material has attained intense red colouration. Few aggregates of clay resemble to aggregate nodules of iron oxides.

(ii) Code No. T12/7

Location : Baradharmapur, Comilla Sadar

Horizon : C Depth : 200 - 250 cm

Physiography: Summit of Lalmai hills

Flooding: Above flood level.

Microstructures

Apedal soil material shows pellcular grain microstructure. Simple packing voids occupy 10 - 15% area of the section.

Basic mineral components

c/f limit at 20 μm: ratio of 70:30

a) Coarse single mineral grain

85% of the grains are quartz which range from 60 - 800 μm in size. The rest 15% grains constitute highly altered and exfoliated biotite (150 - 500 μm), moderately altered muscovite (400 - 800 μ) and very few grains of microcline and plagioclase (300 - 400 μm).

b) Fine fraction

It consists of clay aggregates and very fine micaceous and quartz particles (<20 μm).

Groundmass

The c/f related distribution is gefuric and chitonic. The b-fabric is undifferentiated.

Textural Pedofeatures

Aggregate nodules of iron oxides and few grains of litho - relicts are seen. Few grain cutans (argillans) of limpid clay are also noted which range from 40 - 60 μm in thickness.