SOIL-LANDFORM DEVELOPMENT OF A PART OF FOLD BELT ALONG EASTERN COAST OF BANGLADESH

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DOCTOR OF PHILOSOPHY

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By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **"SOIL-LANDFORM DEVELOPMENT OF A PART OF FOLD BELT ALONG EASTERN COAST OF BANGLADESH"** in fulfillment of the requirement for the award of the degree of **DOCTOR OF PHILOSOPHY** and submitted in the **Department of Earth Sciences** of the Indian Institute of Technology Roorkee, is an authentic record of my own work carried out during the period from January 07, 2000 to June 2003 under the supervision of **Prof. B. Parkash** and **Dr. Sudhir Kumar**.

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

Date : 30/6/03

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

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ABSTRACT

The investigated Jaldi and Maiskhali structures include a part of coastal region of north-south trending Fold Belt of Bangladesh. It offers an excellent site for studies of soil-geomorphic relationships of undulating coastal regions. Quaternary sea level fluctuations, palaeoclimatic changes and neotectonic activities (folding) have probably influenced significantly the development of soils and landforms of the area. A pedological approach has been taken to unveil the role of these factors in the soil-landform development of the area.

Eight soil-geomorphic units have been delineated in the area are: Mainland Higher Hillocks, Mainland Lower Hillocks, Island Hillocks, Proximal and Distal Piedmont Plains, Old and Active Tidal Flats and River Floodplains. A four member (I – IV) Morphostratigraphic sequence for the study area has been prepared based on Luminescence ages of soils. The various soil-geomorphic units included in different member/sub-members are: Member I - River Floodplains and Active Tidal Flats (< 500 yrs); Member II - Distal Piedmont Plains and Old Tidal Flats (1 – 2 ka); Member III - Proximal Piedmont Plains (6 – 10 ka) and Member IV - Mainland Higher and Lower Hillocks and Island Hillocks (> 15 ka). Member IV is further subdivided into Sub-member IVa - Island Hillocks (15 – 18 ka); Sub-member IVb - Mainland Lower Hillocks (23 –25 ka) and Sub-member IVc - Mainland Higher Hillocks (30 – 35 ka).

Depending on slope and elevation, Member I of the Morpho-stratigraphic sequence forms the 'accreting zone', Member III forms the 'zone of pedogenesis' and Member II occupies a transition zone between the accreting zone and zone of pedogenesis. The Mainland Higher Hillocks, Mainland Lower Hillocks and Island Hillocks in Member IV belong to the 'sloughing zone'.

The soils of the study area with distinctive pedogenic processes can be broadly divided into the following three groups: (a) Poorly developed soils (Member I) - These are least developed and marked by active sedimentation.

Hydromorphism is going on as indicated by diffused mottling. (b) Moderately developed soils (Member II and III) - These soils are marked by mainly translocation of clays as indicated by the presence of thick argilians, ferriargillans and gleyans. Hydromorphic processes are active in these units as indicated by Fe-Mn oxide concretions and Fe-oxide mottles. Mineral alteration is negligible with a relatively stronger alteration in the Member III soils. The clay mineral composition is dominantly inherited from the parent material. The weak alteration of minerals and dominance of 2:1 clays and considerable amount of free iron oxide in the form of Fe-Mn oxide concretions and Fe-oxide mottles suggest that these soils are at the initial stage of weathering i.e. in the fersiallitisation stage of pedogenesis of Duchaufour (1982). (c) Strongly Developed soils (Member IV) - Strong alteration of minerals, the yellowish brown to reddish brown colour of the micromass, dominance of 2:1 and 1:1 clays (illite and kaolinite) suggest that these soils have undergone a ferrugination stage of pedogenesis of Duchaufour (1982). Soils of Member IV exhibit degradation and poor birefringence of argillans and ferriargillans indicating a significant change in conditions of pedogenesis. These soils are characterized by a few orthic Fe-Mn oxide concretions and diffused Fe-oxide mottles. The orthic nature of the concretions and diffuse nature of the mottles suggest their recent formation. These indicate the 'relict' nature of these soils.

Field and laboratory analyses suggest that Member II soils have a relatively higher degree of development as compared to Member III soils and this might be attributed to their finer parent material. Among the Member IV soils, Sub-member IVb soils have a higher degree of development as compared to Sub-members IVa and IVc. Lower soil development of Sub-members IVa and IVc is probably due to their present position at the top of local catena, which causes lateral movement of eluviated materials, whereas similar process is probably acting only in a minor way on the Sub-member IVb, as these soils developed on broad flat-topped Mainland Lower Hillocks.

Sea level fluctuated several times with some stillstands during the late Quaternary Period. Eustatic stillstands at 35 – 30 ka and 23 – 20 ka may have affected the palaeodrainage in the study area, made streams to migrate laterally and to form fluvial terraces of the Mainland Higher Hillocks and Lower Hillocks (Jaldi anticline). The age of the Lower Hillock terrace is a little higher than the corresponding eustatic stillstand. This may be due to the fact that timing of stationary sea level in the study area may be slightly different from that in the eustatic curve. The LGM (18 – 15 ka probably) was probably marked by local stillstand of sea and was responsible formation of Island Hillock terrace (Maiskhali island). Deposition of Piedmont zone started at 10 ka and it peaked at 7 ka that coincided with a major transgression in the area. Later a regression at about 1.5-2.0 ka led to the formation of Old Tidal Flats.

The tentative uplift rate as estimated from the samples of the Maiskhali structure during the period between 18 ka up to 8 ka is about 4.5 mm/yr and afterwards (8ka –present) the rate of uplift is retarded to about 0.37 mm/yr. The over all uplift rate (18 ka – present) is 2.43 mm/yr. The tentative uplift rate for the Mainland Higher Hillocks (Jaldi structure) is about 7.9 mm/yr during the period 35 – 25 ka. The relative uplift rate for the Mainland Lower Hillock (Jaldi structure) is calculated as 1.5 mm/yr for the period 25 ka – present. The Maiskhali structure is separated from the mainland by a N-S trending fault and this block uplifted at a higher rate as compared to the mainland during the period 18 – 8 ka.

The Late Quaternary Period in the area was marked by two major phases of palaeoclimate. (a) a subhumid to semiarid phase (40 to about 16 ka) (Vishnu-Mittra and Sharma, 1984; Rangarajan and Sant, 2000) and (b) a hot humid to subhumid phase (16 ka to present) (Sirocko et al., 1993; Sirocko, 1996; Rangarajan & Sant., 2000). The thick argillans and ferriargillans present in Member IV soils were probably formed during the subhumid to semiarid phase. The presence of few orthic Fe-Mn oxide concretions and diffused Fe-oxide mottles indicate their probable formation during the later hot humid to subhumid phase. This humid phase caused degradation of argillans and ferriargillans and their poor birefringence in Member IV soils.

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30/6/03

Md. Sharif Hossain Khan

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Chapter 1

INTRODUCTION

1.1 RATIONALE

Physically Bangladesh can be divided into four major regions: Eastern and northeastern hilly regions; the great table land (Modhupur and Barind tracts in the center and west); flood plains of Ganges, Brahmaputra and Meghna river systems and the delta (Khan, 1991; Fig. 1.1). The investigated area lies in the western part of the Tertiary hill region of Chittagong and Cox's Bazar districts and forms a part of the Chittagong – Tripura Fold Belt. This belt along with more easterly Arakan-Yoma fold belt developed as a consequence of the collision between Indian and Burmese plates. This neotectonic activity is still continuing and particularly the compression towards east to the Arakan – Yoma ridge is affecting and shaping the geomorphology of the area. The area offers a varied topography from hillocks, valleys/basins, flood plains and tidal flats to the sea within a small distance. The region with diverse topographic features merits exploration for working out mode of develcpment and its evolution with time.

A pedological approach is taken to evaluate the landscape development of the area, as soils are the integral part of all land surfaces. Soils experience and record the imprints of the processes operating during their formation. Keeping these in view, the following aspects were studied:

1. Detailed study of soils and landforms was undertaken to evaluate the evolution of landforms in the area.
2. Morphostratigraphy of the region was attempted by dating different soils by Optical Stimulated Luminescence Dating technique.
3. Hills and the bay are juxtaposed in the area. It is highly probable that the soils and landforms developed might inherit signatures

of the neotectonic activity, climatic changes and sea level fluctuations that occurred during the Late Pleistocene to the Recent past and their roles need to be worked out.

1.2 LOCATION AND EXTENT

The investigated area belongs to the Satkania, Lohagora, Banshkhali thanas of Chittagong district and Maiskhali thana of Cox's Bazar district. The area lies between 21°30' - 22°15'N latitude and 91°45' - 92°15'E longitude (Fig. 1.2). The studied area is included in Survey of Bangladesh topographic sheets number 79N/16, 79O/13, 79O/14, 84B/4, 84C/1 and 84C/2.

1.3 CLIMATE

Bangladesh has a tropical monsoon climate. There are four main seasons in Bangladesh, which vary in length and intensity from year to year. The Pre – monsoon (or summer) season lasts from March to May. It has the highest temperature and evaporation rates. Periodic thundershowers and devastating cyclones like Nor'wester (Kal Baishakhy in Bengali) associated with ocean wave surges occur during this period. The Monsoon (or rainy) season extends from June to September. It is warm, humid and receives about 80 – 90% of the total annual rainfall. The Post–monsoon, from October to November, is hot and humid and sunny. Cyclonic storms and wave surges from the Bay of Bengal affect severely the coastal areas during this period. The Dry (or winter) season extending from December to February is cool, dry and sunny. The period receives very little rainfall and has the lowest temperatures and humidities of the year.

The investigated area (Chittagong and Cox's Bazar districts) is a zone of heavy rainfall and small range of mean temperature (Rashid, 1977). The temperature rarely goes over 32°C and below 13°C. Rainfall is heavy, usually in the range of 280 cm to about 350 cm annually (Fig. 1.3). Humidity ranges from about 69 and 77% in the dry season to about 84 and ~90% in the rainy season. There is an excess of rainfall over evaporation annually and particularly in the rainy season (Naqvi, 1964).

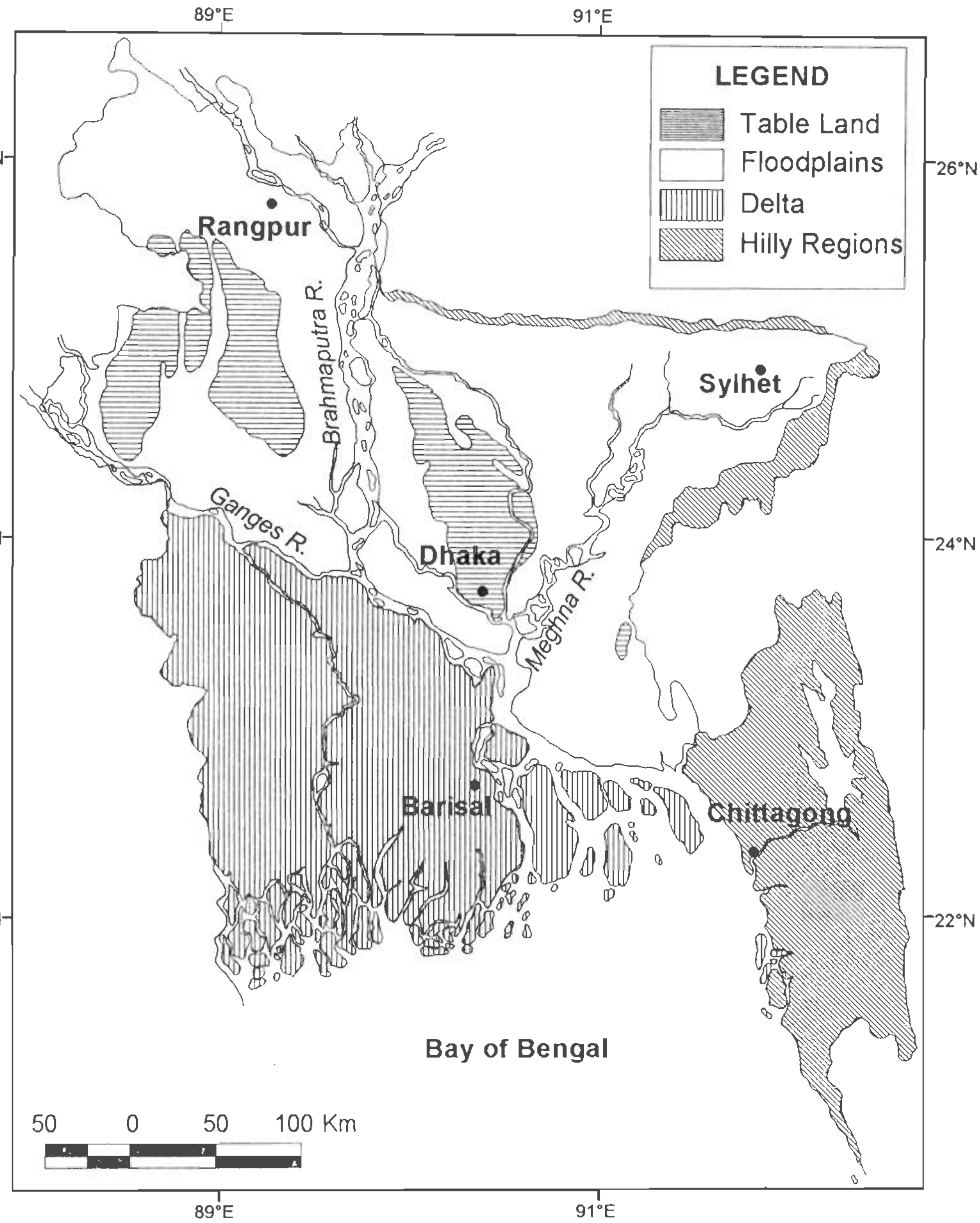


Fig. 1.1 Physiographic divisions of Bangladesh (after Khan, 1991).

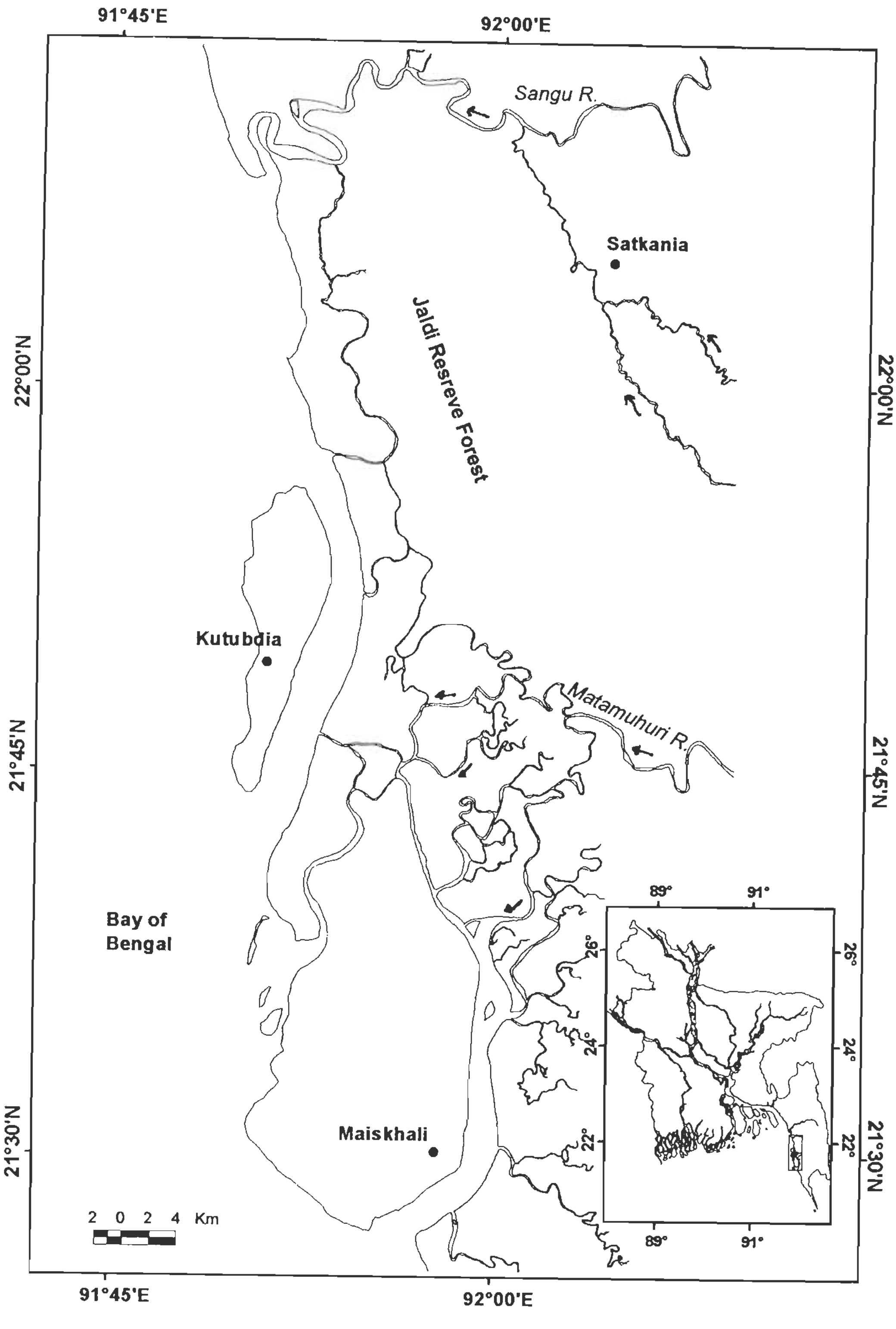


Fig. 1.2 Location of the study area.

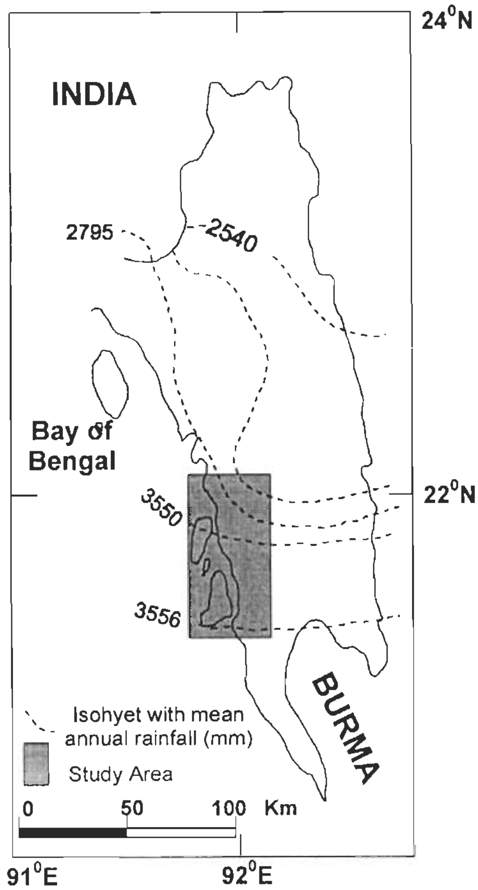


Fig. 1.3 Isohyet map of the study area (after Rashid, 1977).

Winds are moderate throughout the year, except in the period from March to May, when south – southeast winds up to 100 – 160 kmph may occur in association with thunderstorms. Occasional hailstorms also occur in this period. From June to September, the winds are southeasterly and sometimes easterly. The winds are very variable in October due to strengthening of the northerly winds and occasionally bring cyclonic storms from the Bay. Northerly to northwesterly winds continue during the period November to February.

1.4 GROUND WATER

Chittagong hill tracts and coastal plains of Chittagong and Cox's Bazar are least explored in terms of ground water assessment. There are two major aquifers in the area – one is shallow and the other is deep seated, treated as main aquifer (MPO, 1987). In the hill ranges, the thickness of the aquifers is highly variable ranging from few tens of meters to more than 100 meters. The shallow aquifer is unconfined and depth is variable due to folding. The deep aquifers may be semiconfined to confined and their depth is highly variable. In the coastal plains, the shallow aquifers are at a depth of about 50 m and have a thickness of 20 – 50 m. The aquifers are semiconfined to unconfined in nature and affected by saline water intrusion, as they are hydraulically connected with the tidal rivers. The depth of the main aquifer is not precisely known, but may be at a depth of more than 230 m. It is not affected by saline water intrusion. Artesian wells are common both in the hill tracts and in coastal plains.

1.5 STRUCTURE AND STRATIGRAPHY OF THE AREA

1.5.1 Regional Structure

Bangladesh constitutes the major portion of the Bengal Basin, a part of the Indo – Gangetic trough (Curray and Moore, 1974; Sengupta, 1964). Based on the available results of geophysical investigation, geological mapping and well data, the tectonic framework of Bangladesh has been constructed. A number of workers (Bakhtine, 1966; Alam, 1972; Guha, 1978; Hoque et al., 1982; Khan, 1991; Reimann, 1993) have discussed the structural configuration of Bangladesh.

Tectonically, Bangladesh is divided into three major divisions – Indian Platform, a stable shelf part in the western and northwestern part, and another deep basin area, the Bengal Basin at the center and the Folded belt in the east (Fig. 1.4). A Hinge zone separates the Indian Platform and the Bengal Basin. Brief descriptions of these tectonic zones are given below.

Indian Platform

The zone is limited on the north and northwest by the Himalayan Foredeep, the Indian shield to the west and bounded on the south – southeast by the Hinge zone. Indian Platform within Bangladesh territory is divided into three sub units: Dinajpur slope (northern slope of the Rangpur saddle, 60 km wide), Rangpur saddle (~ 100 km wide) and Bogra slope (southern slope of

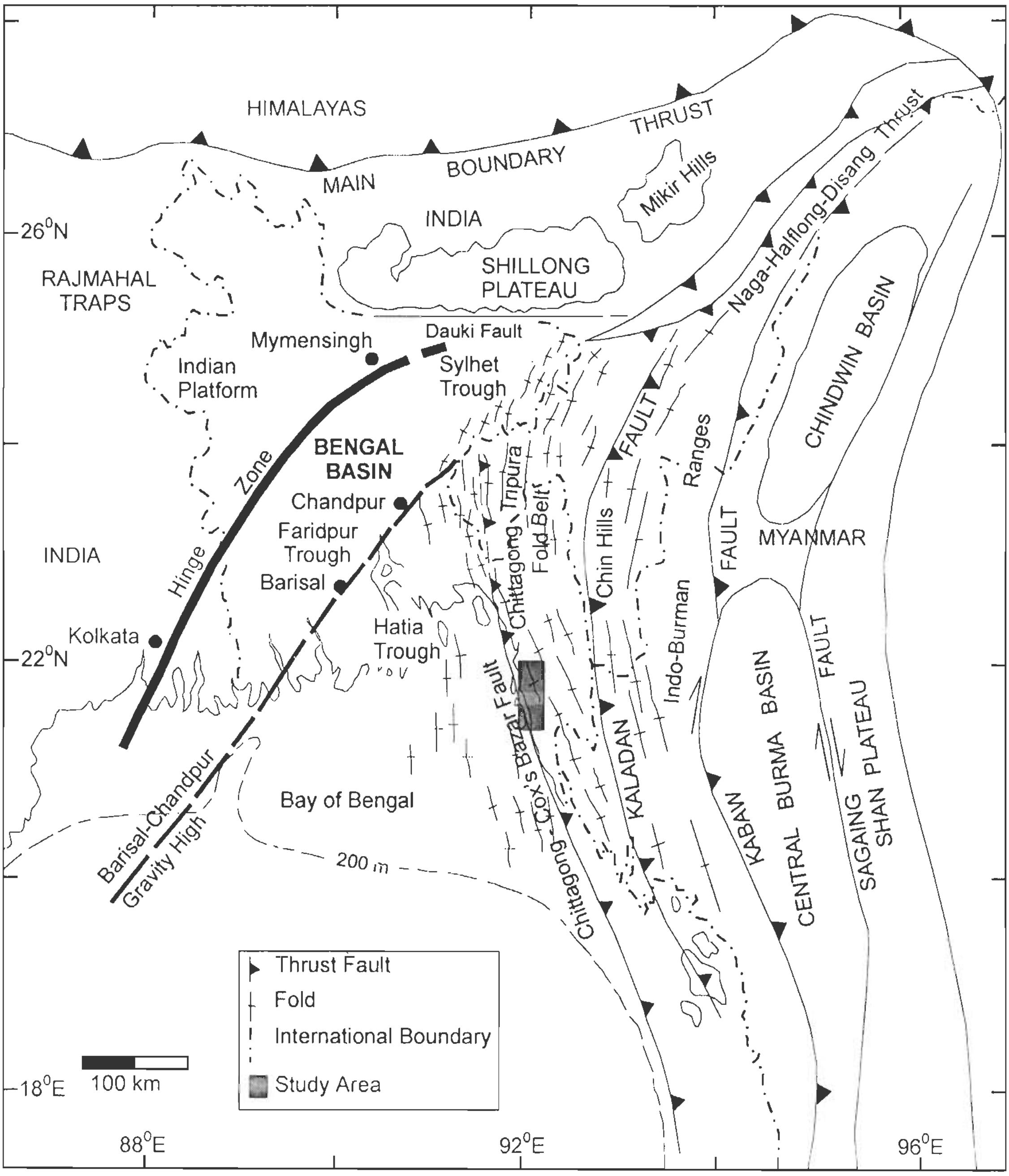


Fig. 1.4 Tectonic elements of Bangladesh and adjoining areas (after Alam et. al., 2003).

the Rangpur saddle, 60-125 km wide). Rangpur saddle is a buried Precambrian ridge that connects the Indian shield and the Shillong Plateau. The shallowest basement occurs at about 150 m depth at Madhyapara.

Hinge Zone

The entire Bengal – Assam shelf shows an important feature in the southwestern part known as the Hinge zone. It is a narrow strip of 25 km wide, trends N30^{0}E and coincides with the NE–SW trending Kolkata – Mymensingh gravity high and seems to be connected with the Dauki fault by a series of east – west trending faults (Guha, 1978). The zone marks the structural as well as the depositional transition zone between the Bengal Basin and the Indian Platform.

Bengal Basin

Bengal Basin is bounded by the Hinge zone on the north – northwest and limited by the frontal folded system on the east (Arakan-Yoma Geoanticline) and opens to the Bay of Bengal in the south. Its width varies from 200 km in the northeast to about 500 km in the south. The Bengal Basin is a deeply subsided basin formed by subsidence between the Indian Platform and the Arakan Yoma Geoanticline. The zone started developing during Oligocene, the period of intensive central uplift of the Arakan Yoma fold belt. The thickness of Neogene sediments in the zone varies from 11 km to >20 km (Guha, 1978; Banerjee, 1984; Paul and Lian, 1975; Matin et. al., 1986; Hiller, 1988).

Fold Belt

It is the most spectacular and prominent structural element in Bangladesh. Neogene sediments are compressed into linear, elongated folds parallel to the Arakan Yoma Geoanticline on the western front. The structures are mainly anticlinal and synclinal folds represented by hill ranges and valleys, respectively and thrust faults. The intensity of folding and elevation of the structures increases in the easterly direction towards Arakan-Yoma ridges and the thrust component increases westward (Alam et al. 2003). Alam et al. (2003) deciphered three compartments within the regional oblique subduction zone between Indian and Burmese plates. From east to west these are: the Central Burma Basin between the Sagaing fault and the Kabaw fault; the Indo-Burman Range between Kabaw fault and Kaladan fault; and the Chittagong – Tripura Fold Belt Between the Kaladan fault and the Chittagong – Cox's Bazar fault structures. The study area is a part of the Chittagong-Tripura Fold Belt.

1.5.2 Regional Stratigraphy

Sedimentary rocks are exposed only along the basin margins in the eastern frontal folded belt of Indo – Burman ranges in Chittagong, Chittagong hill tracts, Comilla and Sylhet districts. Pleistocene clays are also exposed in the Modhupur, Barind and Lalmai areas. The remaining portions of Bangladesh are covered entirely by alluvial deposits (Fig. 1.1). The present limited knowledge of the Bangladesh stratigraphy and facies development is primarily based on exploratory well data and seismic evidence from the subsurface. Stratigraphic correlations have been attempted recently by several workers (Ahmed, 1968; Ismail, 1978; Chowdhury, 1982; Lietz and Kabir, 1982; Gani and Alam, 2003 and unpublished reports of Bangladesh Petroleum Exploration and Production Company). Alam et al. (2003) described the evolution of Bengal Basin as a 'remnant ocean basin' since Miocene and divided the basin into three geo-tectonic provinces that have their own tectonics and stratigraphy and history of sediment-fill. The geo-tectonic provinces are: (1) Passive to extensional cratonic margin in the west, the 'Stable Shelf Province'; (2) the 'Central Deep Basin Province' or remnant ocean; and (3) the subduction related orogen in the east, the 'Chittagong–Tripura Fold Belt Province'. Gani and Alam (2003) have provided an allostratigraphic succession for the Chittagong –Tripura Fold Belt (Table 1.1).

Table 1.1: Allostratigraphic succession of the Chittagong – Tripura Fold Belt of Bangladesh (after Gani and Alam, 2003)

After Evans (1932)					Nomenclature After (Gani and Alam, 2003)
Age (Approx.)			Nomenclature		
Quaternary	Recent		Alluvium		Alluvium
	Plio-Pleistocene		Dupitila Fm.		Kaptai Group (1100-1600 m)
			Tipam Group	Girujan Clay Fm.	
Neogene				Tipam Sst. Fm.	
	Miocene	Late	Surma Group	Boka Bil Fm.	Mirinja Group (1200-1600 m)
		Middle		Bhuban Fm.	Sitapahar Group (1000-1500 m)
		Early			Boundary not established
Paleogene	Oligocene		Base not exposed Barail Group (in subsurface)		Chittagong Group (mostly in subsurface; 2000 m +)

1.5.3 The Study Area

The investigated area includes a region with two anticlines - Jaldi and Maiskhali, the two extreme western fold trends in the fold belt of Bangladesh and are of box shape. The Jaldi structure is trending N18°W (Geological Evaluation Division, Petrobangla, 1975) and lies in en-echelon with Sitakund anticline in the north. The Sangu and Matamuhuri rivers limit the Jaldi anticline in north and south, respectively. Seasonal / ephemeral streams and streamlets of consequent type and dendritic pattern are present in the hilly regions and small braided streams are present in the Piedmont Plains. The area represents an undulating, irregular topography comprising hills, valleys, piedmont plains, river floodplains and tidal flats. The highest elevation is approximately 110 m. Generally the higher hillocks are composed of relatively more resistant rocks (Tipam Sandstone Formation), whereas the lower hills on the flanks of the anticline comprise less resistant rocks (Dupi Tila Formation). Minor patches of the Girujan Clay are also present. The exposed formations include the Tipam Sandstone Formation, Girujan Clay Formation, Dupi Tila Formation and alluvium.

The Maiskhali anticline trends N10°W (Orient Geological Consultants, 1975). The anticline is the northern continuation of the Inani structure and is followed to the east on the main land by the Ukhia syncline. The eastern half of the island comprises the north-south trending Maiskhali hill range with a maximum elevation of about 90 m and the western half forms low land of salt marshes, tidal flats, tidal channels and coastal lagoons. Monsur (1995) assumed that the 5,500 yrs BP shoreline ran along the foot of the hillocks. The supratidal flat in the Maiskhali island has two steps. Monsur (1995) considered that they might be the benchmarks of two Holocene sea levels. The exposed stratigraphic formations in the Maiskhali anticline are the Boka Bil Formation, Tipam Sandstone Formation, Girujan Clay Formation, Dupi Tila Formation and Quaternary deposits.

1.6 TECTONICS OF THE AREA

The evolutionary history of the investigated Jaldi and Maiskhali structures is tied with the evolution of the Bengal Basin, particularly with the development of Arakan – Yoma Geoanticline or Indo – Burman Ranges. The Bengal Basin was an integral part of the major basin that extended from the Shan Massif in the east to the Indian shield on the west during Paleocene period (Reimann, 1993). During this period, the Indian plate was moving towards north and the Tethys and the young Indian Ocean were interconnected across the Upper Assam shelf (Nagappa, 1959; Reimann, 1993). Collision of Indian plate with the Burmese plate in the northern Burma resulted in the uplift of the Indo–Burman Ranges by the Middle Eocene (Curray et al., 1979; Mitchell, 1981; Reimann, 1981; Rangarao, 1983). The uplift of the Indo – Burman Ranges (Eocene island arc) produced a twin gulf that separated the Burmese Tertiary Basins on the eastern and the Bengal – Assam Basins on the western and northern flanks. These basins were fully separated with the rise of the Himalayas and of the Indo – Burman ranges in the Oligocene times (Brunnschweiler, 1966) and Bengal Basin came into existence by about 35 Ma (considered as 'remnant ocean basin' by Alam et al., 2003).

Due to the collision of Indian, Burmese and Eurasian continental plates, at about Oligo-Miocene time, rise of the Himalayas and Indo-Burman ranges took place, sea regressed, initiation of Oligo-Miocene delta complex build-up in the Bengal Basin took place by Mid to Late Miocene, it resulted in a very high rate of sedimentation in the Ganges – Brahmaputra delta system including the formation of the modern Deep Sea Fan complex. These continental plate collision caused the oblique subduction of Indian plate beneath the Burmese plate and has formed the westward migrating Cretaceous–Holocene accretionary prism complex (Dasgupta and Nandy, 1995; Gani and Alam, 1999). These movements in the Indo – Burman ranges produced folding in Bangladesh and Tripura folded belt due to distal compressional wave since Pliocene (Bender, 1983; Reimann, 1993). This movement is still active at the present day and affecting the structure and geomorphology of the area. The Chittagong – Tripura Fold Belt is the westward continuation of the Indo-Burman accretionary prism and younging towards west (Gani and Alam, 1999). The Jaldi and Maiskhali anticlines lie along the extreme western margin of the fold belt. These are low amplitude anticlines mark the youngest fold trends in the region.

1.7 CLIMATIC AND SEA LEVEL CHANGES DURING THE LATE QUATERNARY

The Indian subcontinent including the study area experienced a varied climate during the Late Quaternary period. The temperature pattern over northern Tibet may be the key driving force of the southwest monsoon, which in turn affects the climate over the region (Rangarajan and Sant, 2000; Sirocko et al., 1993; Sirocko, 1996). A warm and humid climate was prevailing around 40 ka (Vishnu-mittra and Sharma, 1984) and seems to have continued till 30 ka marked by a sea transgression along the eastern coast of India (Merh, 1992). A stable arid climate and weaker southwest monsoon were prevailing in the region during the late glacial period up to around 19 ka. About 18 ka, during the Last Glacial Maximum, the sea level in the Bay of Bengal was about 120 m below the present mean sea level and the coastline was some hundreds of kilometers southward from the present coast (Alam, 1989; Monsur, 1995). From 19 ka to 16.5 ka, a temperature increase in the Tibetan plateau caused a huge melting of ice masses accompanied by a sudden increase in the sediment influx of the river systems (Rangarajan and Sant, 2000). Umitsu (1987) assumed that this was the period when rivers deposited the lowest gravel member in the incised valleys in Ganga-Brahmaputra Deltaic region. Eustatic sea level also started rising rapidly and the shoreline of the Bay of Bengal started shifting northward during this period. An abrupt increase in the southwest monsoon and precipitation between 16.5 ka to 13.5 ka favoured an increased humidity on land. A decrease in temperature in Tibet during the 13.5 ka – 10 ka resulted in the weaker monsoon and relatively a more arid phase (Sirocko et al., 1993; Sirocko, 1996; Rangarajan and Sant, 2000). Based on sedimentary characteristics, radiocarbon ages of sediments from different depths from western coastal area of Bangladesh, Umitsu (1987) proposed that around 12 ka the sea level rose to about – 45 m elevation with a temporal regression between 12 ka and 10 ka. Islam and Tooley (1999) showed that the sea level was at a depth of 6 m from the present sea level around 9 ka.

During Early and Middle Holocene between 10 ka to 3.4 ka, the climate was in a moist phase and southwest monsoon strengthened again. Since 3.4 ka, a more arid climate compared to Middle Holocene has been prevailing, but locally it also shows moist phases in the region. About 5.5 ka to 6 ka, the sea level in the region attained its maximum height about 4 to 5 m higher than the present sea level (Monsur and Kamal, 1994), whereas Merh (1992) reported a 6 – 10 m rise of sea level and Banerjee and Sen, (1987) showed the timing of sea transgression is at 6 – 7 ka. The coastline moved about 100 km inland passing through a line with an arc that swung across from the south of Kolkata to Dhaka (Alam, 1989;) during this period. The sea level curve oscillated for a few times afterwards. Tarafder and Monsur (1999) reported two drops of Holocene sea level around 2,370 and 1,110 yrs BP. Since 6 ka the Ganges – Brahmaputra – Meghna delta system prograded towards south and finally built up the present configuration.

Proxy records of climate and eustatic sea level changes suggest a strong correlation between them. Eustatic sea level (Fig. 1.5) fell with some reversals to about 18 ka (Chappell, 1994; Shackleton, 1987) and then it has risen in stages to about 6-7 ka and then gone down to the present level. Climate fluctuated from subhumid to semiarid from about 40 ka to about 16.5 ka. Since 16.5 ka, climate has varied between hot humid to subhumid with small periods of aridity.

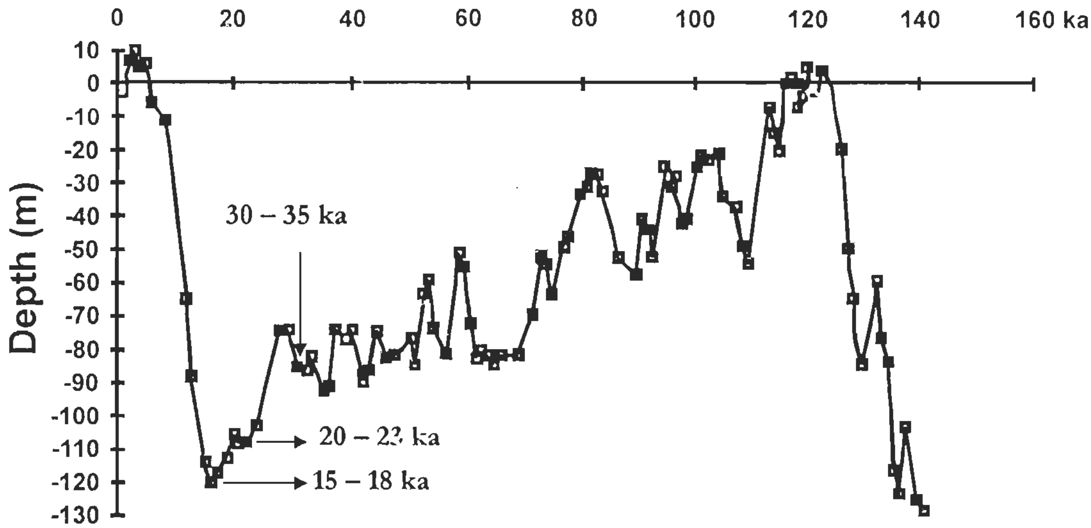


Fig. 1.5 Eustatic sea level curve after Chappell (1994) and significant stillstands of the Late Pleistocene are also marked.

1.8 PREVIOUS WORKS

Physiography of Bengal Basin has been described by Johnson (1957), Morgan and McIntire (1959) and Rashid (1977). The structural configuration of Bangladesh has been worked out by several authors (Bakhtine, 1966; Alam, 1972; Hoque, 1982; Guha, 1978; Brunnschweiler and Khan, 1978).

Bakhtine's (1966) classification provided the foundation of the present knowledge of the structure and tectonics of Bangladesh. The regional tectonics and stratigraphic framework of the Bengal Basin was dealt by several authors (Salt et al., (1986), Alam (1989, 1997); Lindsay et al. (1991) and Shamsuddin and Abdullah (1997). The stratigraphy of Bangladesh was established by lithological correlation with the stratigraphy of Assam and West Bengal provinces of India and suffered from diachronism of formations (Khan and Muminullah, 1980; Reimann, 1993). Different workers (Ahmed, 1968; Ismail, 1978; Chowdhury, 1982; Leitz and Kabir, 1982; Gani and Alam, 2003) have attempted to refine the stratigraphic scheme of Bangladesh. Alam et al. (2003) have provided the latest comprehensive integrated review of structure, stratigraphy and tectonic evolution of Bangladesh and adjoining areas.

Bakr (1977), Oya (1977) and Umitsu (1985, 1987, 1993) have studied the Late Quaternary sedimentary environments, landform evolution and geomorphology of Bangladesh floodplains. Quaternary stratigraphy and palaeoclimatic impacts have been outlined by Hassan (1986), Monsur and Paepe (1992) and Alam (1998). Hossain and Parkash (1999) studied the role of neotectonics on the evolution of the Quaternary landforms and soils of Bangladesh.

Brammer (1964, 1971, 1996), Brammer and Brinkman (1977), Brinkman (1970, 1977) and Habibullah et al. (1971) have provided the basic frameworks and outlines of the soil resources of Bangladesh. They have concentrated their efforts on study of the genesis, classification and distribution of Bangladesh soils from agricultural and pedological points of view.

Geological evaluation Division, Petrobangla (1975) and Orient Geological Consultants (1975) worked out the structure and stratigraphy of Jaldi and Maiskhali anticlines, respectively. Rob and Hoque, (1999), Monsur and Kamal, (1994) and Monsur (1995) studied the geomorphological environments of Maiskhali island.

Chowdhury and Hoque (1997) Chowdhury et. al. (1997 , 1997b, 2003) investigated the distribution of planktonic foraminifera on the continental slopes of Bay of Bengal. Several workers worked on Indian coast for the exploration of economic mineral deposits (Mohan and Rajamanickam, 2000; Anandaraj and Seralathan, 2002) and environmental implications (Joseph and Thrivikramji, 2002). Bhattacharya and Banerjee (1979) worked on the Quaternary geology and geomorphology of the coastal areas of West Bengal, India. Several workers discussed the Quaternary sea level changes, shoreline displacement and coastal environments in a volume edited by Rajamanickam and Tooley (2001). Islam and Tooley,(1999) and Umitsu (1987) proposed Holocene sea level curves for the Bangladesh coast.

1.9 SCOPE OF THE PRESENT STUDY

The present study aims to work out the evolution of soils and landscape of Jaldi and Maiskhali structures of southeastern Bangladesh during the Pleistocene.

Topography or local relief controls much of the distribution of soils in a landscape. Soils formed on the hill-slopes record the history of slope stability / instability over thousands of years. Soils record gains to and losses from geomorphic surfaces and are thus especially appropriate in the examination of the evolution of diverse landforms (McFadden and Knuepfer, 1990).

The soil-geomorphological evolution of the area is yet to be worked out in detail. The varying degree of soil development and the ages of soils from different geomorphic units can help to elucidate the evolution of the landscape in the area since Late Pleistocene. Soil-geomorphological studies may also provide insights on the impacts of neotectonics, palaeoclimatic and sea level changes on soils and landscape of the area since Late Pleistocene period.

To achieve the aforementioned objectives the following studies have been undertaken:

i. Different soil – geomorphic units have been delineated using Landsat (TM) images, toposheets and available soil – resource maps.

ii. Field investigations were carried out for the ground-truth checking of the boundaries between the soil – geomorphic units along the three traverses. Seventeen typical pedons were studied by recording morphological characters of sub-horizons of each pedon and several other places were also checked to find out the continuity of the units. Both bulk (disturbed) and in-situ (undisturbed) soil samples were collected from the sub-horizons of pedons for laboratory analyses.

iii. The soil samples were analyzed in the laboratory for grain size distribution, clay mineralogy, EC-pH and micromorphology.

iv. In-situ samples (undisturbed – collected in pipes) were also collected from C/BC horizons of each pedon to ascertain the ages of the samples. Infrared stimulated luminescence (IRSL) technique was adopted to measure the depositional events of the samples.

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

1.10 PLAN OF THE THESIS

Chapter 1 outlines the objectives of the study, a review of the physiography, climate, structure and stratigraphy of the area and proxy records of sea level and climate.

Chapter 2 describes various methods used in pre-field and field investigations. General morphology of various soil-geomorphic units is presented in brief with a detailed account of field characteristics of the soils. Relationships of soils and geomorphology of the area and Luminescence morphostratigraphic sequence of the area are introduced in this chapter.

Chapter 3 deals with the methodology for physical and clay mineralogical analyses of the soil samples collected during the fieldwork. Textural and clay mineralogical variations within the soil profiles and between the different members of Morphostratigraphic sequence are the subject matters of the chapter.

Chapter 4 describes the procedure for preparation of large sized thin sections and detailed description of micromorphological aspects of pedogenic importance in relation to different members of Morphostratigraphic sequence.

Chapter 5 includes the protocol for Infrared stimulated luminescence dating of soils and the ages obtained from the soils of the different members of the Morphostratigraphic sequence.

Chapter 6 documents and integrates all field and laboratory findings, discusses the pedogenic processes and controls on the development of soils and landforms of the area. It also summarizes major conclusions of the investigation.

Chapter 2

SOIL-GEOMORPHIC UNITS AND FIELD MORPHOLOGY OF SOILS

2.1 INTRODUCTION

Soil-geomorphic units are geomorphic units overlain by soils marked with fairly uniform characters or with characters that vary within a small range. To understand the geomorphic evolution of the area, a soil-geomorphic map has been constructed using digital Landsat (TM) data, toposheets and available soil-resource map (Brammer, 1971). Fieldwork was carried out to confirm the delineation of soil-geomorphic units and the continuity of soil characteristics and to collect representative soil samples for laboratory analyses.

2.2 IDENTIFICATION OF SOIL-GEOMORPHIC UNITS

Different geomorphic units have been identified based on visual interpretation of various Landsat image elements such as colour / tone, texture, moisture and drainage pattern along with different band combinations of digital Landsat (TM) data (False colour composite image shown in Fig. 2.1). These were then correlated with topographic sheets and available soil-resource map to produce a soil-geomorphic map (Fig. 2.2). ERDAS imagine and Arc View softwares were used in all these operations. The digital Landsat (TM) data, toposheets and soil-resource map were collected from Space Research and Remote Sensing Organization (SPARRSO), Dhaka; the Deptt. Of Geological Sciences, Jahangirnagar University, Savar, Dhaka and Soil Resources Development Institute (SRDI), Dhaka, Bangladesh, respectively.

The major Landsat image characteristics of the study area are as follows: (i) Smooth dark blue to light blue colour in the FCC image represents active channels and the Bay, (ii) Dry and barren cultivated land (particularly the Piedmont Plain) with exposed soils / sediments show greenish yellow colour, (iii) The intensity of blue colour on the land surfaces in FCC image depends on the moisture content of the soils / sediment, (iv) Red colour in the FCC image represents vegetation, (v) Rough texture and bright red colour in the FCC image indicate hillocks in the study area, which are readily noticeable as large patches. Important characteristics of different units as interpreted from the images, toposheets and field checks are given in Table 2.1.

Table 2.1: Remotely sensed characteristics and physiography of the different soil-geomorphic units.

Soil-geomorphic Units	Physiography	Characteristics in Landsat (TM) 432 (RGB) FCC
Mainland Higher Hillocks (MHH)	High relief, dendritic drainage, well drained, streams and streamlets are incised.	Rough texture, bright red colour due to dense vegetation cover, incised drainage is in yellowish gray tone.
Mainland Lower Hillocks (MLH)	Moderate relief, dendritic drainage, well drained, stream courses are wide relative to Mainland Higher hillocks unit and incised in nature.	Rough texture, relatively smooth with respect to Mainland Higher hillocks. Red to pink colour, at places dark red due to soil moisture, incised drainage having yellowish tone.
Island Hillocks (IH)	Same as MHH.	Same as MHH.
Piedmont Plains (PP)	Moderate to low relief, braided channels, channels are incised at the proximal part, imperfectly drained.	Red to brown mottles in greenish yellow base. Red colours due to vegetation. Red to brown mottles appear to be the pattern of palaeochannel / levees.
Old Tidal Flats (OTF)	Low relief, imperfectly drained, meandering channels.	Sparse dark brown mottles over smooth yellowish base, some bluish gray patches due to water logged (for salt cultivation in the main land); Smooth bluish gray tone mark the unit in the island with striated appearance (due to cultivation).
Active Tidal Flats (ATF)	Low relief, poorly drained, meandering channels.	Smooth bluish gray areas due to high soil moisture; some smooth red patches indicate mangroves; beaches marked by smooth elongated white patches.
River Floodplains (RFP)	Low relief. Poorly drained and meandering channels.	Smooth bluish at the active channels, smooth bright red to pinkish due to aquatic vegetation with smooth yellowish sandy areas on the levees, some dark red / brown mottles mark vegetation on the levees.

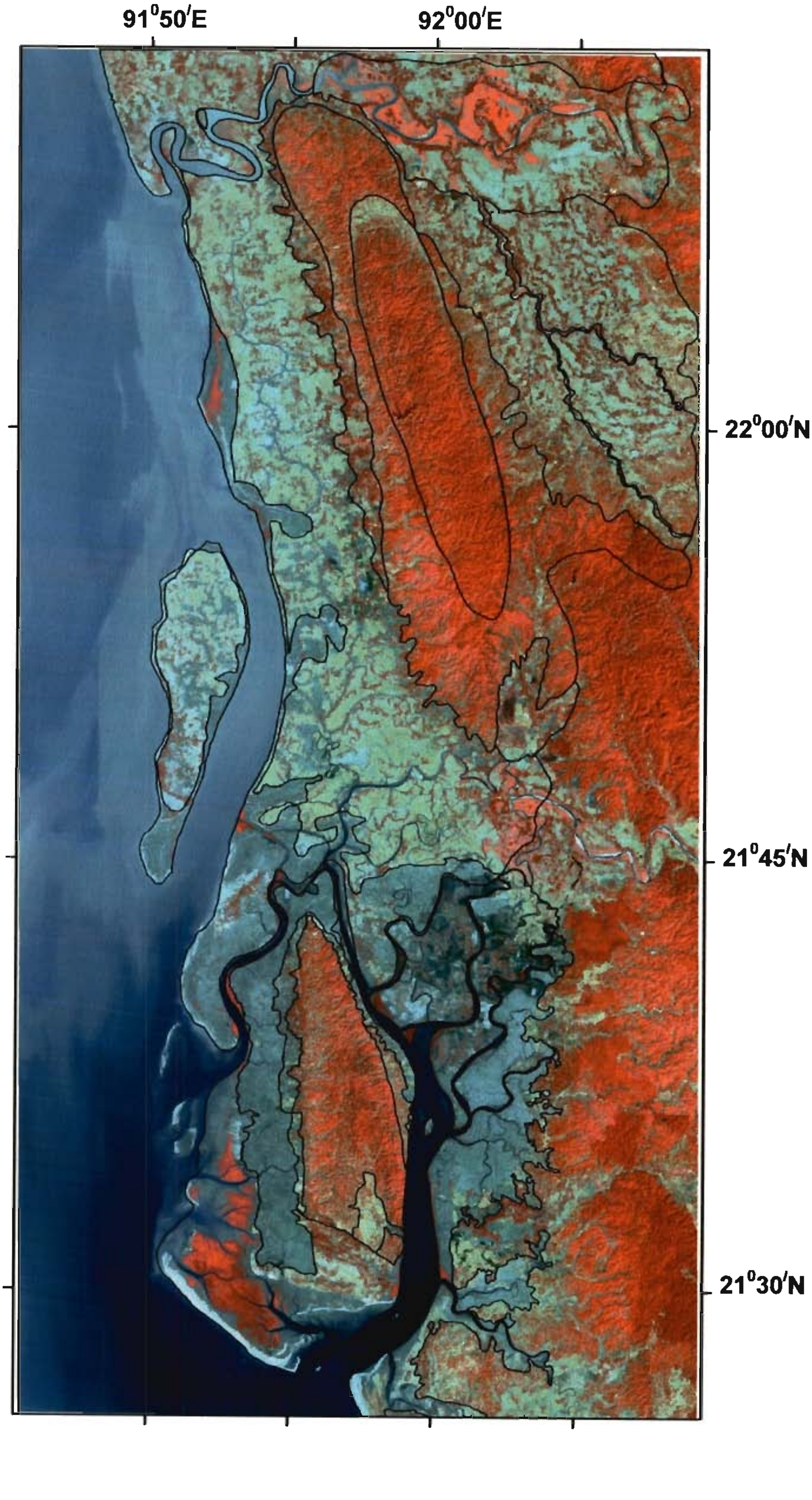


Fig. 2.1 False colour composite image of the study area.

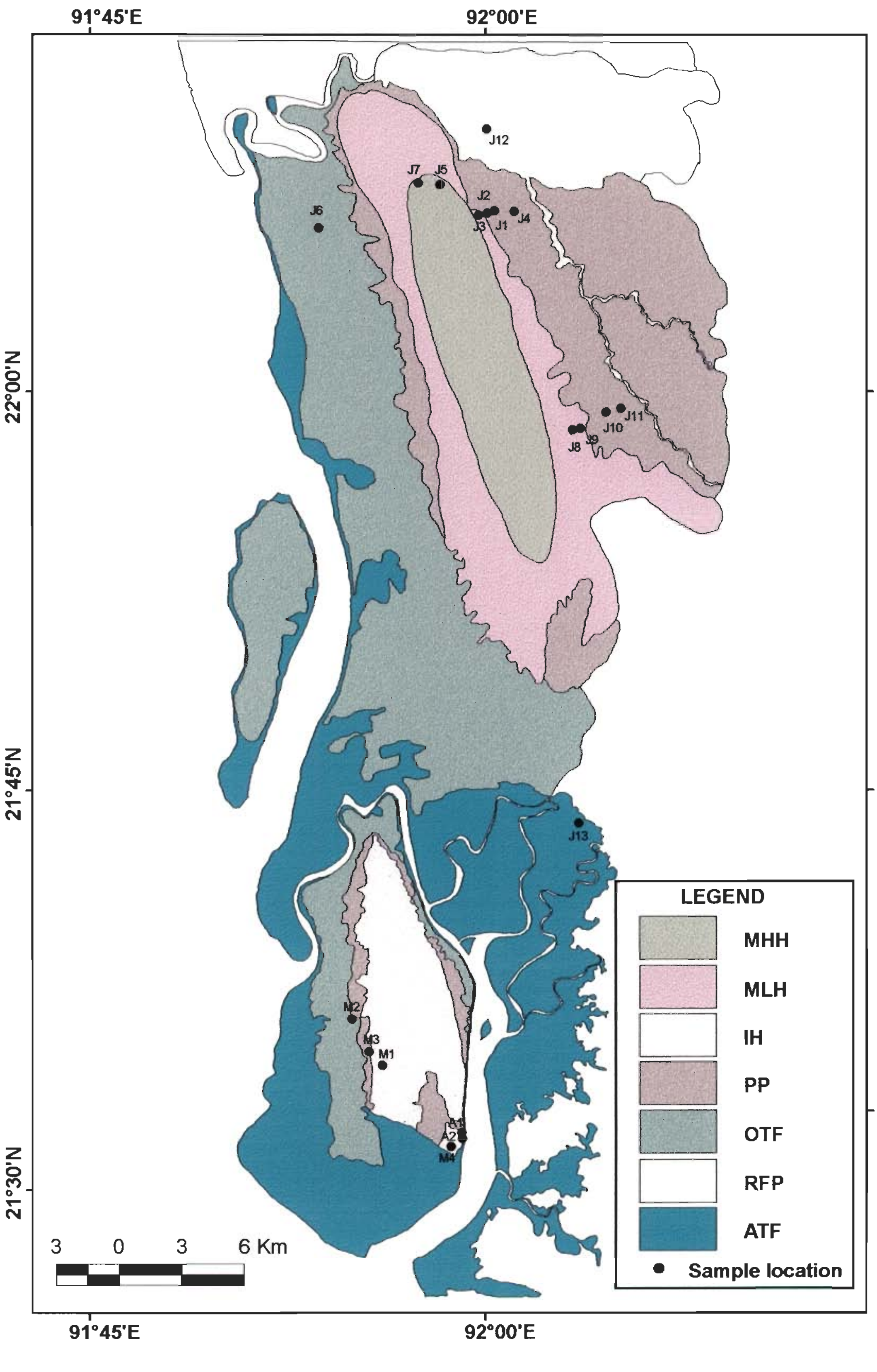


Fig. 2.2 Soil-geomorphic map of the study area and sample locations.

2.3 FIELD INVESTIGATIONS

Field investigations were carried out for checking the ground-truth of soil-geomorphic unit boundaries and to determine the characteristics of the soil-geomorphic units. Sampling sites were selected with the help of soil-geomorphic map and toposheets of the area. Seventeen excavations of approximately 1m X 1.5 m size and extending up to parent material or up to a minimum of 1.0 m depth were made along the three traverses. Several other places were also checked through auguring to find out the continuity of the units as well as to select sites of typical soil profiles for detailed study.

Each pedon was subdivided into different horizons and sub-horizons based on various soil properties such as colour, texture, structure, consistency, pores and roots, mottling, concretions and pH. These properties along with the depth/ thickness of each sub-horizon were noted and described in the field. Soil pH was also measured in the laboratory along with EC (Appendix I). Field measured pH is written in the brackets in description of pedons given later in the chapter. The horizons and sub-horizons were designated as Ap, A1, B1, B2, C, etc. according to USDA nomenclature (Soil Survey staff, 1992).

Samples were collected from each sub-horizon of each pedon for laboratory analyses. Bulk (disturbed) samples were collected for grain size and clay mineralogical analyses. In-situ (undisturbed) samples were collected in boxes and in pipes. In-situ box samples were used for micromorphological study and the in-situ pipe samples were used for dating purposes. Each sample was given a number, such as, J1/1, J2/2, M3/4, etc., where J or M indicates Jaldi or Maiskhali (location), the preceding (first) digit marks the pedon number and the latter digit denotes the horizon number. A1 and A2 samples have been collected for dating only.

2.4 MORPHOLOGY OF THE SOIL-GEOMORPHIC UNITS AND FIELD CHARACTERISTICS OF SOILS

The study area has been divided into eight soil-geomorphic units.

Soil-geomorphic Units	Abbreviated as
i. Mainland Higher Hillocks	MHH
ii. Mainland Lower Hillocks	MLH
iii. Island Hillocks	IH
iv. Piedmont Plains (Proximal and Distal)	PP (PPP and DPP)
v. Old Tidal Flats	OTF
vi. River Floodplains	RFP
vii. Active Tidal Flats	ATF

Mainland Higher Hillocks and Mainland Lower Hillocks (Fig. 2.3a) compose the Jaldi anticline proper, which is surrounded by Piedmont Plains. On the eastern flank, the Piedmont Plain is broad and divided into proximal and distal parts. The tidal flats lie on the western flank of the structure.

The Maiskhali island (underlain by Maiskhali anticline; Fig. 2.3b) suddenly rises up to an average elevation of 65 m can be divided into two halves: the eastern half comprises the Maiskhali anticline and the western half includes the piedmont plains, tidal flats and beaches. The eastern margin of the Maiskhali anticline is sheltered from wave action and is marked by straight, sharp cliffs, which might be the result of fault(s). Khan and Arefin (1999) considered the anticline to be fault-bound on all sides.

The box shaped nature of the Jaldi and Maiskhali anticlines, the relatively flat top surfaces of the hillocks as well as the small variations in the elevations of the peaks of the Hillocks helped to identify three terrace surfaces (Fig. 2.4). The terraces are the top surfaces of the Mainland Higher and Mainland Lower Hillocks in the Jaldi anticline and the top of the Island Hillocks in the Maiskhali island. These terraces mark the strath terraces in the region. The surfaces of narrow Piedmont Plains is 2-3 m higher than the Old Tidal flats in the Maiskhali island. Near the top of the Piedmont Plains of the Maiskhali Island, Hillocks are marked by V-notches, which indicate sea

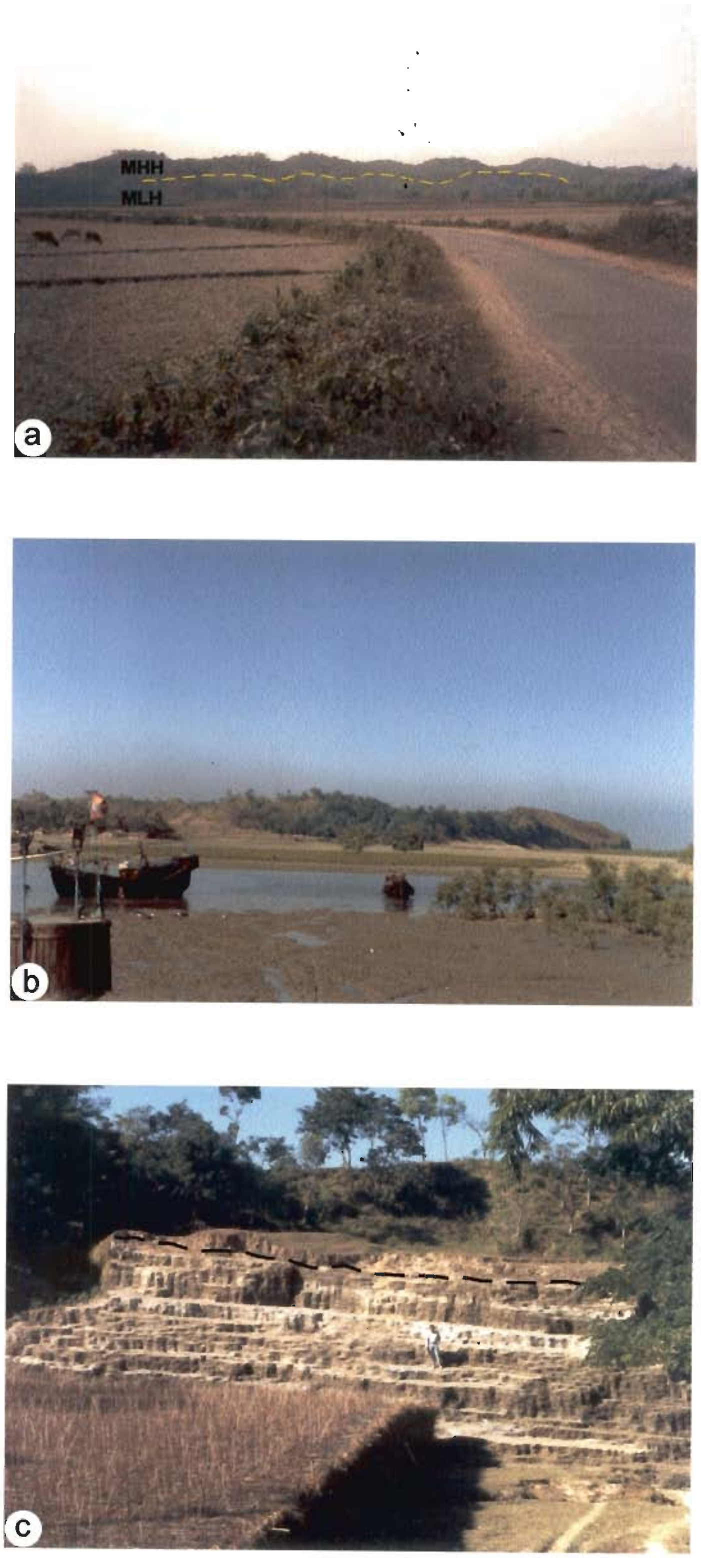
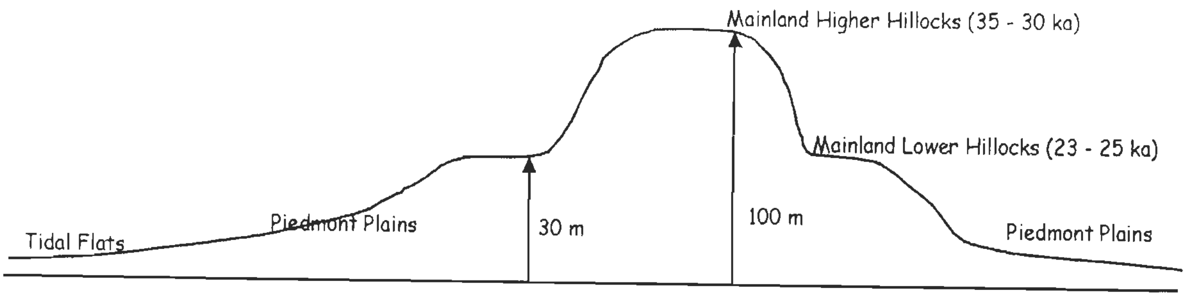
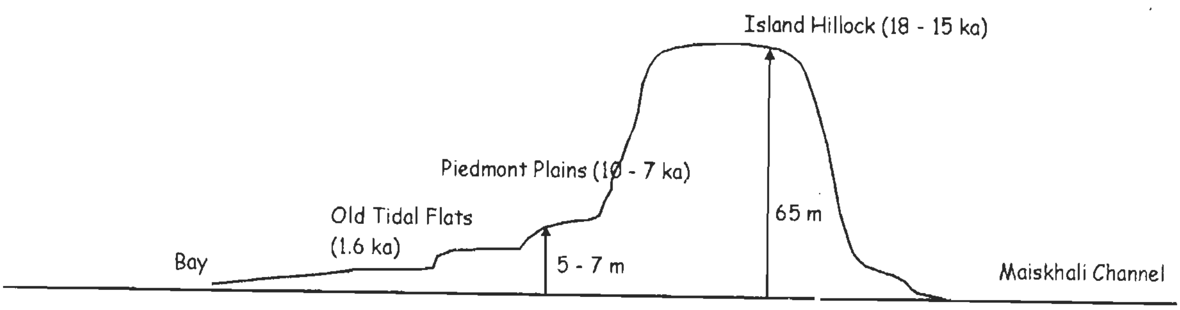


Fig. 2.3 Plan view of (a) Mainland Higher (MHH) and Lower Hillocks (MLH) at Jaldi Structure (b) Island Hillocks at Maiskhali island (c) Soils developed on flat lying Quaternary sediments unconformably overlying Bokabil Formation at Maiskhali island.

erosion during a recent high stand of sea level. Thus the top of the Piedmont Plains of the Maiskhali island is a marine terrace. The Old Tidal flat surface with a relief of about 2-3 m above the amsl also indicates a marine terrace.



Jaldi Structure



Maiskhali Island

Fig. 2.4 Schematic diagram showing five terraces recognized in the area.

Soils developed on the different geomorphic units as well as on these terrace deposits have been investigated. Three traverses were undertaken: two across the Jaldi structure and one across the Maiskhali island. A brief account of the field characteristics of the soils is given in Table 2.2 and the variation in morphological characters of the various horizons of typical pedons from different soil-geomorphic units is presented in Fig. 2.8.

2.4.1 Mainland Higher Hillocks

The Mainland Higher hillocks form the core of the Jaldi structure marked with relatively higher hills and form fairly continuous N-S running ridges. Soils are developed in a few meters thick, flat-lying and unconsolidated Quaternary sediments overlying unconformably rocks of the Tipam Sandstone Formation. Hillocks are strongly dissected, rugged with steep to very steep slope and an elevation ranging from 65 m to 110 m. The average elevation is about 100 m. Soils of the unit are Dystric Eutrochrepts – Typic Dystrochrepts. Sandy, sandy loam to sandy clay loam soils of brown – yellowish brown colour with a solum thickness of 70 – 100 cm and strong to weak, coarse to medium subangular blocky structure are developed in the B-horizons in the unit. The pH ranging from 4.0 – 5.3 (strongly acidic) marks these soils. Brammer (1996) has also found similar results and considered this due to the high rainfall and lack of ground water influence. Description of typical pedons (Fig. 2.5a,b) from the unit is given below.

Pedon No. J5

Classification	: Dystric Eutrochrepts.
Location	: Rupnagar, Satkania.
Date of examination	: 05.02.2001.
Parent material	: Quaternary sandy sediments.
Erosion	: Strong.
Slope	: Steep.
Drainage	: Well drained.
Moisture condition	: Dry.
Physiography	: Low hill / summit of dome shaped steep hillock.
Land use	: Thickets.

Typifying pedon

A1	0 – 10 cm	Yellowish brown (10YR 5/4) moist and dry; sandy loam; moderate coarse and medium subangular blocky; slightly sticky, non plastic, slightly hard dry; many very fine, fine and medium pores; many very fine, fine and few medium roots; pH – 4.7 (5.0); clear smooth boundary.

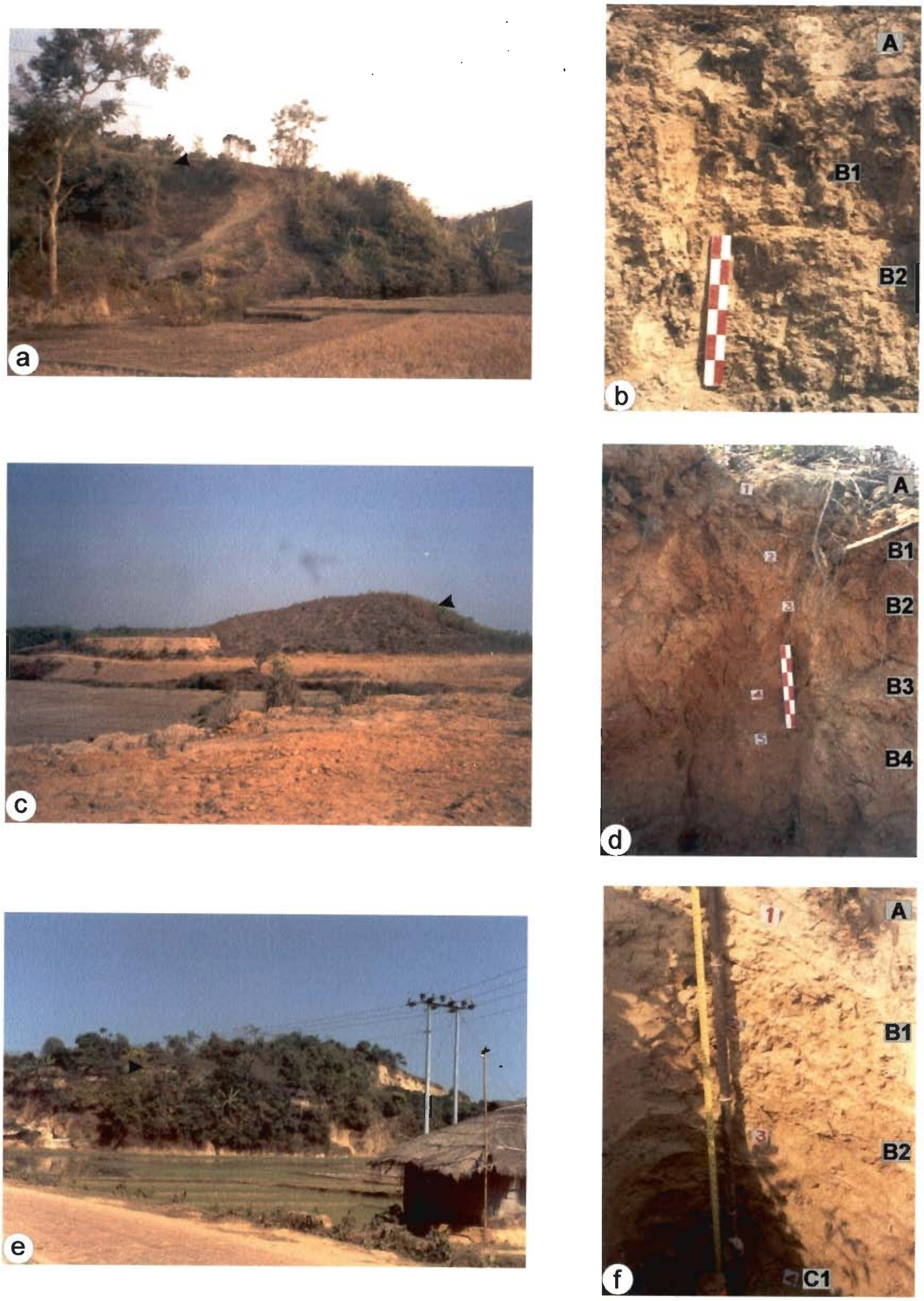


Fig. 2.5 Photographs showing (a) Field view and (b) A typical pedon (J7) from the Mainland Higher Hillocks unit; (c) Field view and (d) A typical pedon (J9) from the Mainland Lower Hillocks unit; (e) Field view and (f) A typical pedon (M1) from the Island Hillocks unit (arrows in the field view mark the pedon positions).

A2	10 – 20 cm	Brown (7.5YR 4/2) moist and dry; sandy loam; moderate coarse and medium subangular blocky; slightly sticky, non plastic, friable moist, slightly hard dry; many very fine and fine pores; many very fine and few medium roots; pH – 4.9; clear smooth boundary.
B1	20 – 40 cm	Brown (7.5YR 4/4) moist and dry; sandy loam; moderate coarse and medium subangular blocky; slightly sticky, non plastic, friable moist; broken thin dark brown cutans along vertical and horizontal ped faces and pores; many very fine and fine tubular pores; common very fine, fine and few medium roots; pH – 5.0; clear smooth boundary.
B2	40 – 70 cm	Yellowish brown (10YR 5/8) moist and dry; sandy; weak coarse and medium subangular blocky; non sticky, non plastic, loose moist; broken thin brown cutans along ped faces; common very fine, fine and medium pores; few fine and medium roots; pH – 5.2; clear smooth boundary.
C	70 – 100+ cm	Yellowish brown (10YR 5/8) moist and dry; sandy; non sticky, non plastic, loose moist; common pieces of semi consolidated sandstone; few very fine and medium roots; pH – 5.3 (5.5).

Pedon No. J7

Classification	: Typic Dystrochrepts.
Location	: Between Rupnagar & Bahigram, Satkania.
Date of examination	: 05.02.2001.
Parent material	: Quaternary sandy clay deposits.
Erosion	: Strong.
Slope	: Steep.
Drainage	: Well drained.
Moisture condition	: Dry.
Physiography	: Upper slope of very steep low hill.
Land use	: Thickets, scrubs and shrubs.

Typifying pedon

A	0 – 20 cm	Brown (10YR 5/3) moist and dry; sandy clay loam; massive; slightly sticky, slightly plastic, friable moist, slightly hard dry; many very fine and fine and few tubular pores; many fine and medium roots; pH – 4.0 (5.0); abrupt smooth boundary.
B1	20 – 65 cm	Yellowish brown (10YR 5/6) moist and dry; sandy clay loam; strong coarse and medium subangular blocky; sticky, plastic, firm moist, hard dry; broken thin yellowish brown cutans along vertical and horizontal ped faces; many very fine and fine tubular pores; common very fine and fine and few coarse roots; pH – 4.1; clear smooth boundary.
B2	65 – 100 cm	Yellowish brown (10YR 5/6); sandy clay loam; strong coarse and medium subangular blocky; sticky, plastic, firm moist; broken thin yellowish brown cutans along vertical and horizontal ped faces; many very fine and fine tubular pores; few very fine and fine and medium roots; pH – 4.2 (6.0); gradual smooth boundary.
B3	100+ cm	Yellowish brown (10YR 5/6) moist and dry; sandy clay loam; sticky, plastic, firm moist; few very fine and coarse roots; pH – 4.2 (6.0).

2.4.2 Mainland Lower Hillocks

The unit represents low, isolated, elongated and dome shaped hillocks on the flanks of the Jaldi anticline with an elevation of 30 – 40 m. Soils are developed in the unconsolidated Quaternary sediments that unconformably overlie the partially consolidated Dupi Tila Sandstone Formation. The hillocks are entrenched with transverse dendritic drainage. Soils are mostly Typic Hapludults – Typic Dystrochrepts. Yellowish brown, strong brown – yellowish red coloured soils developed in the unit with a solum thickness of 85 – >140 cm and strong to moderate, medium to fine subangular blocky structure. Soils of the Mainland Lower hillocks have the best development in terms of the solum thickness, thickness of B-horizons and degree of pedality among the Hillock soils. Few small hard Fe-Mn oxide concretions are observed in the lower horizons of the typical pedons from the unit indicates weak hydromorphism is going on in the unit. The pH ranges from 3.7 to 5.1 (strongly acidic). Typical pedons (Fig. 2.5c,d) from the unit are described below.

Pedon No. J3

Classification	: Typic Hapludults.
Location	: Dakhin Kanchana, Satkania.
Date of examination	: 03.02.2001.
Parent material	: Quaternary clayey deposits.
Erosion	: Moderate.
Slope	: Moderately steep phase.
Drainage	: well drained.
Moisture condition	: Dry.
Physiography	: Foot slope of the low hill.
Land use	: Thickets and grasses.

Typifying pedon

A	0 – 10 cm	Strong brown (7.5YR 5/8) moist and dry; loam; massive; slightly sticky, plastic, friable moist, slightly hard dry; many very fine and fine roots; pH – 3.8 (4.5); abrupt smooth boundary.
B1	10 – 20 cm	Yellowish red (5YR 5/8) moist and dry; sandy loam; moderate medium subangular blocky structure; sticky, plastic, firm moist; broken thin yellowish red cutans along vertical and horizontal ped faces; many very fine and fine tubular pores; common very fine and fine roots; pH – 3.7; clear smooth boundary.
B2	20 – 60 cm	Yellowish red (5YR 5/8) moist and dry; loam; moderate medium subangular blocky; sticky, plastic, firm moist; broken thin yellowish red cutans along ped faces; many very fine and fine tubular pores; common very fine and fine roots; pH – 3.75 (5.0); clear smooth boundary.

B3	60 – 100 cm	Yellowish red (5YR 5/8) moist and dry; clay loam; moderate medium subangular blocky; sticky, plastic, firm moist; broken thin yellowish red cutans along vertical and horizontal ped faces; many very fine and fine tubular pores; few very fine and fine roots; few small hard iron-manganese concretions; pH – 4.0; abrupt smooth boundary.
C1	100 – 140+ cm	Yellowish red (5YR 4/6) moist and dry; clay loam; moderate medium to fine subangular blocky structure; sticky, plastic, firm moist; many very fine and fine tubular pores; few very fine and fine roots; few small hard spherical iron-manganese concretions; pH – 4.8 (6.0).

Pedon No. J8

Classification	: Typic Dystrochrepts.
Location	: Chunati, Lohagora.
Date of examination	: 17.02.2001.
Parent material	: Quaternary silty clay sediments.
Erosion	: Moderate.
Slope	: Steep phase.
Drainage	: Well drained.
Moisture condition	: Dry.
Physiography	: Middle slope of steep low hill.
Land use	: Thickets, scrubs and shrubs.

Typifying pedon

A	0 – 15 cm	Brown (10YR 4/3) moist and brown (10YR 5/3) dry; loam; massive; slightly sticky, non plastic, friable moist, slightly hard dry; many very fine, fine and few medium pores; many fine and medium and few coarse roots; pH – 5.0; abrupt smooth boundary.
Bt_1	15 – 46 cm	Yellowish brown (10YR 5/6) moist and dry; silty clay loam; strong medium subangular blocky; slightly sticky, slightly plastic, friable moist, slightly hard dry; patchy thin yellowish brown cutans along vertical and horizontal ped faces; many very fine

and fine tubular pores; many fine and medium and few coarse roots; pH – 4.4 (5.0); abrupt smooth boundary.

Bt_2	46 – 60 cm	Yellowish brown (10YR 5/6) moist and dry; silty clay; strong medium subangular blocky structure; sticky, plastic, firm moist, hard dry; broken thin yellowish brown cutans along vertical and horizontal ped faces; many very fine and fine tubular pores; common very fine and fine and few coarse roots; pH – 4.5; clear smooth boundary.
Bt_3	60 – 85 cm	Yellowish brown (10YR 5/6) moist and dry; silty clay; moderate medium subangular blocky; sticky, plastic, firm moist; broken thin yellowish brown cutans along ped faces; many very fine and fine tubular pores; few very fine to coarse roots; pH – 4.6 (5.0); gradual smooth boundary.
Bt_4	85 – 120+ cm	Yellowish brown (10YR 5/6) moist and dry; silty clay loam; sticky, plastic, firm moist; few fine and coarse roots; pH – 5.1.

Pedon No. J9

Classification	: Typic Hapludults.
Location	: Chunati, Lohagora.
Date of examination	: 17.02.2001.
Parent material	: Quaternary sandy clay deposits.
Erosion	: Moderate.
Slope	: Steep phase.
Drainage	: Well drained.
Moisture condition	: Dry.
Physiography	: Summit and upper slope of steep low hill.
Land use	: Thickets, scrubs and forest plantation.

Typifying pedon

A	0 – 20 cm	Brown (7.5YR 4/4) moist and dry; sandy loam; weak medium and fine subangular blocky; non sticky, non plastic, very friable moist; many very fine and fine tubular pores; many very fine and fine

		and few medium roots; pH – 4.6; clear smooth boundary.
B1	20 – 40 cm	Yellowish red (5YR 4/6) moist and dry; clay loam; moderate medium and fine subangular blocky; sticky, slightly plastic, firm moist; broken thin yellowish red cutans along vertical and horizontal ped faces and pores; many very fine and fine tubular pores; common very fine, fine and few medium roots; pH – 4.5 (5.0); gradual smooth boundary.
B2	40 – 70 cm	Yellowish red (5YR 4/6) moist and dry; sandy clay loam; moderate medium and fine subangular blocky; slightly sticky, non plastic, friable moist; broken thin yellowish red cutans along vertical and horizontal ped faces and pores; many very fine and fine tubular pores; common very fine, fine and few medium roots; pH – 4.7; gradual smooth boundary.
B3	70 – 90 cm	Yellowish red (5YR 4/6) moist and dry; sandy clay loam; moderate medium and fine subangular blocky; slightly sticky, non plastic, friable moist; broken thin yellowish red cutans along vertical and horizontal ped faces and pores; many very fine and fine tubular pores; few fine and medium roots; pH – 4.7; gradual smooth boundary.
B4	90 – 140+ cm	Yellowish red (5YR 4/6) moist and dry; sandy loam; moderate medium and fine subangular blocky; slightly sticky, non plastic, friable moist; broken thin yellowish red cutans along ped faces; common very fine and fine tubular pores; few fine and medium roots; few angular quartz gravels; pH – 4.7 (5.0).

2.4.3 Island Hillocks

Almost the entire eastern half of the Maiskhali island composes the unit with a narrow band of Piedmont Plain on the western side. Soils are developed in the Quaternary sediments (Fig. 2.3c) that unconformably overly the Tertiary formations (Boka Bil Formation, Tipam Sandstone Formation and Dupi Tila Sandstone Formations). The Hillocks are marked by an elevation of 60 – 75 m with an average elevation of 65 m. Incised dendritic drainage characterizes the unit. Soils are mostly Typic Dystrochrepts. Sandy loam,

loam to sandy clay loam soils of strong brown to yellowish brown colour with a solum thickness of ~ 90 cm are developed. Moderate to strong and coarse to medium subangular blocky structure is developed in the B-horizons. Thus, soils of this unit show development comparable to that of Mainland Higher Hillocks. The pH ranging from 4.2 – 4.4 (strongly acidic) marks the soils of the unit. Description of the typical pedon (Fig, 2.5e,f) from the unit is given below.

Pedon No. M1

Classification	: Typic Dystrochrepts.
Location	: Pani chara, Maiskhali.
Date of examination	: 31.01.2001.
Parent material	: Quaternary sandy loam deposits.
Erosion	: Strong.
Slope	: Very steep to steep.
Drainage	: Well drained.
Moisture condition	: Dry.
Physiography	: Summit and upper slope of very steep high hill.
Land use	: Thickets, scrubs and shrubs.

Typifying pedon

A	0 – 20 cm	Strong brown (7.5YR 5/6) moist and dry; sandy loam; massive; slightly sticky moist, non plastic, friable dry; many very fine and fine and few medium tubular pores; many fine and medium and few coarse roots; pH – 4.2; abrupt smooth boundary.
B1	20 – 55 cm	Yellowish brown (10YR 5/6) moist and dry; sandy clay loam; moderate to strong coarse and medium subangular blocky; sticky, plastic, firm moist, hard dry; broken thin yellowish brown cutans along vertical and horizontal ped faces; many very fine and fine tubular pores; common very fine and fine and few coarse roots; pH – 4.3; clear smooth boundary.

B2	55 – 90 cm	Yellowish brown (10YR 5/6) moist and dry; loam; moderate to strong coarse and medium subangular blocky; sticky, plastic, firm moist; broken thin yellowish brown cutans along vertical and horizontal ped faces; many very fine and fine tubular pores; few fine and coarse roots; pH – 4.4; gradual smooth boundary.
B3	90 – 140+ cm	Dark yellowish brown (10YR 4/6) moist and dry; sandy loam; slightly sticky, slightly plastic, firm moist; few fine pores; few very fine and coarse roots; pH – 4.4.

2.4.4 Piedmont Plains

The Piedmont Plains form a narrow strip of colluvial deposits surrounding the Mainland Lower Hillocks on the western flanks of the Jaldi anticline and on the Maiskhali anticline. The Piedmont plains are broad and wide in the eastern flank of the Jaldi anticline. This broad Piedmont Plain is the surface morphology of Lohagora syncline, which is bounded by the Jaldi, Bandarban and Matamuhuri anticlines on the west, east and south, respectively. Minor transverse streams of consequent, ephemeral type drain the Piedmont Plains and at the foot of the fans, join with an axial stream of semi-perennial type. Minor streams are little entrenched at the Proximal Piedmont Plains, which give a higher development of soils in the proximal region than in the distal region. The Proximal Plains may be flooded due to exceptional floods, while the Distal Plain may be flooded for considerable periods during monsoon period. Thus, two soil-geomorphic units Proximal Piedmont Plains and Distal Piedmont Plains are identified within this geomorphic unit. Also, sediments in the proximal and distal region are colluvial and fluvial origin, respectively. However, these two units require further detailed mapping to present them separately in the soil-geomorphic map.

Soils of the unit are Typic Haplaquepts. Olive gray to dark yellowish brown soils with a better development in terms of solum and B-horizon thickness mark the Proximal Piedmont Plains and a relatively stronger ped development in the B-horizon is observed in the Distal Piedmont Plains.

Common fine to medium Fe–Mn oxide concretions and mottles are present in the soils of the Piedmont Plains. The Piedmont Plain soils show a wide variation in pH values, which ranges from 4.2 to 7.1. The Piedmont soils in the upper horizons are extremely acidic and in the lower horizons the soil acidity reduces towards neutral. The acidic condition might be the result of periodic flooding and oxidation-reduction causes displacement of cations either laterally or leached downward through the profile and rapidly acidified the upper horizons by ferrolysis reactions (Brinkman, 1970). Description of typical pedons (Figs. 2.6, 2.7a,b) from these units is given below.

2.4.4.1 Proximal Piedmont Plains

Pedon No. J1

Classification	: Typic Haplaquepts.
Location	: Dakhin Kanchana, Satkania.
Date of examination	: 03.02.2001.
Parent material	: Sandy deposits.
Erosion	: Nil.
Slope	: Gentle.
Drainage	: Imperfectly drained.
Moisture condition	: Dry at the upper part and wet at C-horizon.
Depth of ground water	: 50 m.
Physiography	: Piedmont (nearly level piedmont plain).
Flooding	: Occasionally flooded for a few days after heavy rainfall during the monsoon.
Land use	: Cultivation.

Typifying pedon

Ap1	0 – 12 cm	Gray (5Y 5/1) moist and dry; sandy loam; massive; slightly sticky, slightly plastic, firm moist, slightly hard dry; many very fine and fine roots; pH – 4.2 (5.0); clear smooth boundary.
B1	12 – 24 cm	Olive Gray (5Y 5/2) moist and dry; sandy loam; massive; slightly sticky, slightly plastic, firm moist,

		hard dry; many very fine pores; many very fine and fine roots; pH – 5.2; clear smooth boundary.
B2	24 – 42 cm	Olive Gray (5Y 5/2) moist and dry; common fine and medium distinct yellowish brown mottles; sandy loam; moderate coarse and medium subangular blocky; slightly sticky. slightly plastic, firm moist; broken thin gray cutans; many very fine and fine tubular pores; fine roots common; pH – 6.3; clear smooth boundary.
Bw1	42 – 70 cm	Dark yellowish brown (10YR 4/4) moist and dry; common fine and medium distinct dark brown mottles; sandy loam; moderate coarse and medium subangular blocky; slightly sticky, slightly plastic; broken thick gray cutans along vertical and horizontal ped faces; many very fine and fine pores; few very fine roots; pH – 6.2 (7.0); gradational wavy boundary.
Bw2	70 – 142 cm	Dark yellowish brown (10YR 4/4) moist and dry; common fine and medium distinct yellowish brown mottles; loam; moderate coarse and medium subangular blocky; slightly sticky, slightly plastic; broken moderately thick gray cutans along vertical ped surfaces; common very fine and fine pores; few very fine roots; pH – 6.6; abrupt wavy boundary.
Bg1	142 – 170 cm	Dark greenish gray (5BG 4/1) moist; loamy sand; massive; slightly sticky, slightly plastic, friable moist; common very fine and fine tubular pores; pH – 6.5 (8.0); gradational wavy boundary.
Bg2	170 – 200+ cm	Dark greenish gray (5BG 4/1) moist; loamy sand; massive; slightly sticky, slightly plastic, friable moist; common very fine and fine tubular pores; pH – 6.8.

Pedon No. J2

Classification	: Typic Haplaquepts.
Location	: Dakhin Kanchana, Satkania.
Date of examination	: 03.02.2001.
Parent material	: Sandy to silty sediments.
Erosion	: Nil.
Slope	: Gentle.

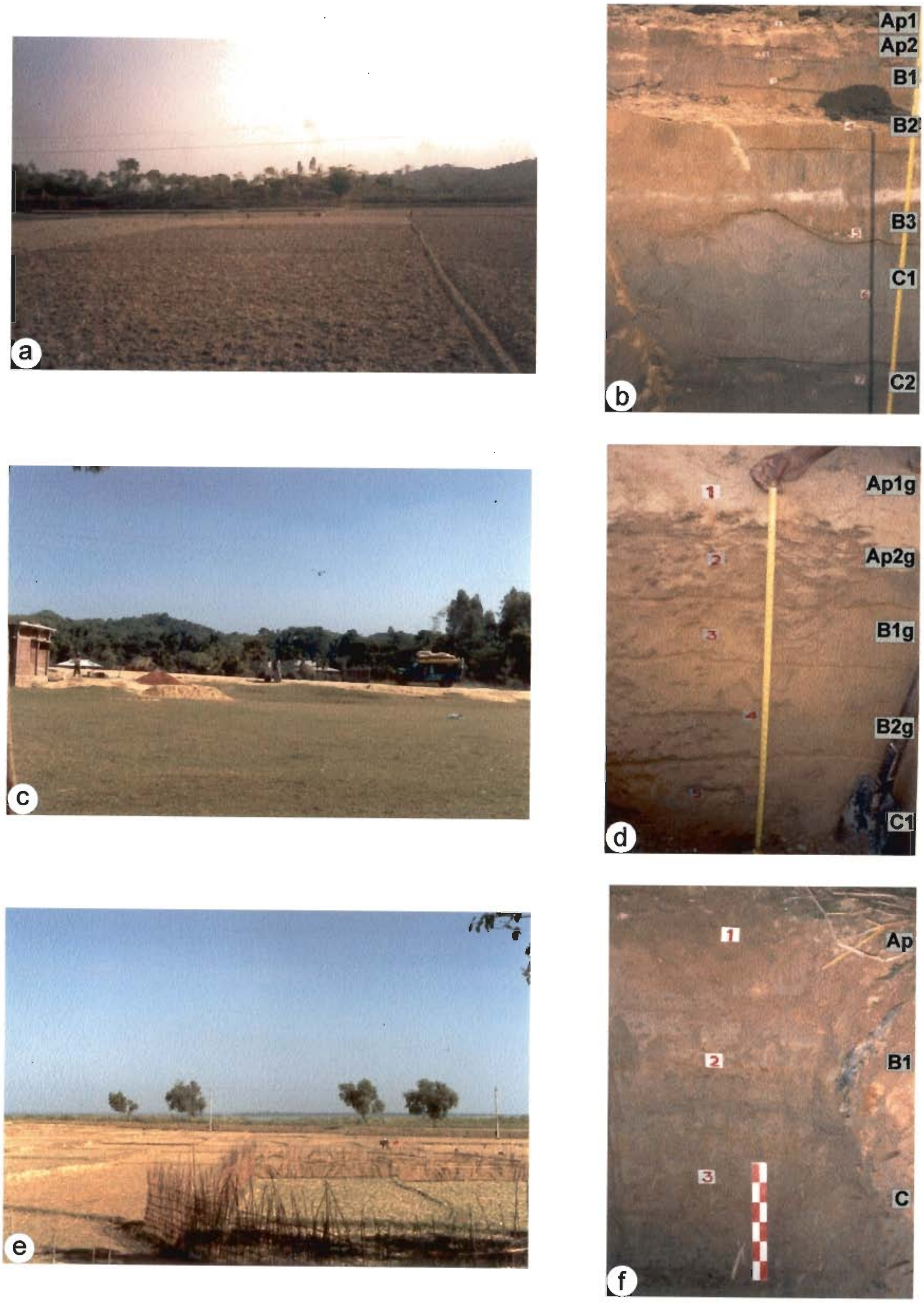


Fig. 2.6 Photographs showing (a) Field view and (b) A typical pedon (J1) from the Proximal Piedmont Plains at Jaldi Structure; (c) Field view and (d) A typical pedon (M3) from the Piedmont Plains at Maiskhali island; (e) Field view and (f) A typical pedon (J4) from the Distal Piedmont Plain at Jaldi structure.

Drainage	: Imperfectly drained.
Moisture condition	: Dry.
Depth of ground water	: 50 m.
Physiography	: Piedmont (nearly level piedmont plain).
Flooding	: Intermittently flooded by rainwater for few days in the monsoon season.
Land use	: Cultivation.

Typifying pedon

Ap	0 – 20 cm	Gray (5Y 5/1) moist and dry; loam; massive; slightly sticky, slightly plastic, firm moist, slightly hard dry; many very fine and fine and few medium pores; many very fine and fine roots; pH – 5.2 (4.5); abrupt smooth boundary.
B1	20 – 30 cm	Gray (5Y 5/1) moist and dry; sandy clay loam; moderate medium to coarse subangular blocky structure; sticky, plastic, very firm moist; patchy thin gray cutans along vertical and horizontal ped faces and pores; common very fine and fine tubular pores; common very fine roots; pH – 5.8 (6.5); clear smooth boundary.
B2	30 – 50 cm	Gray (5Y 5/1) moist and dry; loam; moderate medium to coarse subangular blocky structure; sticky, plastic, very firm moist; patchy thin gray cutans along vertical ped faces and pores; few very fine roots; few small iron-manganese concretions; pH – 7.1; clear smooth boundary.
B3	50 – 80 cm	Gray (5Y 5/1) moist and dry; loam; moderate medium to coarse subangular blocky structure; sticky, plastic, firm moist; continuous thin gray cutans along ped faces; many very fine and fine tubular pores; few very fine roots; common small iron-manganese concretions; pH – 7.0 (8.0); clear smooth boundary.
B4	80 – 100 cm	Gray (5Y 5/1) moist and dry; silty loam; moderate medium to coarse subangular blocky structure; sticky, plastic, firm moist; patchy thin gray cutans along ped faces; many very fine and fine tubular

		pores; common small iron-manganese concretions; pH – 6.9; clear smooth boundary.
B5	100 – 140+ cm	Gray (5Y 5/1) moist and dry; loam; massive; slightly sticky, slightly plastic, friable moist; common very fine and fine tubular pores; few small iron-manganese concretions; pH – 6.5 (8.0).

Pedon No. M3

Classification	: Typic Haplaquepts.
Location	: Kalalliakhata, Maiskhali.
Date of examination	: 31.01.2001.
Parent material	: Sandy sediments.
Erosion	: Nil.
Slope	: Gentle.
Drainage	: Imperfectly drained.
Moisture condition	: Moist at the lower portion of the profile.
Depth of ground water	: 30 m.
Physiography	: Piedmont.
Flooding	: Occasionally flooded for a few days in the rainy season.
Land use	: Cultivation.

Typifying pedon

Ap	0 – 10 cm	Olive gray (5Y 5/2) moist and light olive gray (5Y 6/2) dry; sandy loam; massive; non sticky, non plastic, friable moist; many very fine tubular pores; many very fine and fine roots; pH – 5.5 (5.0); clear smooth boundary.
Bwg1	10 – 30 cm	Gray (5Y 5/1) moist and dry; sandy loam; massive; non sticky, non plastic, friable moist; common very fine tubular pores; common fine roots; pH – 5.2; abrupt smooth boundary.
Bwg2	30 – 55 cm	Olive gray (5Y 5/2) moist; sandy loam; very weak coarse subangular blocky; non sticky, non plastic, friable moist; patchy thin gray cutans along ped faces; common very fine tubular pores; pH – 4.6; clear smooth boundary.

Bwg3 55 – 90 cm — Olive gray (5Y 5/2) moist; sandy loam; weak coarse subangular blocky; non sticky, non plastic, friable moist; patchy thin gray cutans along ped faces; common very fine tubular pores; pH – 4.7; clear smooth boundary.

Bw 90 – 120+ cm — Dark yellowish brown (10YR 4/4) moist; sandy loam; non sticky, non plastic, loose moist; common very fine tubular pores; pH – 4.3 (6.0).

Pedon No. M4

Classification	: Typic Haplaquepts.
Location	: Adinath (Chhoto Maiskhali), Maiskhali.
Date of examination	: 01.02.2001.
Parent material	: Sandy sediments.
Erosion	: Nil.
Slope	: Gentle.
Drainage	: Imperfectly drained.
Moisture condition	: Moist at the lower portion of the profile.
Depth of ground water	: 30 m.
Physiography	: Piedmont (terrace valley).
Flooding	: Occasionally flooded by rain water and wave surges in the rainy season.
Land use	: Cultivation.

Typifying pedon

Ap 0 – 10 cm — Gray (5Y 6/1) moist and dry; silt loam; massive; slightly sticky, slightly plastic, firm moist, slightly hard dry; many very fine and fine roots; pH – 5.9 (7.5); abrupt smooth boundary.

Bg1 10 – 30 cm — Gray (5Y 5/1) moist and dry; loam; massive; slightly sticky, slightly plastic, firm moist, hard dry; many very fine and fine tubular pores; many very fine and fine roots; pH – 6.1; clear smooth boundary.

B1	30 – 60 cm	Gray (5Y 5/1) moist; sandy loam; very weak medium subangular blocky; slightly sticky, slightly plastic, firm moist; broken thin gray cutans along vertical and horizontal ped faces; common medium distinct yellowish brown mottles; few small iron-manganese concretions; many very fine and fine tubular pores; common very fine and fine roots; pH – 6.6; clear smooth boundary.
B2	60 – 100+ cm	Dark yellowish brown (10YR 4/4) moist; sandy loam; weak medium subangular blocky; slightly sticky, slightly plastic, slightly friable moist; broken thin gray cutans along ped faces; few medium distinct yellowish brown mottles; common small soft iron-manganese concretions; many very fine and fine tubular pores; few very fine roots; pH – 6.7.

2.4.4.2 Distal Piedmont Plains

Pedon No. J4

Classification	: Typic Haplaquepts.
Location	: Dakhin Kanchana, Satkania.
Date of examination	: 03.02.2001.
Parent material	: Clayey sediments.
Erosion	: Nil.
Slope	: Nearly level.
Drainage	: Imperfectly drained.
Moisture condition	: Moist.
Depth of ground water	: 30 – 50 m.
Physiography	: Basin (at the middle; lowest part of Piedmont plain).
Flooding	: Rainwater retained during the monsoon season.
Land use	: Cultivation.

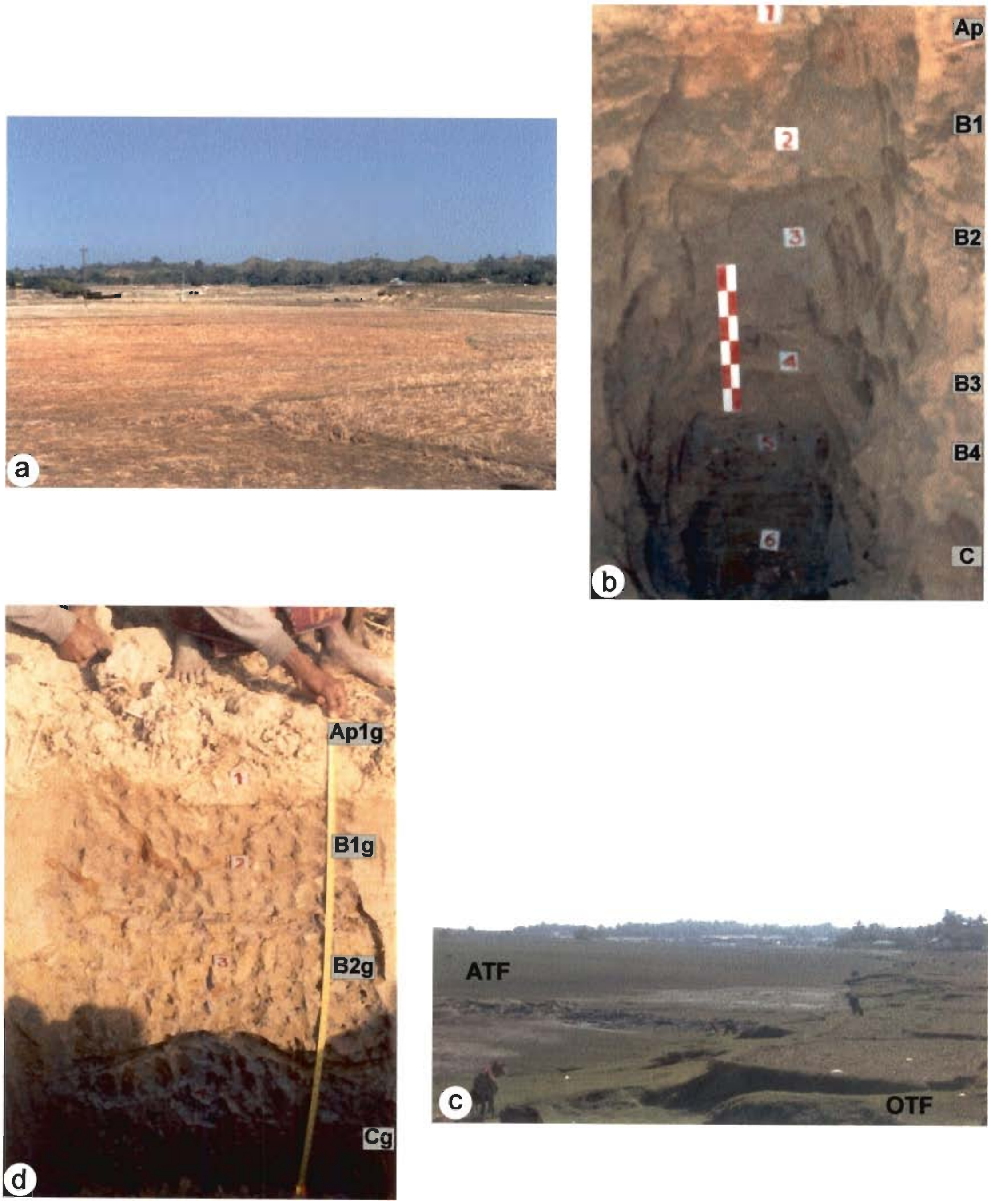


Fig. 2.7 Photographs showing (a) Field view and (b) A typical pedon (J10) from the Distal Piedmont Plains at Jaldi Structure; (c) Field view of Active (ATF) and Old (OTF) Tidal Flats at Maiskhali Island and (d) A typical pedon (M2) from Old Tidal Flats at Maiskhali Island.

Typifying pedon

Ap	0 – 20 cm	Gray (5Y 6/1) moist and dry; loam; massive; slightly sticky, slightly plastic, firm moist, hard dry; common very fine and fine tubular pores; many very fine roots; pH – 4.4 (5.0); abrupt smooth boundary.
B1	20 – 65 cm	Gray (5Y 5/1) moist; clay loam; strong coarse and medium subangular blocky structure; sticky, plastic, firm moist; continuous thick gray cutans along horizontal and vertical ped faces; common very fine tubular pores; few very fine roots; pH – 5.9 (7.0); clear smooth boundary.
B_2wg	65 – 100+ cm	Dark greenish gray (5BG 4/1) moist; clay; weak coarse and medium subangular blocky; sticky, plastic, firm moist; patchy thin gray cutans along ped faces; common very fine tubular pores; pH – 5.1 (7.0).

Pedon No. J10

Classification	: Typic Haplaquepts.
Location	: Adhunagar, Lohagara.
Date of examination	: 18.02.2001.
Parent material	: Sandy clay sediments.
Erosion	: Nil.
Slope	: Nearly level.
Drainage	: Imperfectly drained.
Moisture condition	: Moist.
Depth of ground water	: 30 – 50 m.
Physiography	: Middle part of gently sloping broad Piedmont plain.
Flooding	: Rain water retained for few days in the monsoon season.
Land use	: Cultivation.

Typifying pedon

Ap	0 – 15 cm	Gray (5Y 6/1) moist and dry; silt loam; massive; slightly sticky, slightly plastic, firm moist, hard dry; common very fine tubular pores; many very fine roots; pH – 4.5 (5.0); abrupt smooth boundary.
B1	15 – 40 cm	Gray (5Y 5/1) moist; silt loam; moderate coarse and medium subangular blocky; slightly sticky,

		slightly plastic, firm moist; patchy thin white silt cutans and gray cutans along ped faces; few very fine tubular pores; common very fine roots; pH – 4.8 (7.0); clear smooth boundary.
B2	40 – 75 cm	Gray (5Y 5/1) moist; silt loam; moderate coarse and medium subangular blocky; slightly sticky, slightly plastic, firm moist; continuous thick gray cutans along horizontal and vertical ped faces; patchy thin white silt cutans along vertical ped faces; few very fine tubular pores; common very fine roots; pH – 5.8; clear smooth boundary.
Bwg1	75 – 90 cm	Dark greenish gray (5BG 4/1) moist; clay loam; moderate coarse and medium subangular blocky; sticky, plastic, firm moist; broken thick gray cutans along vertical and horizontal ped faces; few small iron-manganese concretions; common very fine tubular pores; few fine roots; pH – 6.3 (7.0); clear smooth boundary.
B3	90 – 110 cm	Gray (5Y 5/1) moist; clay loam; weak to moderate medium subangular blocky; sticky, plastic, firm moist; broken thin gray cutans along ped faces; few small iron-manganese concretions; common very fine tubular pores; pH – 6.2; clear smooth boundary.
B4	110 – 140+ cm	Gray (5Y 5/1) moist; sandy loam; massive; slightly sticky, slightly plastic, firm moist; common very fine tubular pores; pH – 5.2 (7.0).

Pedon No. J11

Classification	: Typic Haplaquepts.
Location	: Adhunagar, Lohagara.
Date of examination	: 18.02.2001.
Parent material	: Silty sediments.
Erosion	: Nil.
Slope	: Nearly level.
Drainage	: Imperfectly drained.
Moisture condition	: Moist at lower portion of the profile.
Depth of ground water	: 30 – 50 m.
Physiography	: Piedmont (nearly level piedmont plain).
Flooding	: Intermittently flooded by rainwater during the monsoon.
Land use	: Cultivation.

Typifying pedon

Ap	0 – 15 cm	Gray (5Y 6/1) moist and dry; loam; massive; slightly sticky, slightly plastic, firm moist, slightly hard dry; many very fine, fine and medium pores; many very fine, fine and medium roots; pH – 4.6 (5.0); abrupt smooth boundary.
B1	15 – 30 cm	Gray (5Y 5/1) moist; loam; moderate coarse and medium subangular blocky; sticky, plastic, very firm moist; continuous moderately thick gray cutans along vertical and horizontal ped faces and pores; common very fine and fine tubular pores; common very fine roots; pH – 5.4 (6.0); clear smooth boundary.
B2	30 – 90 cm	Gray (5Y 5/1) moist; clay loam; weak coarse and medium subangular blocky; sticky, plastic, firm moist; broken moderately thick gray cutans along vertical and horizontal ped faces; many very fine and fine tubular pores; few very fine roots; pH – 6.35; clear smooth boundary.
B3	90 – 140+ cm	Gray (5Y 5/1) moist; silt loam; massive; sticky, firm moist; few very fine roots; pH – (6) (Auger).

2.4.5 Old Tidal Flats

Old tidal flats occupy the area at the western flank of the Jaldi anticline and half of the western part of the Maiskhali island. Backswamps and active minor tidal channels are common in this unit. The Old tidal flats are sometimes flooded during monsoon season and also occasionally flooded by tidal surges. Major soils developed in the unit are Typic Haplaquepts show a 70 – >120 cm thick solum and the thickness of B-horizon varies between 50 – 60 cm. The structure of B-horizon ranges from strong to weak, medium and fine subangular blocky, which is also comparable to that of Distal Piedmont Plains.

The Old tidal flat soils are gray to dark gray coloured and also marked by gleyed horizons. Fe–Mn concretions and fine to medium and yellowish brown – strong brown mottles are present in these soils. The soils show strongly acidic to near neutral pH condition (3.8 – 6.8). Typical pedons (Fig. 2.7c,d) from the unit is described below.

Pedon No. J6

Classification	: Typic Haplaquepts.
Location	: Dongra, Banshkhali.
Date of examination	: 05.02.2001.
Parent material	: Silty clay sediments.
Erosion	: Nil.
Slope	: Nearly level.
Drainage	: Poorly drained.
Moisture condition	: Moist.
Depth of ground water	: 15 m.
Physiography	: Old mangrove tidal flats.
Flooding	: Flooded for 1 – 2 months by both rainwater and tidal water in the rainy season.
Land use	: Cultivation.

Typifying pedon

Ap	0 – 20 cm	Gray (5Y 5/1) moist; sandy clay loam; massive; sticky, plastic, slightly firm moist; many very fine and fine pores; many very fine and fine roots; pH – 4.8 (7.0); abrupt smooth boundary.
Bw	20 – 80 cm	Gray (5Y 5/1) moist; silty clay; strong coarse subangular blocky breaking into medium and fine subangular blocky; sticky, plastic, firm moist; continuous thick gray cutans along vertical and horizontal ped faces and pores; many very fine and fine tubular pores; common very fine and fine roots; few small iron-manganese concretions; pH – 6.6 (8.0); clear smooth boundary.
BC	80 – 120+ cm	Gray (5Y6/1) moist; silty clay; weak medium to fine subangular blocky; sticky, plastic, firm moist; broken thin gray cutans along ped faces and pores; many very fine and fine tubular pores; few very fine and fine roots; few small Fe-Mn concretions; pH – 6.8 (8.0).

Pedon No. M2

Classification	: Typic Haplaquepts.
Location	: Dakshin Hoanok, Maiskhali.
Date of examination	: 31.01.2001.
Parent material	: Silty clay sediments.
Erosion	: Nil.
Slope	: Gentle.

Drainage	: Imperfectly to poorly drained.
Moisture condition	: Moist.
Depth of ground water	: 15 m.
Physiography	: Plain land.
Flooding	: Often flooded during monsoon period.
Land use	: Cultivation.

Typifying pedon

Ap	0 – 20 cm	Gray (5Y 5/1) moist; loam; massive; sticky, plastic, very firm moist; few very fine and fine tubular pores; common very fine roots; pH – 3.8; abrupt smooth boundary.
B1g	20 – 40 cm	Gray (5Y 5/1) moist; silty clay loam; moderate to strong medium subangular blocky; sticky, plastic, firm moist; continuous thick gray cutans along vertical and horizontal ped faces and pores; common very fine and fine tubular pores; few very fine roots; pH – 4.5; abrupt smooth boundary.
Bw2g	40 – 70 cm	Dark gray (10YR 4/1) moist; silty clay loam; moderate medium subangular blocky; sticky, plastic, firm moist; common medium distinct yellowish brown mottles; broken moderately thick gray cutans along vertical and horizontal ped faces and pores; many very fine and fine tubular pores; few partially decomposed plant tissues; pH – 5.2; clear smooth boundary.
Cg	70 – 110+ cm	Gray (N 5/) moist; silty clay loam; sticky, plastic, firm moist; few partially decomposed plant tissues; pH – 4.2.

2.4.6 River Floodplains

The Sangu river valley in the north and the axial stream at the foot of the Piedmont Plains in the Mainland form the minor River Floodplains unit. The rivers are meandering in nature and the Sangu river is a perennial one, whereas the axial stream is a tributary to Sangu and of semi-perennial type. The unit comprises a nearly level to very gently undulating landscape including ridges (levees) and inter-ridge depressions. The ridge and inter-ridge depressions are slightly to deeply flooded during the rainy season. Gray to yellowish brown silt loamy with weak and coarse to medium subangular blocky structured soils are developed in the unit. Soils are Typic

Haplaquepts. The soils are free from Fe-Mn oxide concretions. But, fine and medium yellowish brown – strong brown Fe-oxide mottles are present through out the soils of these units. Description of a typical pedon from the unit is given below.

Pedon No. J12

Classification	: Typic Haplaquepts.
Location	: Batajuri, Satkania.
Date of examination	: 19.02.2001.
Parent material	: Silty sediments.
Erosion	: Nil.
Slope	: Nearly level.
Drainage	: Imperfectly to poorly drained.
Moisture condition	: Moist.
Depth of ground water	: 15 – 20 m.
Physiography	: River flood plain (plain land).
Flooding	: Flooded for a considerable period during the monsoon.
Land use	: Cultivation.

Typifying pedon

Ap1g	0 – 8 cm	Gray (N5/) moist; silt loam; massive; many fine distinct dark yellowish brown and few fine prominent strong brown mottles; slightly sticky, slightly plastic, friable moist; common fine and few medium tubular pores; many very fine and fine roots; pH – 6.0; abrupt smooth boundary.
Ap2g	8 – 15 cm	Gray (N5/) moist; silt loam; massive; many fine distinct yellowish brown and few fine prominent strong brown mottles; slightly sticky, slightly plastic, friable moist; common very fine and fine tubular pores; common very fine and fine roots; pH – 6.8; abrupt smooth boundary.
B2g	15 – 30 cm	Gray (5Y 5/2) moist; silt loam; weak to moderate coarse and medium subangular blocky; many fine distinct yellowish brown and few fine prominent strong brown mottles; slightly sticky, slightly plastic, firm moist; broken moderately thick gray cutans along ped faces and pores; many very fine and fine tubular pores; few very fine roots; pH – 7.0; clear smooth boundary.
Bw3g	30 – 60 cm	Dark yellowish brown (10YR 4/4) moist; silt loam;

weak coarse and medium subangular blocky; many fine and medium gray to dark brown mottles; slightly sticky, slightly plastic, friable moist; many very fine and fine tubular pores; few very fine roots; pH – 6.6.

2.4.7 Active Tidal Flats

These plains occupy the westernmost bayhead area of the mainland and the Maiskhali Island. These comprise sandy to muddy beaches, nearly level tidal flats intersected by tidal creeks. The areas are subjected to regular tidal flooding. Typic Fluvaquents, Typic Haplaquents, and Typic Psammaquents mark the unit. The soils represent A/C profiles only. A typical pedon of the unit is described below.

Pedon No. J13

Classification	: Typic Haplaquents.
Location	: Palakata, Chakaria.
Date of examination	: 19.02.2001.
Parent material	: Silty clay sediments.
Erosion	: Nil.
Slope	: Nearly level.
Drainage	: Poorly drained.
Moisture condition	: Moist.
Physiography	: Active tidal flats.
Flooding	: Regularly flooded during high tides.
Land use	: Mangrove thickets.

Typifying pedon

A1g	0 – 15 cm	Gray (5Y 5/1) moist; silty clay loam; massive; common fine and medium distinct dark brown and dark yellowish brown and few fine prominent strong brown mottles; sticky, plastic, firm moist; many very fine and fine roots; pH – 7.0; clear smooth boundary.
C1g	15 – 50 cm	Gray (5Y 5/1) moist; silty clay loam; massive; common fine distinct dark brown and few fine prominent black mottles; sticky, plastic, firm moist; few partially decomposed roots; common very fine and fine roots; pH – 6.5.

Table 2.2 Field characteristics of the soils of the study area

Soil-geomorphic Units	Soil Classification	Solum (cm)	Thickness B-horizon (cm)	Structure of B-horizon	Colour of B-horizon	Texture	Fe – Mn mottles & concretions
Mainland Higher Hillocks	Dystric Eutrochrepts – Typic Dystrochrepts	70 – 100	50 – 80	Strong to weak and coarse to medium subangular blocky	7.5YR – 10YR 4 – 5 / 2 – 8	Sandy, Sandy loam to clay loam	Nil
Mainland Lower Hillocks	Typic Hapludults – Typic Dystrochrepts	85 - > 140	70 - > 120	Strong to moderate, medium to fine subangular blocky	5YR – 10YR 4 – 5 / 6 – 8	Sandy loam, silt loam, clay loam and loam	Few small hard concretion at the lower part of the profile
Island Hillocks	Typic Dystrochrepts	90	70	Strong to weak and coarse to medium subangular blocky	7.5YR – 10YR 4 – 5 / 6	Sandy, Sandy loam to clay loam	Nil
Proximal Piedmont Plains	Typic Haplaquepts	90 – 142	60 – 118	Moderate and coarse to medium subangular blocky	5Y – 10YR 4 – 6 / 1 – 4	Sandy loam, sandy clay loam, silt loam, clay loam and loam	Common fine to medium mottles and concretions
Distal Piedmont Plains	Typic Haplaquepts	65 – 110	45 – 95	Strong to weak and coarse to medium subangular blocky	5Y 5 – 6 / 1	Sandy loam, sandy clay loam, silt loam, clay loam and loam	Common fine to medium mottles and concretions
Old Tidal Flood Plains	Typic Haplaquepts	70 - > 120	50 – 60	Strong to weak, medium to fine subangular blocky	5Y – 10YR 4 – 5 / 1	Sandy clay loam, silty clay, silty clay loam and loam	Common small concretions and mottles
Active Tidal Flood Plains	Typic Fluvaquents, Typic Haplaquents, Typic Psammaquents	–	–	–	–	Silty clay loam to sandy	Common to few, fine to medium mottles
River Flood Plains	Typic Haplaquepts	30	15	Weak, coarse and medium subangular blocky	5Y 5/2	Silt loam	Many, medium to fine mottles

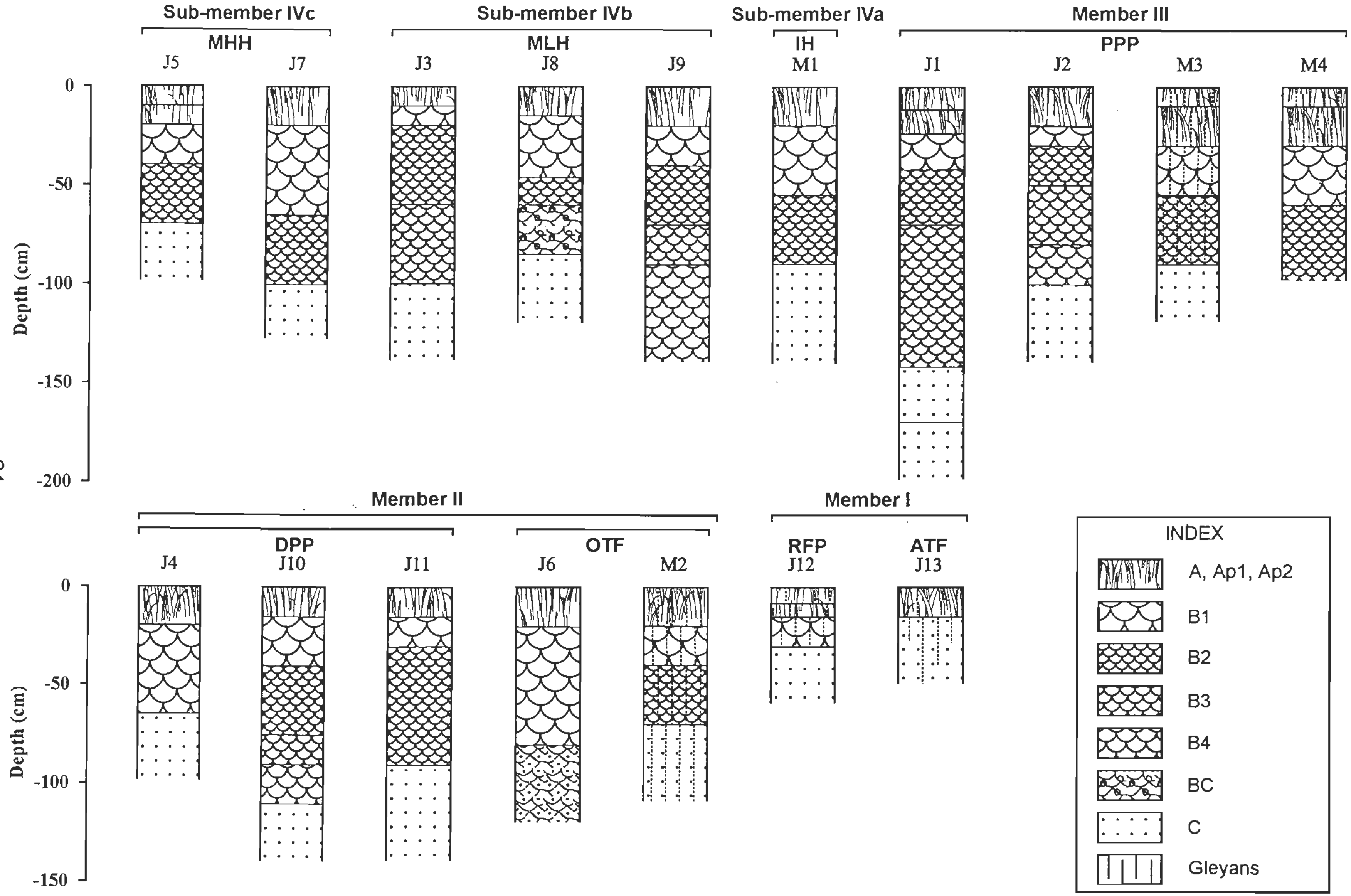


Fig. 2.8 Variation in morphological characters of the various horizons of typical pedons from different soil-geomorphic units.

2.5 SOILS AND GEOMORPHOLOGY OF THE AREA

Depending upon slopes and altitudes in an area, a landscape can be classified into three major zones: zones where material is being eroded (sloughing zone), zones where material is being deposited (accreting zones), and zones, which are neither losing nor gaining materials (Gerrard, 1992) are zones of pedogenesis. In the present study, the River floodplains and Active tidal flats units are parts of 'accreting zone'. The Proximal Piedmont Plains unit form 'zone of pedogenesis'. The Distal Piedmont Plains and Old Tidal Flats are a couple of meters above the adjoining regime of deposition and receive sedimentation due to exceptional flooding of stream or tides and form a transitional zone between zones of deposition and pedogenesis. The Hillocks - Mainland Higher hillocks, Mainland Lower hillocks and Island hillocks units belong to the 'sloughing zone'.

2.6 MORPHOSTRATIGRAPHIC SEQUENCES

As mentioned earlier, samples collected from the C/BC horizons from the typical pedons of the different soil-geomorphic units have been dated by Infrared stimulated luminescence (IRSL) dating technique in the laboratory and details are given in Chapter 5. The ages from the samples indicate the time of deposition (last burial episode) and approximate maximum ages of the soils. IRSL ages obtained for the soils of different soil-geomorphic units are: (i) Old tidal flats- 0.5 – 1.5 ka, (ii) Distal Piedmont Plains- 1 – 2 ka, (iii) Proximal Piedmont Plains- 6 – 10 ka, (iv) Island hillocks- 15 – 18 ka, (v) Mainland Lower hillocks- 23 – 25 ka, (vi) Mainland Higher hillocks- 30 – 35 ka. The age of River floodplains and Active tidal flats soils are assumed to be less than 500 yrs.

Earlier workers (Mohindra and Parkash, 1992; Srivastava, et. al., 1994; Kumar, et. al., 1996) used soil-chronoassociation to rank the soils developed in different broad soil-geomorphic units, based on the degree of soil development. But in the present study, as the soils developed on different parent materials, ranking of soils based on degree of development does not reflect their relative ages. Frye and Willman (1960) defined a morphostratigraphic unit to identify a body of rock or deposit to recognize primarily from its surficial form and the unit may or may not be distinctive lithologically from contiguous units and might not transgress time throughout its extent. In the present study, Luminescence age supported Morphostratigraphic sequence is prepared to understand controls on the degree of soil development in different soil-geomorphic units and evolution of landforms and soils of the area. On the basis of ages, four members I to IV of Luminescence Morphostratigraphic Sequence with ages as <500 yrs, 0.5 – 2 ka, 6 – 10 ka and >15 ka, respectively, are identified. Member IV is further divided into Sub-members IVa (15-18 ka), IVb (23-25 ka) and IVc (30-35 ka), as these represent distinctive events, as shown later.

2.7 RESUME

The Jaidi anticline is on the mainland and the Maiskhali island, the only island containing hills in Bangladesh, contains the Maiskhali anticline. Eight soil-geomorphic units have been identified in the area through remote sensing techniques and field investigations. The units are Mainland Higher hillocks, Mainland Lower hillocks, Island hillocks, Proximal Piedmont Plains, Distal Piedmont Plains, Old Tidal flats, River floodplains, and Active Tidal flats. The River floodplains and Active tidal flats units represent the 'accreting zone'. The Proximal Piedmont plains form the 'zone of pedogenesis'. The Distal Piedmont plains and Old tidal flats form a transitional zone between zones of deposition and pedogenesis. The Hillocks - Mainland Higher hillocks, Mainland Lower hillocks and Island hillocks units belong to the 'sloughing zone'. Depending upon field characteristics, the degree of development of soil profiles, the soils on the Mainland Lower hillocks have best development among the hillock soils.

These soil-geomorphic units are grouped into six member / sub-member Morphostratigraphic Sequences based on Luminescence ages. The different soil-geomorphic units included in various Morphostratigraphic members are: Member I – River floodplains and Active tidal flats; Member II – Old tidal flats and Distal Piedmont Plains; Member III – Proximal Piedmont

Plains and Member IV – Mainland Higher Hillocks (IVc), Mainland Lower Hillocks (IVb) and Island Hillocks (IVa).

Five terrace surfaces were inferred through field investigations. Among them two are from the Jaldi anticline marked by the top surfaces of Mainland Higher and Mainland Lower Hillocks. The top surfaces of Island Hillocks and the surfaces of Piedmont Plains and the Old tidal flats in the Maiskhali island mark the rest three terraces.

The units exhibit various soil classes: Mainland Higher Hillocks – Dystric Eutrochrepts / Typic Dystrochrepts; Mainland Lower Hillocks – Typic Hapludults / Typic Dystrochrepts; Island Hillocks – Typic Dystrochrepts; Piedmont Plains – Typic Haplaquepts; Old tidal flats – Typic Haplaquepts; River floodplains – Typic Haplaquepts; Active tidal flats – Typic fluvaquents / Typic Psammaquents / Typic Haplaquents.

Chapter 3

PARTICLE SIZE DISTRIBUTION AND CLAY MINERALOGY OF THE SOILS

3.1 INTRODUCTION

The pedogenic and geomorphic history of an area can be reconstructed by detailed field studies together with supporting physical, chemical and clay mineralogical analyses of representative profiles. Particle size distribution is an indicator of the nature of parent material and some soil forming processes, such as clay illuviation (Catt, 1986). Clay illuviation and clay mineral transformations are favoured by the nature of soil parent material and past climatic conditions. Keeping all these in view, grain size analyses and clay mineralogical studies have been carried out for typical soil profiles from different Members of the Morphostratigraphic Sequence of the area.

3.2 PARTICLE SIZE DISTRIBUTION

A total of 68 soil samples from typical profiles of different members of Morphostratigraphic sequence were investigated for particle size distribution. Particle size analysis was carried out to determine the soil texture and the amount of clay present in soils.

3.2.1 Methodology

To determine the grain size distribution in the soil profiles, all the samples were dried and meshing them with fingers or gently crushing them with wooden pastel in a mortar broke all the lumps and clods in the samples. These samples were then mixed up thoroughly and split into quarters and the opposite parts were taken for further analysis.

Soil particles adhere each other due to the presence of organic matter, calcium carbonate, iron oxides and soluble salts. It is necessary to remove all these binding materials and separate individual particles for determining the particle size distributions. The removal of these binding materials was done following the methods described by Galehouse (1971). The carbonates were removed by treating the samples with 1N HCl. 6% - 30% H_2O_2 was used gradually to remove organic fraction of the samples. Placing pieces of aluminum foils and 15 gm of oxalic acid into the soil solution and then boiling it gently removed iron oxides. Soluble salts were removed through repeated washing with distilled water. After removing all the binding materials a small amount of sodium hexametaphosphate [Na $(PO_3)_6$] was used as dispersing agent for complete dispersion.

Sand fraction was separated from the dispersed sample by wet sieving with 230-mesh (>62.5 μm) size sieve. Silt and clay fractions were separated by pipette method (Galehouse, 1971). Sand, silt and clay percentages were calculated according to the size classification used by Soil Survey Manual (1966) (i.e. Sand = 2 mm to 0.05 mm, Silt = 0.05 mm to 0.002 mm and Clay = <0.002 mm size fraction).

Pedogenic clay content was determined by subtracting the percentages of clay of A or C-horizons from that of the B-horizons (Birkeland, 1984). Clay accumulation index (sum of increase in clay content over that of A or C-horizon multiplied by thickness of B-subhorizons) proposed by Levine and Ciolkosz (1983) was also calculated for typical pedons. Where trenches were excavated up to C-Horizons, the clay percentages were calculated taking the clay abundances of C-horizon into account as A-horizon is a dynamic horizon and is continuously modified due to depletion of fine material and leaching.

3.2.2 Textural Variation and Amount of Pedogenic Clays in Soils of the Different Members of Morphostratigraphic Sequence

Textural classes were determined from the particle size data according to Soil Survey Manual (1966) by plotting the sand, silt and clay percentages in a triangular diagram. The results of the particle size analyses are given in Appendix I. Textural variation with depth in different members has helped in determining the soil development indices as well as an idea of the sedimentation characteristics. The Hillocks (Mainland Higher Hillocks – Sub-Member IVc, Mainland Lower Hillocks - IVb and Island Hillocks - IVa) with Member IV soils developed on the Quaternary parent material derived from the erosion of Boka Bil, Tipam Sandstone and Dupi Tila Sandstone formations. The Member III soils (Proximal Piedmont Plain) developed on colluvial material; and the Member II soils of the Distal Piedmont Plain and the Old tidal flats developed on alluvial parent materials, which are eroded and transported from the Hillocks. As a result a wide variety of textures ranging from sand, sandy loam to clay are found in the soils of the region.

Plots of total clay content and pedogenic clay contents with depth for typical pedons from different Morphostratigraphic members are given in Fig. 3.1. In most cases, an increase of pedogenic clay contents in the B-horizons over the C-horizons is observed. Sub-Member IVb soils have higher clay accumulation index (827-1500) as compared to Member IVa (350) and IVc (220) soils. The Member III soils have the clay accumulation index of 180-130. The pedogenic clay content of Member II soils showed a higher pedogenic clay content (1100-1300), which might be attributed to the high flooding conditions, elevated illuviation conditions due to cultivation and high content of clay in the parent material due to tidal or flood plain environments. Very young age (discussed in Chapter 4 and 5) of Member II soils with insignificant alteration of minerals suggests that the estimated pedogenic clay content may be the product of illuviation only. There is probably no pedogenic clay in Member I soils as they are very weakly or not pedogenised and active sedimentation is going on in the regions marked by these soils.

3.3 CLAY MINERALOGY

Clay minerals in soils can be formed from weathering of non-clay primary minerals or from the weathering of phyllosilicate primary minerals. In the former, weathering releases cations, silica and alumina; and clay minerals form by their recombination, whereas in the latter, the alteration takes place in the solid state. Different factors like the content of silica and the concentration of different cations in the soil solution, the soil pH and the amount of leaching dictate the type of clay mineral formation (Birkeland, 1984). These factors of weathering or soil environment are controlled mainly by climate and drainage conditions of the area. The clay mineral assemblages of the soils of the study area may be the cumulative affect of all these factors. It is difficult to work out the contribution of each of the factors. Attempt has been made to detect the dominant factor(s) controlling the clay mineralogy of the soils of the area.

The present study deals with the identification and semi-quantitative estimation of clay minerals, vertical variation of clay minerals within the soil profiles and the variation of clay minerals between the different members of the Morphostratigraphic Sequence. Attempts have also been made to find out the factors / geomorphic processes controlling the distribution of clay minerals in the study area.

3.3.1 Sample Preparation

A total of 36 soil samples from different horizons of 9 typical pedons from different Morphostratigraphic members of the area have been investigated for their clay mineralogy. Method of X-ray diffraction of oriented clay mineral sides has been employed for clay mineralogical studies. The methodology adopted for the preparation of oriented clay slides is described below.

Clay size fractions have been separated from the soil samples as the optimum size of clay minerals is less than 2 microns. In order to do this, about 15 to 20 grams of soil sample was air dried and sieved through 230-mesh (62.5 μm). The finer fractions (< 62.5 μm) were taken in a series of 1 liter glass cylinders and little distilled water was added. These mixtures were kept undisturbed for one day for soaking the samples. More distilled water was added after a day and stirred thoroughly and kept undisturbed for a day. Samples settle down leaving clear water above them containing dissolve salts. The clear water was decanted and fresh distilled water was added to the samples. This step was repeated till dispersion occurred. Then the final dispersed samples were stirred thoroughly and kept undisturbed for a period determined according to Stoke's law for allowing the particles larger than

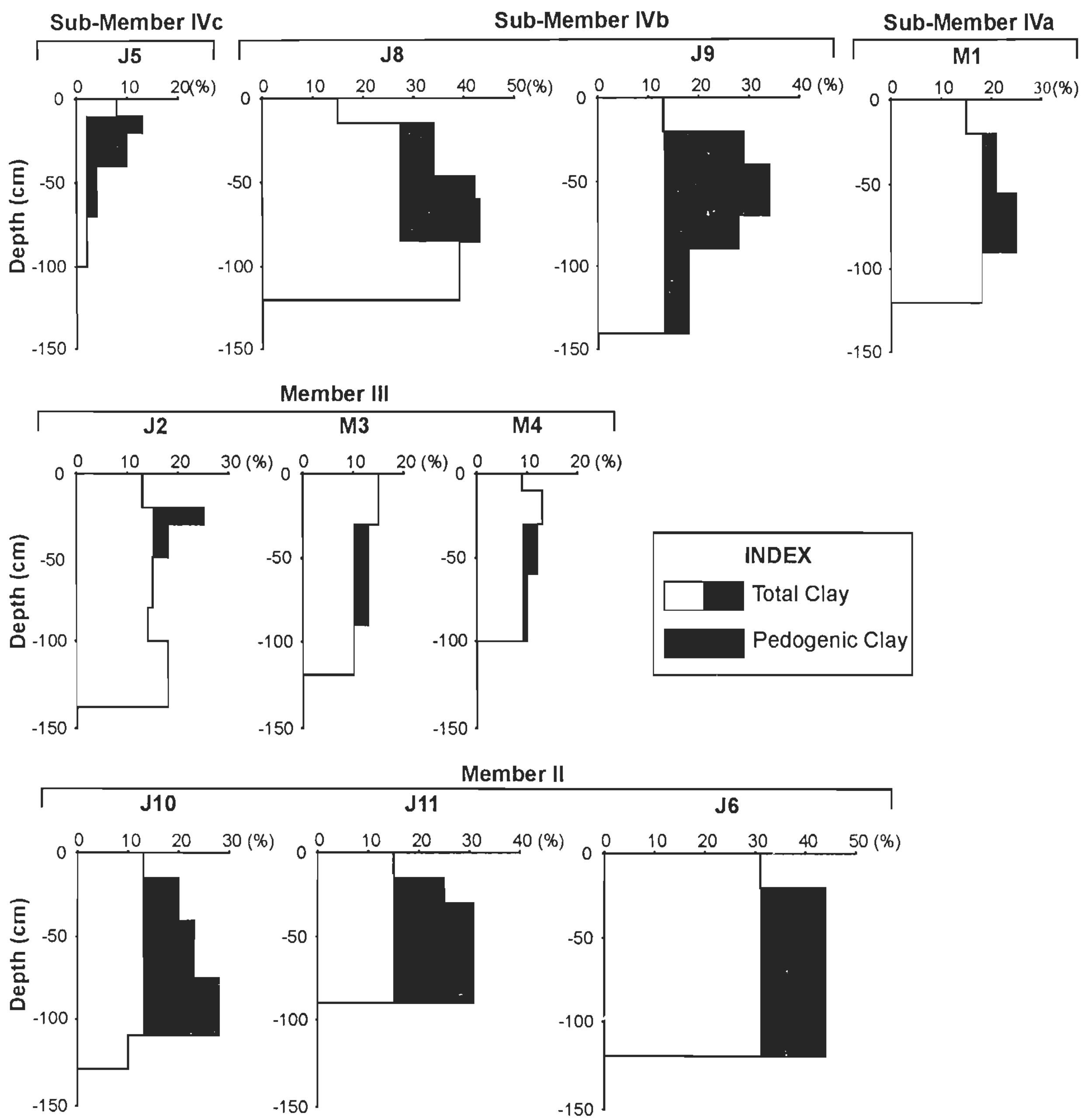


Fig. 3.1 Variation of total clay and pedogenic clay in the soils of Member II to Member IV.

2 microns to settle down. The clay size fraction was then pipetted out from 5 cm depth and collected in wash dishes. This procedure was repeated till sufficient amount of clay fractions was collected to prepare the slides.

The separated clay fractions were divided into three parts for different treatments. The first and second parts of clay fractions were saturated with Mg^{+2} and K^{+} using 1N solution of $MgCl_2$ and KCl, respectively (Klages and Hopper, 1982). The third part was treated with 1N HCl (Srivastava et. al., 1998). Excess salt solutions were decanted off after complete saturation for 12 hours and washed at least twice with distilled water to make sure that there are no excess salts. These clay slurries were then used to prepare five oriented clay slides of almost equal size and uniform thickness by pippetting the same amount of clay-water suspension on to glass slides and dried at room temperature. The pipette method was used as it is easy, quick and provides a fairly good reproducible orientation (Wilson, 1987).

Two slides were prepared from Mg^{+2} saturated clay fraction. One goes without further treatment and the other was glycolated by putting the slides on a perforated porcelain plate placed in a desiccator over a dish filled with ethylene glycol for one day. Two slides have also been prepared from the K^{+} saturated clay fraction. They were heated for 350^0C and 550^0C for 3 hours (Klages and Hopper, 1982). Heated slides were kept in an airtight desiccator with silica gel to prevent rehydration before exposing them to X-rays. The fifth slide was prepared from the HCl treated clay fraction and X-rayed without any further treatment.

X-ray analysis of all these slides was carried out on a Philips PW 1140/09 X-ray diffractometer at the Institute Instrumentation Centre, Indian Institute of Technology Roorkee. Diffractograms were obtained under the following operating conditions:

Target: Cu$K\alpha$	Filter: Ni
Current: 20 mA	Voltage: 35 kv
Wave length: 1.5418	Chart speed: 1 cm / min
Goniometer speed: 1^0 of 2θ angle / min	Range: 2 kc / s

Scanned angle: Mg^{+2} saturated slides: $5^0 - 35^0$ of 2θ angle

Rest: $5^0 - 15^0$ of 2θ angle

3.3.2 Identification of Clay Minerals

The basal reflections of the oriented clay samples in the X-ray diffractograms have been used for identification of different clay mineral species. The X-ray identification of clay minerals has been done mostly following the scheme proposed by Wilson (1987). Major characteristics used for identifications of various minerals are described in the following sections.

Kaolinites

Kaolinite refers to the kaolinite group of clay minerals as it is not possible to differentiate kaolinite from several other members of the kaolinite group unless the clay is nearly monomineralic. Kaolinites were characterized by intense first and second order basal reflections at 7.15 – 6.95 Å (001) and 3.57 – 3.51 Å (002). Basal reflections of chlorites also occur in this region. Leaching of chlorites with 1N HCl treatment without affecting kaolinites was done. All the kaolinites were found unaffected on glycolation, HCl and 350^0C heat treatment. On heating to 550^0C, the crystallinity of all kaolinites is destroyed and it results in the disappearance of basal reflections.

Chlorites

Chlorite group of minerals were recognized by a series of basal reflections at 13.9 – 13.5 Å, 7.15 – 6.95 Å, ~4.7 Å, ~3.5 Å, which persisted on heating to 350^0C or 550^0C or treatment with ethylene glycol. But the mineral is leached, when treated with 1N HCl.

Vermiculite

Vermiculite minerals are characterized by strong reflections at ~ 14 Å. Montmorillonites and chlorites also provide reflections at this region. On glycolation vermiculites produce basal reflections at ~ 14 Å, which distinguished it from montmorillonite. On heating to 350^0C and 550^0C, the 14 Å basal reflection of vermiculite collapses to 10 A^0 and this distinguished it from chlorites.

Illites

Illite is the aluminous, K-deficient mica fraction of clay size materials. It usually covers a range of clay compositions, which may be represented by the general formula: $K_{1-1.15}\ Al_4\ (Si_{7-6.5}\ Al_{1-1.15})\ O_{20}\ (OH)_4$. The Illite-mica minerals are recognized by strong basal reflections at ~9.8 Å, ~4.9 Å and ~3.3 Å. The 002-reflection intensity is generally one third of the intensity at ~10 Å reflections. On different treatments the illite peaks generally remains unaltered, but it becomes intensified, when it gets contributions from the collapse of other minerals on heating to 550^{0}C.

Smectites

Smectites were identified by broad and diffuse basal reflections at ~14 Å which shifted toward lower angles i.e. around 17 Å when glycolated. On heating the peaks of smectites get destroyed and contribute to 10 Å that results in the increased intensity of 10 Å peak.

Mixed layer minerals

Illite, smectite, chlorite, vermiculite and kaolinite often occur in a mixed order of stacking because of their structural similarities and are commonly referred to as mixed layer or interstratified minerals. The interstratified minerals are marked by very small peaks and assumed to be in trace amounts and not taken into account during semi-quantitative estimation and also assumed to be randomly interstratified. The characteristics of X-ray diffractogram peaks of different interstratified minerals are given below.

Illite-vermiculite

The small basal diffraction peaks between 10 Å and 14 Å from Mg-saturated samples and the absence of these peaks on diffraction profiles of K-saturated plus heated to 350^{0}C identifies Illite-vermiculite interstratified minerals.

Illite-smectite

Illite-smectite minerals are identified by their 2nd order basal peaks between 10 Å – 8.5 Å from the Mg-saturated samples and their disappearance on K-saturated plus heated to 350^0C.

Kaolinite-smectite

Kaolinite-smectite minerals are identified by their basal diffraction peaks between 7 Å – 8.5 Å from Mg-saturated slides and on K-saturation plus heating to 350^0C the peaks are destroyed or shifted to higher d-spacings (~ 9 Å) and at 550^0C they completely disappear.

3.3.3 Semi-quantitative Estimation of Clay Minerals of the Soils of the Study Area

Relative abundance estimation of clay minerals in sediments has long been recognized as a difficult and rather unsettled problem. A unique accepted method for semi-quantitative clay mineral estimation is lacking. The complex relationships between the peak intensity and their controlling factors do not allow an easy solution to the problem.

The intensity of diffraction pattern (generally estimated as peak area) of a mineral in a mixture is proportional to its concentration. The relative sizes of the X-ray diffraction peaks from the basal planes of clay minerals in the ~7 Å to ~17 Å range provide a basis for estimating the relative abundances of different clay minerals and mixed layer minerals. Factors such as degree of crystallinity, impurities / composition of clay minerals, evenness and thickness of the sample mount and irradiation setup of X-ray diffractometer affect the intensity as well as size of the diffraction peaks. Care has been taken to keep conditions uniform for all the samples during sample mounting and X-ray irradiation to minimize the error in the estimation of the clay mineral contents.

Two methods of estimating clay mineral contents i.e. measurement of peak height and peak areas are commonly used (Brindley, 1961; Biscaye, 1965). In the present study, peak area has been calculated following the method of Schultz (1960). The peak areas were calculated by taking the sum of three height measurements at 0.4-degree intervals across the peak. The technique provides a good compromise between the two methods and it takes peak shape into consideration.

The abundances of all the clay minerals except vermiculite and chlorite were calculated from the first order peaks of Mg-saturated plus ethylene-glycolated (Mg-Eg) clays. Vermiculite was calculated from the difference between the 14 Å peak area of Mg-Eg and K-350^{0}C slides, and chlorite from the 14 Å peak area of the K-350^{0}C slide. Several workers have worked out factors for semi-quantitative estimation of different clay minerals. In the present study, semi-quantitative estimation of different clay minerals was made using the factors worked out by Klages and Hopper (1982). The calculation involved dividing the peak areas of first order peaks of smectite by 10, vermiculite and chlorite by 5, illite by 1, kaolinite by 2.5.

3.3.4 Results

Clay mineralogical variations in the different Morphostratigraphic members are discussed below. The typical X-ray diffraction patterns of oriented clay slides of soils from the different members are shown in Figs. 3.2 – 3.6 and semi-quantitative estimation of clay minerals has been presented in Table 3.1.

Member IV

Sub-Member IVc (Mainland Higher Hillocks)

The dominant clay minerals in the member are illite (51 – 70%), and kaolinite (11 – 35%) followed by vermiculite (2 – 16%) and chlorite (1 – 2%). Illite decreases downward and vermiculite increases downward in these soils. Kaolinite and chlorite do not show any trend with depth. Illite shows an antipathetic relationship with kaolinites.

Sub-Member IVb (Mainland Lower Hillocks)

The soils of the member are dominantly composed of illite (62 – 71%) and kaolinite (22 – 26%) followed by Vermiculite (3 – 8%) and chlorite (2 – 4%). Illite increases and kaolinite decreases downward in these soils.

Vermiculite does not show any trend with depth. Chlorite decreases with depth.

Sub-Member IVa (Island Hillocks)

The dominant clay minerals in the soils of the member are illite (57 – 65%), kaolinite (24 – 32%), vermiculite (7 – 8%) and Chlorite (1 – 2%). Traces of smectite are also present in the upper horizons of the typical profile in the unit. Clay minerals do not show any pattern with depth, but illite and kaolinite show an antipathetic relationship.

Member III (Proximal Piedmont Plains)

The soils of the member are characterized mainly by illite (38 – 66%) and kaolinite (20 – 40%) followed by vermiculite (7 – 21%) and chlorite (1 – 4%). The clay minerals in the soils of the unit do not show any significant trend with depth. Illite and kaolinites show antipathetic relationship to each other. Chlorite is absent from the soil parent materials (C-horizon) in the member at Jaldi structure.

Member II

Distal Piedmont Plains

Illite (46 – 56%), kaolinite (32 – 40%) and vermiculite (11 – 12%) are the dominant clay minerals in the soils of the unit. Illite increases downward and kaolinite and vermiculite decrease with depth. Chlorite is absent from the soils of the typical pedon in the unit.

Old Tidal Flats

Illite (47 – 73%) and kaolinite (19 – 41%) are found to be dominant clay minerals associated with vermiculite (4 –7%) and chlorite (1 – 4%) in the soils of the unit. Illite increases and kaolinite decreases downward with minor variations in the B-horizon soils. Vermiculite and chlorite do not show any pattern with depth.

Sub-member IVc

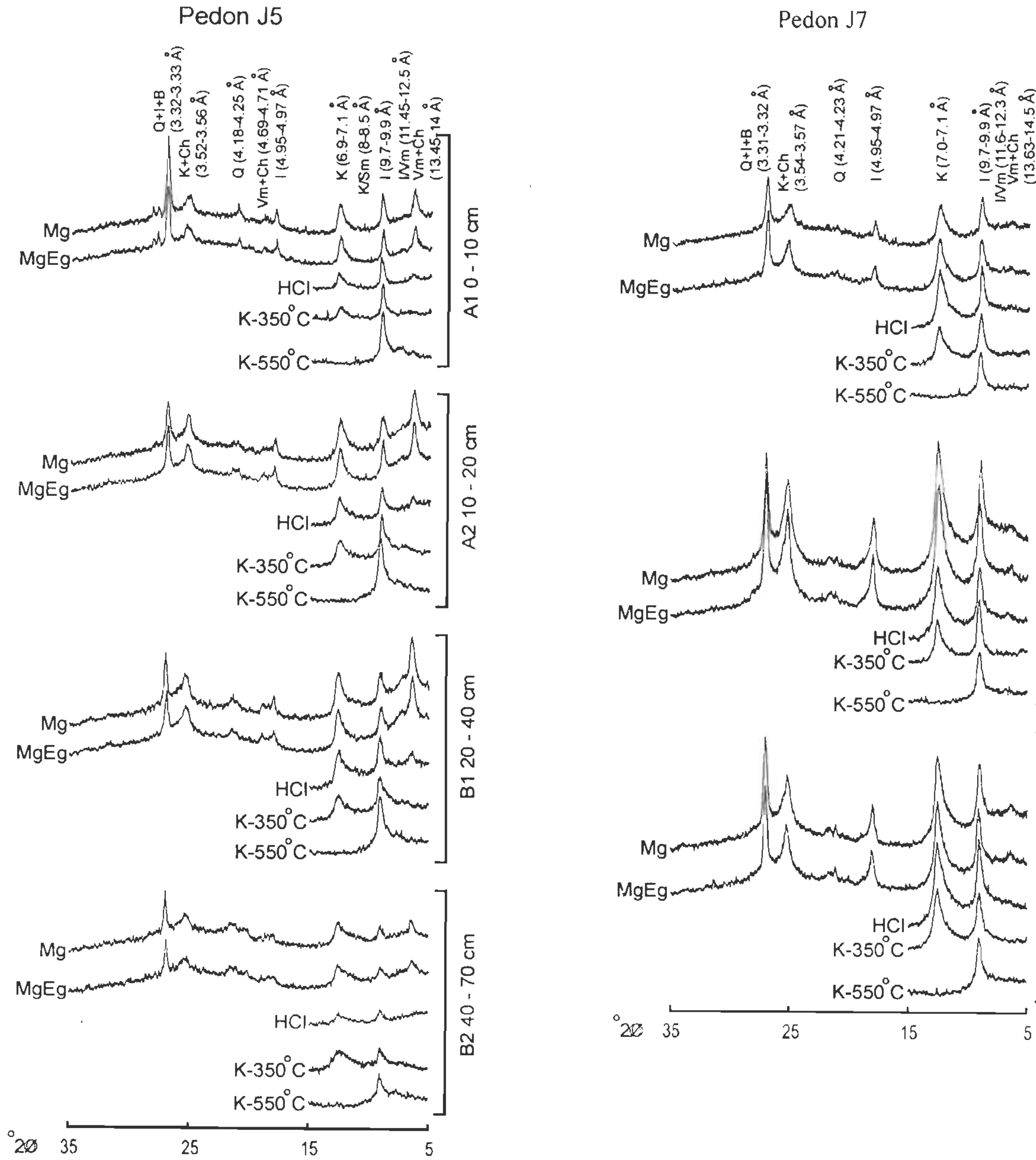


Fig. 3.2 X-ray diffraction patterns of the total clay (< 2 μm) fractions of soils from different horizons of typical pedons J5 and J7 (Vm = Vermiculite, Ch = Chlorite, I = Illite, K = Kaolinite, I/Vm = Illite-vermiculite, K/Sm = Kaolinite-smectite, Q = Quartz, B = Biotite) from Mainland Higher Hillocks.

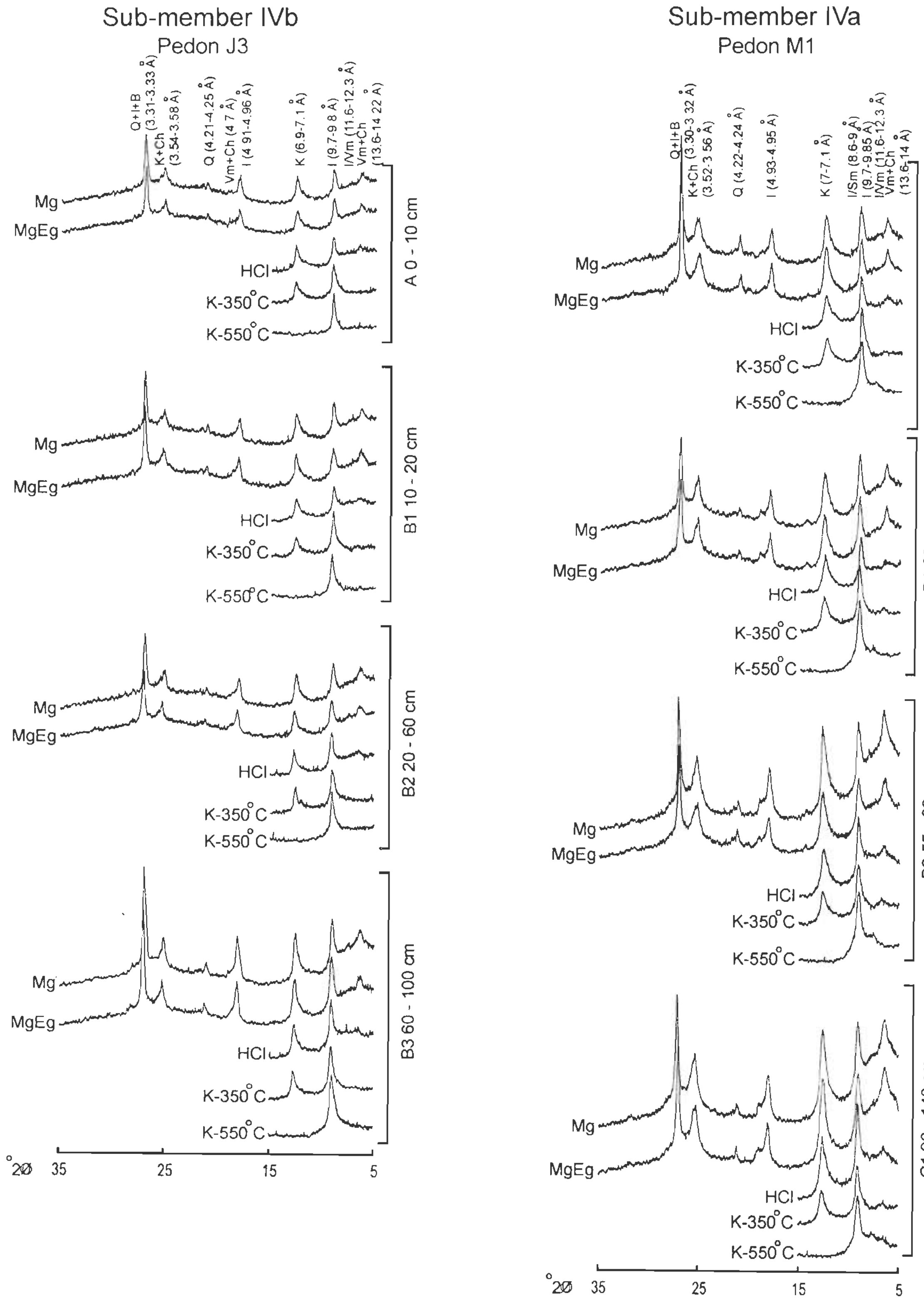


Fig. 3.3 X-ray diffraction patterns of the total clay (< 2 μm) fractions of soils from different horizons of typical pedons J3 and M1 (Vm = Vermiculite, Ch = Chlorite, I = Illite, K = Kaolinite, I/Vm = Illite-vermiculite, I/Sm = Illite-smectite, Q = Quartz, B = Biotite) from Mainland Lower Hillocks and Island Hillocks, respectively.

Member III

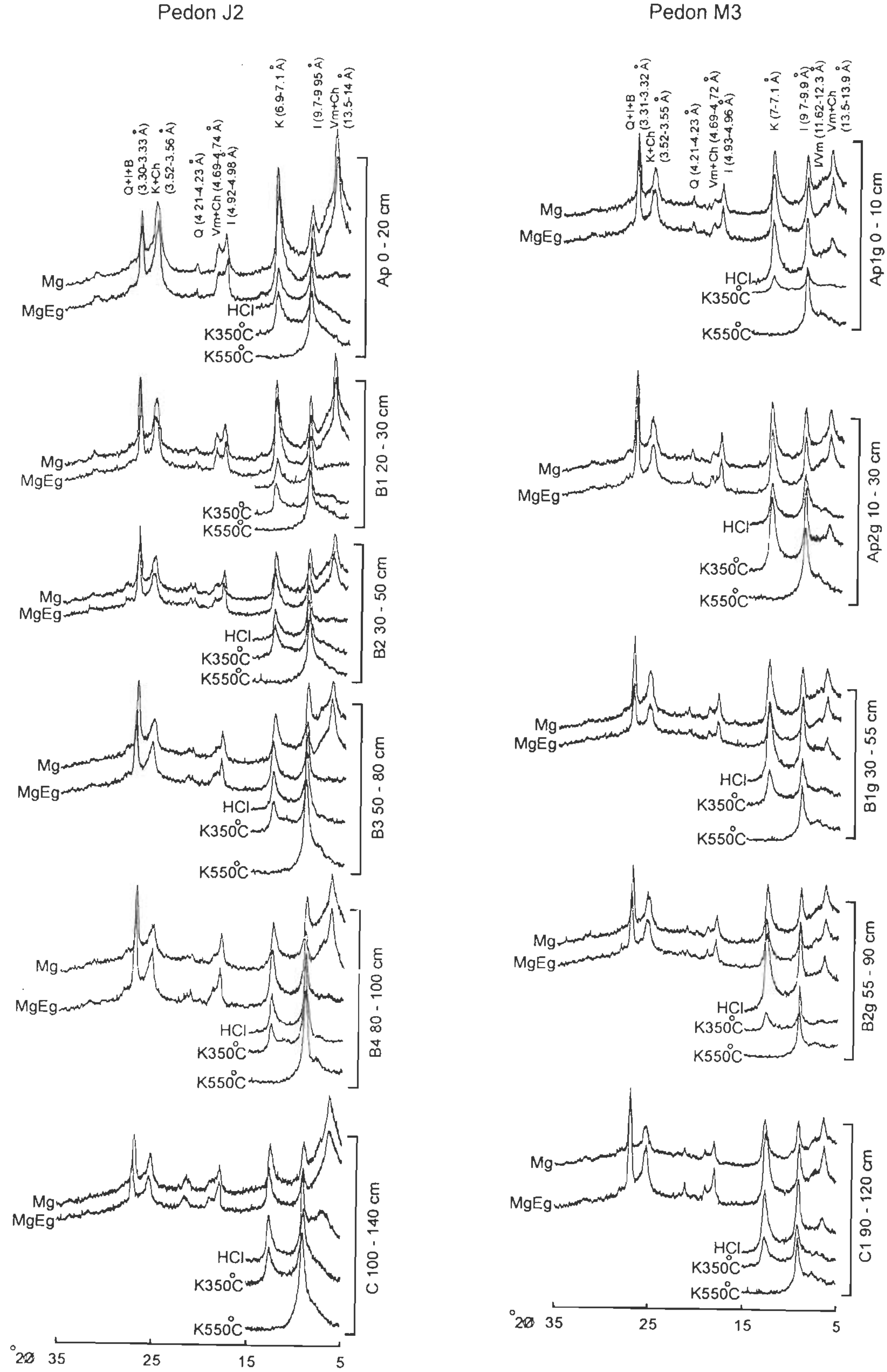


Fig. 3.4 X-ray diffraction patterns of the total clay (< 2 μm) fractions of soils from different horizons of typical pedons J2 and M3 (Vm = Vermiculite, Ch = Chlorite, I = Illite, K = Kaolinite, I/Vm = Illite-vermiculite, Q = Quartz, B = Biotite) from Proximal Piedmont Plains.

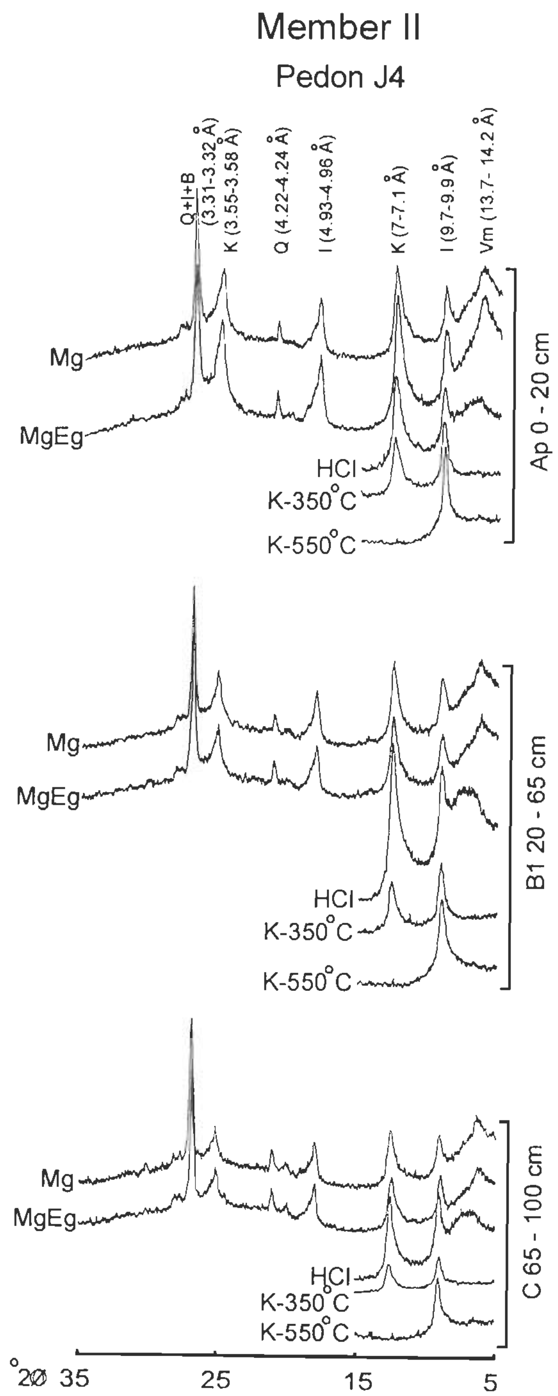


Fig. 3.5 X-ray diffraction patterns of the total clay (< 2 μm) fractions of soils from different horizons of typical pedon J4 (Vm = Vermiculite, Ch = Chlorite, I = Illite, K = Kaolinite, Q = Quartz, B = Biotite) from Distal Piedmont Plains.

Member II

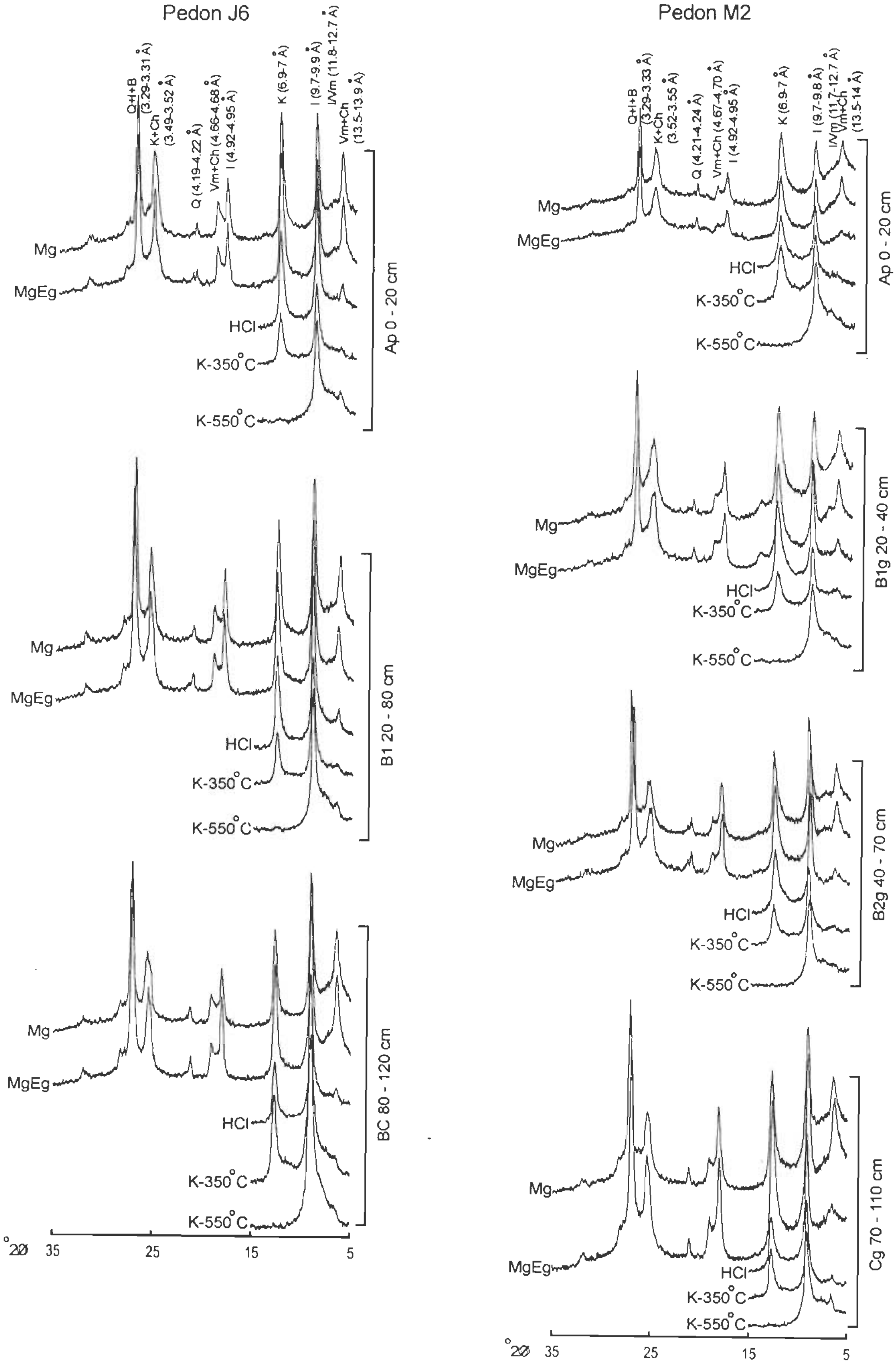


Fig. 3.6 X-ray diffraction patterns of the total clay (< 2 µm) fractions of soils from different horizons of typical pedons J6 and M2 (Vm = Vermiculite, Ch = Chlorite, I = Illite, K = Kaolinite, I/Vm = Illite-vermiculite, Q = Quartz, B = Biotite) from Old Tidal Flats.

Table 3.1 Semi-quantitative abundances of clay minerals in soils of different members of Morphostratigraphy

Sample No.	Sm%	Vm%	Ch%	Illite%	Kaolinite%
Sub-Member IVc					
J7/1	0.0	2.1	1.7	62.5	33.7
J7/2	0.0	2.7	0.8	61.3	35.2
J7/3	0.6	4.5	0.0	60.6	34.3
J5/1	0.0	11.2	1.9	63.4	23.5
J5/2	0.0	16.1	2.4	70.3	11.2
J5/3	0.0	14.6	2.4	52.3	30.7
J5/4	0.0	13.3	0.0	51.5	35.2
Sub-Member IVb					
J3/1	0.0	8.6	0.0	67.9	23.5
J3/2	0.0	6.3	4.4	62.7	26.6
J3/3	0.0	8.8	0.0	68.0	23.2
J3/4	0.0	3.8	2.6	71.3	22.3
Sub-Member IVa					
M1/1	0.5	7.5	2.1	57.5	32.4
M1/2	0.9	7.5	1.9	65.6	24.1
M1/3	0.0	8.5	2.4	64.9	24.1
M1/4	0.0	8.1	1.7	57.2	33.0
Member III					
M3/1	0.0	8.5	0.8	66.7	24.0
M3/2	0.0	8.0	2.3	56.8	32.9
M3/3	0.0	7.4	4.1	59.6	28.9
M3/4	0.0	10.2	2.4	56.3	31.1
M3/5	0.0	8.5	2.3	53.1	36.1
Member II (Distal Piedmont Plains)					
J2/1	0.0	17.7	2.3	39.0	41.0
J2/2	0.0	13.9	4.1	46.7	35.3
J2/3	0.0	13.4	1.9	58.8	25.9
J2/4	0.0	15	1.5	61.3	22.1
J2/5	0.0	19.6	0.0	59.7	20.7
J2/6	0.0	21.9	0.0	51.1	26.9
J4/1	0.0	12.8	0.0	46.7	40.5
J4/2	0.0	11.7	0.0	49.3	38.9
J4/3	0.0	11.3	0.0	56.5	32.1
Old Tidal Flats					
J6/1	0.0	6.7	2.0	62.8	28.5
J6/2	0.0	4.3	1.5	73.4	20.8
J6/3	0.0	7.4	2.1	70.9	19.6
M2/1	0.0	5.9	4.9	47.5	41.7
M2/2	0.0	5.9	2.1	60.5	31.5
M2/3	0.0	6.4	1.9	57.5	34.1
M2/4	0.0	7.6	1.2	66.7	24.5

3.4 RESUME

A wide variety of textures ranging from sand, sandy loam to clay was found in different soils of the region. In terms of increase in illuvial content of clay in B-horizons relative to A/C-horizons of soils, different Morphostratigraphic Sequence Members can be arranged with decreasing illuvial content as II, IVb, IVa, IVc and III. The pedogenic clay distribution is consistent with the field observations of soil development.

The major clay minerals of the clay fraction of the soils from the study area are illite, kaolinite, vermiculite and chlorite with traces of smectite, illite-vermiculite, illite-smectite and kaolinite-smectite (Fig. 3.7). Illite is the most dominant clay mineral in these soils. Kaolinite and vermiculite are respectively next in abundance. Illite concentration is relatively higher in the Member IV soils as compared to the soils of the other members (with only exception from Member II (Pedon J6)). Illite and kaolinite have an antipathetic relationship in the Members III and IV soils. Kaolinite concentration is higher in the soils in comparison to older sedimentary rocks exposed in the area (Hossain et al., 1998). In the soils of Members II and III, kaolinite concentration is higher in Ap-horizons. This might be because of elevated leaching conditions resulted due to anthropogenic activities related to cultivation.

The antipathetic relationship of illite and kaolinite, the presence of illite-vermiculite, illite-smectite and kaolinite-smectite mixed layer minerals, significant amount of kaolinite (11 – 35%) and micromorphological observations of alteration of biotite and feldspars (discussed in chapter 4) in the Members III (weak alteration of minerals) and IV (strong alteration) soils suggest that significant amount of kaolinite has been formed through mineral transformation. The tentative scheme of clay mineral transformations in these members might be:

Biotite → Chlorite or Illite-vermiculite → Vermiculite → Kaolinite and

K-feldspar → Illite → Illite-smectite → Kaolinite-smectite → Kaolinite.

The clay mineral distribution in Member II soils is very similar to soils of Members III and IV. Mineral alteration is negligible in the member (Section 4.3.3). The high percentage of kaolinite in the Member II soils probably reflect

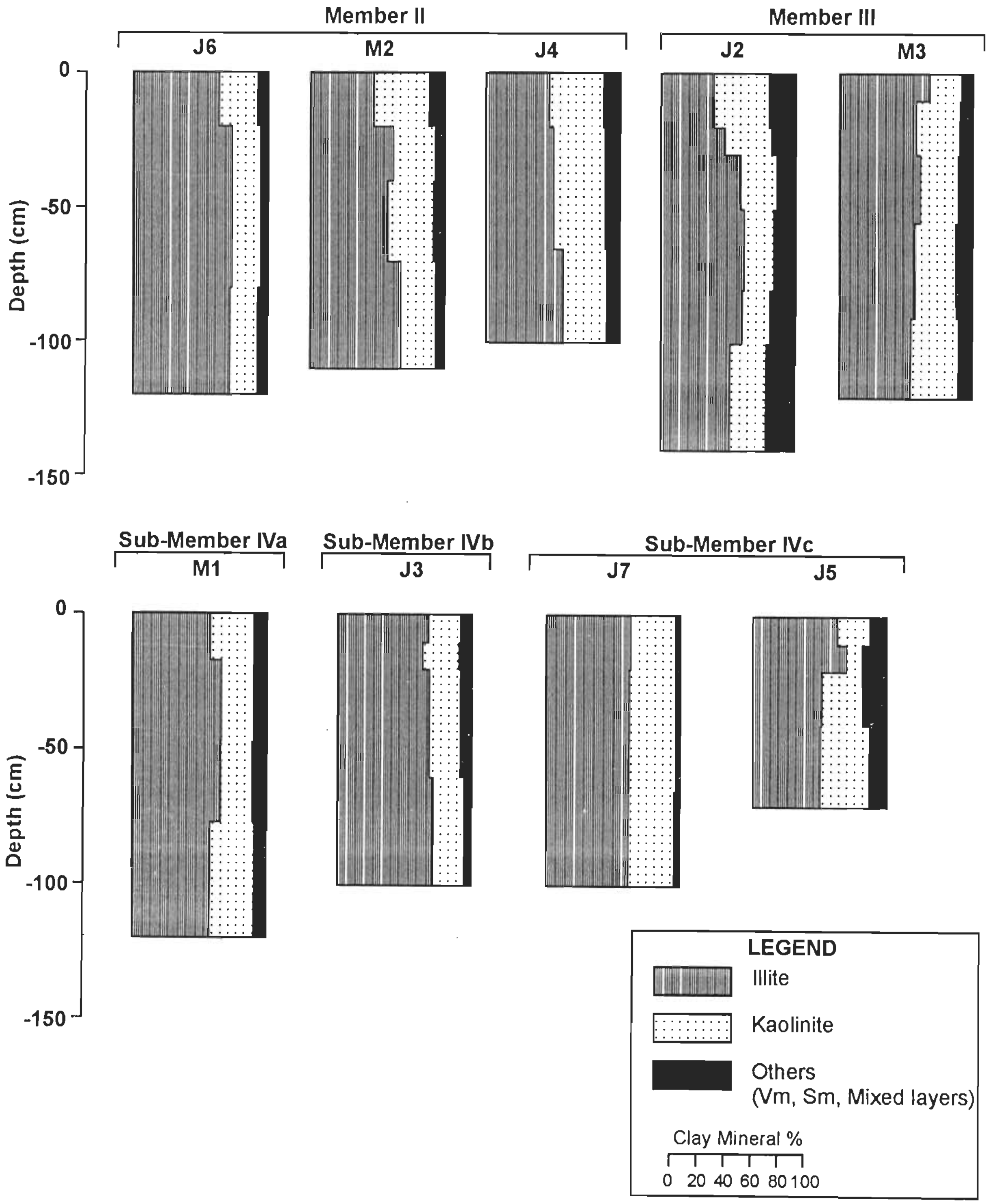


Fig. 3.7 Variation of clay minerals with depth in the soil profiles of Member II – Member IV.

the clay mineral composition of parent materials being derived from erosion of Members III and IV and older formations of the Dupi Tila, Tipam and Boka Bil. Thus the clay mineral variation in soils of the Members III and IV seems to be controlled by mineral transformations. The clay mineral distribution of Member II soils might have been dominantly controlled by clay mineral composition of parent material.

Chapter 4

MICROMORPHOLOGY OF THE SOILS OF THE AREA

4.1 INTRODUCTION

Micromorphology studies the arrangements of skeletal grains, groundmass, voids, microstructures and different pedofeatures in soil thin-sections. These are useful in understanding the processes involved in pedogenesis, degree of soil profile development and also to refine macromorphological / field observations. The procedure involved in the preparation of thin sections, brief micromorphological description of typical thin sections, and variations in micromorphological characters of soils of different horizons from typical profiles of different members of the Morphostratigraphy are the subject matters of the chapter. A total of 48 thin-sections were studied from 15 typical profiles of different Morphostratigraphic members of the area and have been described (Appendix II). The objective of the present study is to find out the relationship of different micromorphological features with the varying ages of soils.

4.2 PREPARATION OF THIN SECTIONS

In-situ (Undisturbed) soil samples were collected in metal boxes of 7.5 cm × 5 cm × 5.5 cm from the major horizons of typical pedons from different Morphostratigraphic Sequence members during the fieldwork. Thin-sections of the soil samples were prepared following the method proposed by Jongerius and Heintzberger (1963) and Miedema et al. (1974). The collected samples were saturated with acetone and dried in a vacuum chamber to remove moisture. Soil samples were then impregnated by adding crystic resin with catalyst and were kept in vacuum chamber for a day. The samples were then cured for 20 – 30 days at room temperature and the curing of the samples produced hard blocks. These impregnated hard blocks were used for preparation of thin sections.

The soil thin sections were studied in two stages. Microstructures have been studied, in the first stage, in comparatively thick sections (about 50–60 μm) to explore the type of ped, grade of pedality, and size, shapes, arrangements and abundances of voids. In the second stage, the thin sections have been ground to 25 – 30 μm and studied for other features like basic mineral components, groundmass and pedofeatures. All these observations were made under a Carl Zeiss Polarizing microscope.

4.3 MICROMORPHOLOGICAL CHARACTERS OF SOILS

Soil thin sections have been described mainly according to the system proposed by Bullock et al. (1985) under the main headings as microstructure, basic mineral components, basic organic components, groundmass and pedofeatures. Some features have also been described following Brewer's (1964) terminologies. Efforts have been made to study the features that bear imprints of pedogenic processes. The micromorphological investigations have been carried out mainly on the features described below. (a) **Pedality:** It explains the type of ped and grade of pedality. Type of peds are defined by the shape of peds as angular blocky, subangular blocky, prismatic, platy, etc. and the grade of pedality have been described by terms as apedal, weakly, moderately and strongly developed depending on the degree of separation of peds by voids. (b) **Voids:** Description of voids include type of voids, their shape, size, abundance and roughness / smoothness of void surfaces. (c) **C/f ratio and c/f related distribution:** Coarse/fine ratios are measured approximately by comparison with the chart provided by FitzPatrick (1980) and the c/f related distributions were expressed mostly as open, single or double spaced porphyric. (d) **Cutans:** Cutans are described following Brewer's (1964) terminology and given names depending upon their composition e.g. clay-rich as argillans, to, clay with iron oxides as ferriargillan and the terms like coating, hypo-coating, quasi-coating after Bullock et al. (1985) are also used to describe the morphological relation of coatings/cutans to the pores/grains. (e) **Development of b-fabrics:** The orientation and distribution patterns of interference colours of the soil micromass is the birefringence fabric or b-fabric. The b-fabrics are described as undifferentiated, crystallitic, striated and speckled b-fabrics. The degree of development of b-fabrics have been described as weakly, moderately and strongly developed. (f) **Degree of alteration of minerals:** Alteration of minerals includes the alteration of feldspars and biotites. The alteration patterns are described as pellicular, linear (irregular, parallel and cross) and dotted alterations. The degree of alterations of these minerals have been expressed as weakly, moderately and strongly altered. (g) **Concretions and mottles:** Different forms and degrees of sesquioxidic (Fe-Mn) concretions are described as diffused mottles, weakly, moderately and strongly impregnated nodules.

4.3.1 Member IV Soils

4.3.1.1 Sub-member IVc

A total of 5 thin sections from 2 typical pedons of the sub-member have been studied and described (Appendix II; Fig. 4.1). In the upper and lower horizons (A2 & C-horizons), the soils show weak development of subangular blocky peds or apedal in nature. The B-horizon soils show moderate development of subangular blocky peds. Channels separate ped faces and ped faces are partially accommodating each other. Ped diameter ranging between 500 μm - 2 mm. Subrounded, channel and vughy voids are dominant. The voids have smooth to undulating surfaces. The smooth internal surfaces of voids indicate leaching or illuviation of materials.

The coarse to fine (c/f) limit is at 30 μm and the c/f ratio varies from 15:85 to 20:80. The c/f related distribution ranging between single to double spaced porphyric. The c/f related distribution suggests that the variation in the distribution patterns of primary particles is in a small range. Coarse fraction comprises dominantly quartz and feldspars along with minor amount of muscovite, biotite and opaque minerals. Feldspar and quartz grains are highly fractured. Pellicular alteration of feldspar and biotites and parallel linear alteration of biotites (Fig. 4.1e,f) are observed. Degree of alteration of minerals is moderate to strong and increases with depth up to C/BC horizon within individual profiles. Fine fraction comprises fine silt sized quartz and feldspars, clay aggregates and micaceous particles, whose optical characters are very poorly defined.

The colour of micromass varies from horizon to horizon and in different pedons of the member. The micromass is mainly yellowish brown, yellowish red to reddish brown. The yellowish red, reddish brown and yellowish brown colours might be due to the presence of fine dispersed hematite, goethite and or Fe-gel.

Argillan and ferriargillan coatings and hypo-coatings range in thickness between 30 – 200 μm. Argillan and ferriargillans are probably degraded as coatings and hypo-coatings are not always continuous along the voids. Mottles and concretions (Fig. 4.1b) are very few. Mottles and concretions seems to be formed by the impregnation of basic soil materials with ferruginous materials. Mottles and concretions are subrounded to elliptical in shape. Mottles have diffused boundaries, whereas the concretions have sharp boundaries. The micromass exhibits development of mosaic- and stipple speckled, cross-, parallel- and random striated and undifferentiated b-fabrics, of which mosaic- speckled and undifferentiated b-fabrics are dominant.

4.3.1.2 Sub-member IVb

From this sub-member 12 thin sections of 3 typical pedons have been studied and described (Appendix II; Fig. 4.2). Micromorphological investigations show the moderate development of subangular blocky peds. In the upper and lower horizons (B1 & C) the ped development is weak or apedal in nature and the B-horizon soils show moderate development of subangular blocky peds (Fig. 4.2a). Channel and planar voids separate peds. Ped faces partially accommodating each other. Ped diameter ranging between 500 μm - 2 mm with a few peds of up to 3 mm in diameter. Subrounded and channel voids are dominant and a few planar, irregular and vughy voids are also present. Void walls are smooth to undulating.

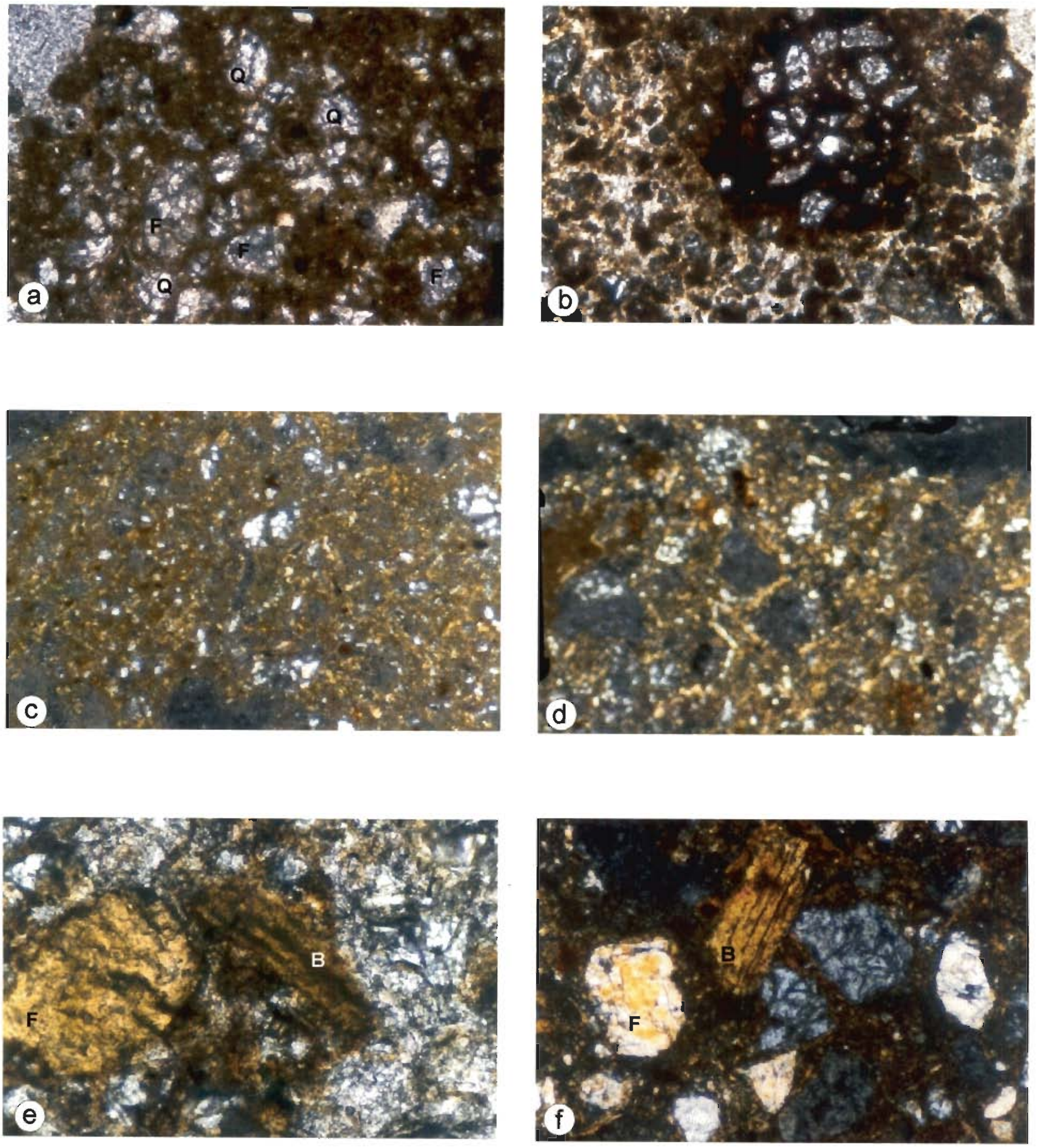


Fig. 4.1 Micromorphological features of Sub-members IVc and IVa soils (a) Porphyric related distribution and highly fractured quartz (Q) and feldspars (F) grains, B1-horizon, Pedon M1, Frame length 4.2 mm, PPL; (b) Moderately impregnated orthic pedofeatures, B1-horizon, Pedon J7, Frame length 4.2 mm, PPL; (c) Mosaic-speckled fine clayey materials, B1-horizon, Pedon M1, Frame length 1.7 mm, XPL; (d) Porostriated b-fabric and irregular sesquioxide accumulation, B2-horizon, Pedon M1, Frame length 1.7 mm, XPL; (e) Parallel linear alteration of feldspar (F) and biotite (B) and release of sesquioxide solution due to alteration of biotite, A2-horizon, Pedon J5, Frame length 0.65 mm, PPL; (f) Pellicular alteration of feldspar(F) and parallel linear alteration of biotite (B) and irregular ferriargillan coating on grains, B1-horizon, Pedon J7, Frame length 1.7mm, XPL.

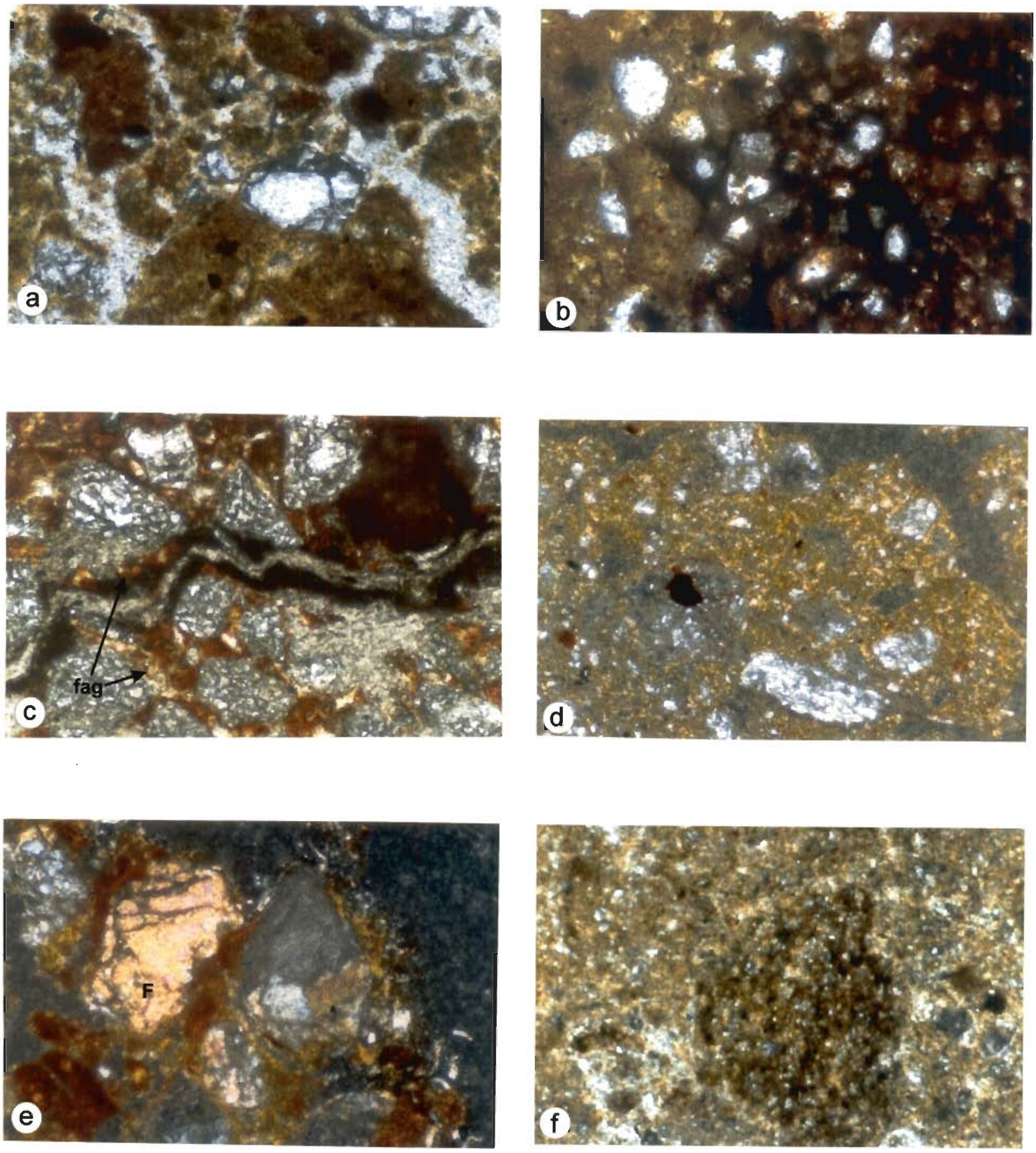


Fig. 4.2 Micromorphological features of Sub-member IVb soils (a) Moderately developed subangular blocky structure and ferruginous groundmass, B2-horizon, Pedon J9, Frame length 1.7 mm, PPL; (b) Yellowish brown and reddish brown coloured groundmass indicating hydromorphic activity and porphyric related distribution, B4-horizon, Pedon J9, Frame length 4.2 mm, PPL; (c) Hypo- and quasi- ferriargillan (fag) coatings along channel void and hypo-coating on grains, B2-horizon, Pedon J9, Frame length 1.7 mm, PPL; (d) Mosaic-speckled b-fabric of fine clayey materials, B3-horizon, Pedon J3, Frame length 1.7 mm, XPL; (e) Pellicular alteration of feldspars (F), B3-horizon, Pedon J9, Frame length 1.7 mm, XPL; (f) Moderately impregnated pseudomorphic, orthic nodule, B1-horizon, Pedon J8, Frame length 1.7 mm, PPL.

The coarse to fine (c/f) limit varies, in most of the sections it is at 30 μm and in a few sections at 15 μm. The c/f ratio varies from 2:98 to 25:75. The c/f related distribution varies from single spaced to open porphyric. Coarse fraction comprises dominantly quartz and feldspar and minor amounts of muscovite, biotite and opaque minerals. Feldspar and quartz grains are highly fractured. Pellicular, parallel-, cross- and irregular linear alteration of feldspar (Fig. 4.2e) and biotites are observed. Degree of alteration of minerals is strong to moderate. The degree of alteration of minerals in the unit is similar to that of Sub-Member IVc soils. Fine fraction comprises fine silt sized quartz, feldspar and opaque / heavy minerals and clay and or micaceous materials.

The micromass is yellowish brown to reddish brown (Fig. 4.2b) dominantly and in some sections it shows yellowish brown to gray coloured. The concentration of these reddish or yellowish colours might be because of fine dispersed hematite, goethite and or Fe-gel. The micromass exhibits mosaic- and stipple- speckled, cross-, parallel – striated and undifferentiated b-fabrics with the dominance of mosaic- speckled (Fig. 4.2d) and undifferentiated b-fabric.

Argillan and ferriargillan hypo- and quasi-coatings (Fig. 4.2c) of 30 – 200 μm thicknesses are observed. The presence of quasi-coatings suggests the higher intensity of illuviation in the unit compared to the soils of the Sub-Members IVc and IVa. Mottles and concretions are very few. The leaching of iron from biotite gives rise to mottling and concretion depending upon whether the leached iron makes a coating on the adjacent grains to form mottles with diffuse boundaries or accumulated to impregnate the soil materials to form concretions. Sporadic, weakly to strongly impregnated and orthic Fe-Mn oxide concretions (Fig. 4.2f) and Fe-oxide mottles have commonly a diameter of 1- 2 mm.

4.3.1.3 Sub-member IVa

A total of 3 thin sections from a typical pedon of the sub-member have been studied and described (Appendix II; Fig. 4.1). In the lower horizon (C), the soils show weak development of subangular blocky peds to apedal nature.

Moderate development of subangular blocky peds is observed in the B-horizon soils. Channels separate ped faces and ped faces are partially accommodating each other. Ped diameter ranges between 1 – 1.5 mm. Subrounded and channel voids are dominant along with planar and irregular voids. Voids have smooth to undulating surfaces.

The coarse to fine (c/f) limit is at 40 μm in the B1 horizon and in the lower horizons the limit is at 30 μm. The c/f ratio varies between 10:90 to 30:70. The c/f related distribution is single to double spaced porphyric (Fig. 4.1a). Quartz and feldspars are dominant and minor amounts of muscovite and biotite are present in the coarse fractions. Feldspar and quartz grains are highly fractured (Fig. 4.1a). Pellicular alteration of feldspars and biotites are observed. Degree of alteration of minerals is moderate. Fine fraction comprises quartz, clay aggregates, and micaceous particles, but their optical characters are very poorly defined.

The micromass is mainly yellowish brown to yellowish red and yellowish gray coloured. Yellowish red and yellowish brown colours might be due to fine dispersed hematite, goethite and or Fe-gel. The micromass generally show mosaic- and stipple- speckled and porostriated b-fabrics (Fig. 4.1c,d). The b-fabrics are marked by a poor preferred orientation of finer particles. Major pedofeatures observed are cutans, mottles and concretions. Argillan and ferriargillan coatings and hypo-coatings range in thickness between 30 – 100 μm. A few strongly to moderately impregnated Fe-Mn oxide concretions and Fe-oxide mottles commonly with a diameter of 0.5 to 1.0 mm and rarely with a diameter up to 2.0 mm are observed in B2 horizon.

4.3.2 Member III Soils

16 thin sections from 4 typical pedons of the member have been studied and described (Appendix II; Fig. 4.3). Micromorphological investigations reveal weak development of subangular blocky peds (Fig. 4.3a) in the member. Channels and voids incompletely separate peds. Ped faces are partially- or non-accommodating types. Subrounded and channel voids are dominant, and few irregular shaped and vughy voids are also observed. The smoothness of the void walls varies from rough to smooth.

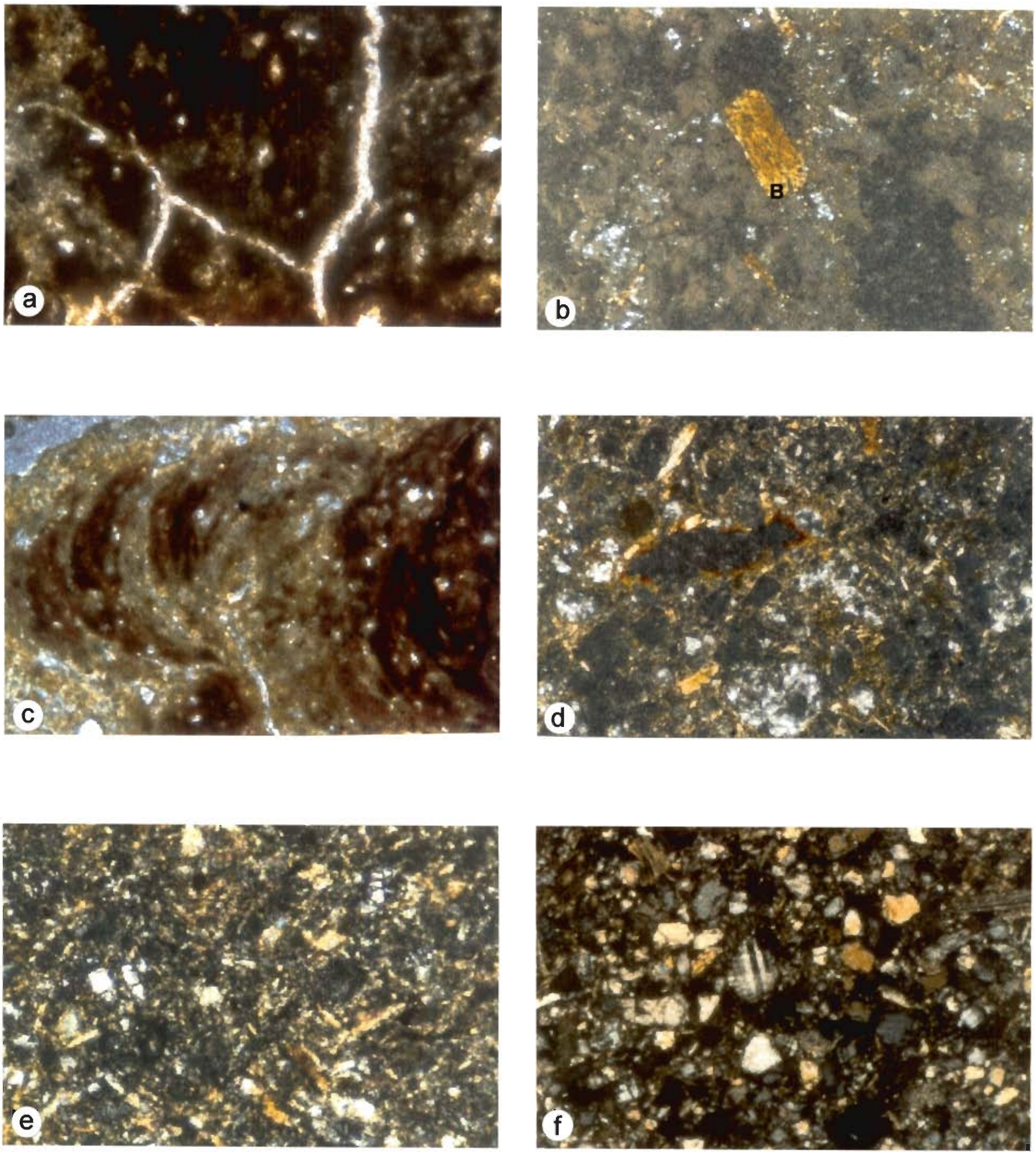


Fig. 4.3 Micromorphological features of Member III soils (a) Moderately developed subangular blocky structure and reddish brown and grayish groundmass indicating hydromorphism and gleying, B1-horizon, Pedon M4, Frame length 4.2 mm, PPL; (b) Weak parallel linear alteration of biotite (B), B1-horizon, Pedon J1, Frame length 1.7 mm, XPL; (c) Bow like structure due to biological activity and accumulation of sesquioxides, Ap2g-horizon, Pedon M4, Frame length 4.2 mm, XPL; (d) Porostriated and random b-fabric, Pedon J1, Frame length 1.7 mm, XPL; (e) Weakly developed cross-striated (reticulate) b-fabric, B1g-horizon, Pedon M3, Frame length 0.65 mm, XPL; (f) Porphyric related distribution and fresh mineral grains, C-horizon, Pedon J1, Frame length 3.4 mm, XPL.

The coarse to fine (c/f) limit varies between 30 – 40 μm. The c/f ratio varies between 10:90 to 30:70 in the soils of the member. The c/f related distribution varies from single spaced to open porphyric. Coarse fraction comprises dominantly quartz and feldspar with minor amounts of muscovite, biotite and opaque minerals. Alteration of minerals is weak. Weak pellicular and parallel linear alteration of feldspars (Fig. 4.3b) and biotites is observed. Fine fraction is composed of very fine silt to clay sized micaceous particles with few quartz, feldspar and opaque mineral grains.

The micromass is yellowish gray to gray dominantly, but in some horizons it exhibits yellowish brown to reddish brown colour. The micromass also exhibits mosaic-speckled, cross-, parallel- and random- striated and porostriated b-fabrics (Fig. 4.3d,e), but cross-, parallel- and random striated b-fabrics are most common. The b-fabric development is moderate but relatively stronger than the Member IV soils. Argillan and ferriargillan hypo-coatings of 50 – 200 μm thickness are observed. Sesquioxides are observed in the form of mottles and concretions. Moderately to strongly impregnated, orthic Fe-Mn oxide concretions commonly with a diameter of 1-2 mm and rarely up to 3mm are observed. Diffused Fe-oxide mottles of commonly 0.5 to 2 mm and rarely up to 3 mm diameters are also observed.

4.3.3 Member II Soils

4.3.3.1 Distal Piedmont Plains

A total of 7 thin sections from 3 typical pedons of the unit have been studied and described (Appendix II; Fig. 4.4). Weak to moderate subangular blocky ped development is observed in these soils. The degree of ped development is higher as compared to that in the Member III soils. Channels and voids incompletely separate peds. Ped faces are partially accommodating each other. Subrounded and channel voids are dominant and a few planar, irregular shaped and vughy voids are observed. The void walls are smooth to undulating.

The coarse to fine (c/f) limit varies between 15 – 30 μm and the c/f ratio varies between 2:98 to 20:80. The c/f related distribution varies from single spaced to open porphyric. Coarse fraction comprises dominantly quartz and feldspar with minor amounts of muscovite, biotite and opaque minerals. Very weak or no alteration of minerals is observed.

The micromass is dominantly yellowish gray to gray, but in some horizons it exhibits yellowish brown to reddish brown colour. The micromass exhibit mosaic-speckled, cross-, parallel- and random- striated and porostriated b-fabrics. Argillan and ferriargillan hypo-coatings of 50 – 300 μm thickness are observed. Sesquioxide movement has also been observed in the form of mottles and concretions. Mottles and concretions are common. Moderately to strongly impregnated, orthic Fe-Mn oxide concretions with 1-2 mm diameters. Most of the Fe-oxide mottles (Fig. 4.4b) have diffused boundaries and diameters 1-2 mm and a few have diameters up to 3mm.

4.3.3.2 Old Tidal Flats

From this unit 5 thin sections of 2 typical pedons have been studied and described (Appendix II, Fig. 4.4). Soils exhibit apedal or very weak ped development in A- and C-horizons and moderate to strong development of subangular blocky peds (Fig. 4.4a) in the B-horizons. Channels and planar voids separate peds. Ped faces are of accommodating type. Channel voids are dominant and planar, subrounded and irregular shaped voids are present rarely. Void walls are undulating to smooth.

The coarse to fine (c/f) limit varies between 15 – 30 μm. The c/f ratio varies between 2:98 to 10:90. The c/f related distribution varies from single spaced to open porphyric. Coarse fraction is composed dominantly of quartz and feldspars along with minor amounts of biotite, muscovite and opaque minerals. Very weak alterations of minerals in the upper horizons are noticed which might have been derived from the Member III-IV soils. Finer fraction comprises fine silt and clay-sized quartz, opaque minerals and micaceous particles.

The micromass is dominantly yellowish brown, yellowish gray to gray. Around the root zones and channels, the micromass shows yellowish red to reddish brown colour. The micromass exhibit mosaic-speckled, cross- and parallel striated and porostriated b-fabrics with the dominance of striated b-fabrics.

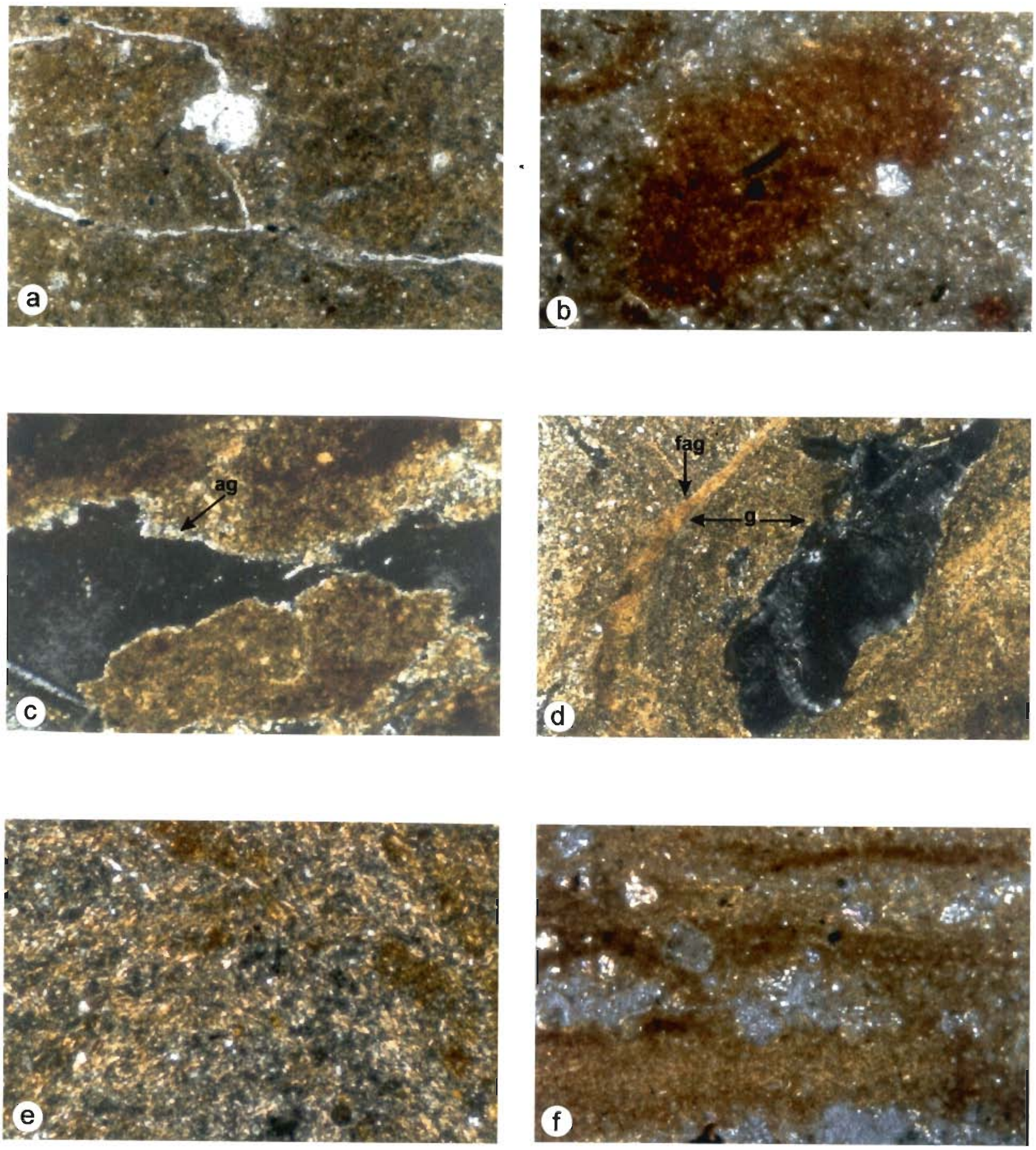


Fig. 4.4 Micromorphological features of Member II soils (a) Moderately developed subangular blocky structure bounded by channels, B1-horizon, Pedon J6, Frame length 3.4 mm, PPL; (b) Diffused Fe-oxide mottle in silty groundmass, B1-horizon, Pedon J10, Frame length 4.2 mm, PPL; (c) Argillan (ag) hypo-coating along a channel void and rough internal surface of channel, B1-horizon, Pedon J6, Frame length 1.7 mm, XPL; (d) Microlaminated ferriargillan (fag) quasi-coating and gleyans (g) along a channel void, B1-horizon, Pedon J6, Frame length 3.4 mm, XPL; (e) Small patches of clay randomly distributed shows random striated b-fabric, B1g-horizon, Pedon M2, Frame length 1.7 mm, XPL; (f) Alternating clay and silt layering in the C-horizon, Pedon J10, Frame length 4.2 mm, XPL.

Argillan and ferriargillan hypo- and quasi-coatings and gleyans (Fig. 4.4c,d) of 50–300 μm thicknesses are continuous along channels and planar voids. Gleyans are identified in the field and under microscope by their uniform gray colour. Mottles and concretions are common. Weakly to moderately impregnated, orthic Fe-Mn oxide concretions concentrated in the upper horizons and diffused Fe-oxide mottles concentrated in the lower horizons.

4.4 RESUME

Micromorphology helps to identify the pedogenic processes and soils of the study area can be classified into three groups, based on soil-forming processes: Poorly-, moderately- and strongly developed soils.

(i) Poorly Developed Soils

This group includes Member I soils, which show A/C horizonation or only minor development of B-horizons and are least developed soils in the area. Active sedimentation is going on in these units. Sedimentary structures as ripple marks, lamination and cross-beddings are observed in the field. Biotite and muscovite minerals are almost fresh. Hydromorphism is going on as indicated by diffused mottling.

(ii) Moderately Developed Soils

This group includes Member III and II soils. The soils have well developed B horizons with thick, continuous argillans and ferriargillans, which indicate significant translocation of clays, as earlier indicated by grain size distribution in different profiles of this group. The presence of thick gleyans indicate swelling and compaction and flooding of the Old Tidal Flat regions. Variety of ferruginous segregation features like Fe-Mn nodules, diffused mottles of iron oxides are observed in the soils. Weak to very weak alteration of minerals like feldspars and biotites are observed in these soils. These observations particularly the weak alteration of minerals, abundance of free Fe-oxide in the form of concretions and mottles and clay mineralogical composition of these soils (dominance of 2:1 clays and detrital in nature as described in section 3.4) suggest that these soils are at the initial stage of pedogenesis i.e at the 'fersiallitisation' stage of pedogenesis (Duchaufour, 1982).

(iii) Strongly developed Soils

Soils of Member IV exhibit poor birefringence marked by mosaic-speckled and undifferentiated b-fabrics might be due to degradation of argillans and ferriargillans. It suggests a significant change in conditions of pedogenesis. These soils are characterised by a few orthic Fe-Mn oxide concretions and diffused Fe-oxide mottles. The orthic nature of the concretions and diffused nature of the mottles suggest their recent formation. Alteration of minerals (biotites and feldspars) is strong. The micromass of these soils are invariably impregnated with yellowish brown to reddish brown Fe-oxides. These observations particularly the strong alteration of minerals, the yellowish brown to reddish brown coloured micromass and dominance of 2:1 and 1:1 clays (with neoformation of kaolinite as described in section 3.4) suggest that these soils have undergone a 'ferrugination' stage of weathering/ pedogenesis (Duchaufour, 1982).

Chapter 5

LUMINESCENCE CHRONOLOGY OF THE SOILS OF THE AREA

5.1 INTRODUCTION

The dating methods applicable to date the Quaternary rocks/sediments can be broadly categorized as absolute dating techniques and relative dating techniques. In absolute dating, the age is derived from currently measurable quantities, whereas ages in relative dating methods can be converted into absolute numbers using calibrating points, the ages of which have to be derived from other methods. Time range of applicability, age resolution, requirement of suitable dating materials and events are varied for different methods. Major dating techniques applicable to Quaternary rocks, with their attributes are given in Table 5.1. Only four methods of dating i.e. the radiocarbon dating, Uranium-series, Electron spin resonance (ESR) dating and Luminescence dating techniques are most suitable for providing numerical ages for materials of the Late Quaternary Period. The advantages and disadvantages of these techniques are discussed in some details in the following paragraphs.

Radiocarbon Dating: Radiocarbon (^{14}C) is produced in the upper atmosphere by reaction between cosmic radiation and nitrogen. Oxygen and radiocarbon combine and produce radioactive carbon dioxide. This radioactive carbon dioxide is mixed uniformly throughout the atmosphere. Plants intake carbon dioxide through photosynthesis and become radioactive themselves and exchange with the hydrosphere resulting in a global equilibrium state of radiocarbon – called the initial radiocarbon activity. The isolation of a subsystem from the global system ceases the regular addition of radiocarbon and the initial ^{14}C activity in the subsystem begins to decrease according to the laws of radioactive decay. The length of time (age) when the

Table 5.1: Quaternary dating techniques with their attributes (After Williams et al., 1993)

Technique	Parameter measured	Age range	Matrix	Application event	Result
Radiocarbon	^{14}C activity or ^{14}C atoms (AMS)	100 a BP – 50 Ka BP	Organic remains e.g., wood, charcoal, soil, bone, shells, etc.		Relative and numerical ages
Thermoluminescence (TL)	TL emissions	100 a BP – 1 Ma BP	Quartz and feldspar mineral grains e.g., loess and sand dunes, fluvial deposits, pottery and ceramics, tephra, carbonates / precipitates.	Thermal agent (volcanics, pottery firing), day light or sun bleaching (aeolian, fluvial, colluvial deposits, etc)	Numerical ages
Optically Stimulated Luminescence (OSL)	OSL emissions	As above	As above	As above	Numerical ages
Electron Spin Resonance (ESR)	ESR of trapped electrons	2 Ka BP – 10 Ma BP	e.g., shells, corals, bones and teeth, organics and some precipitates	As above	Numerical ages
Uranium-series	Concentrations or isotopic ratios of Uranium and its daughter	10 a BP – 1.25 Ma BP	Wide variety of materials containing uranium or thorium		Numerical ages
Potassium-Argon(K-Ar)	^{40}Ar accumulation ^{40}K content	100 Ka BP – no upper age limit	Materials containing potassium – volcanic, metamorphic and igneous rocks	Rock / mineral formation of alteration, recrystallization, faulting, thermal history	Numerical ages
Fission track	Fission track density	100 Ka BP – no upper age limit	Materials containing U^{238} e.g., zircon, glass, basalts, volcanic pumice	Volcanic events, landscape evolution, sea-floor spreading, archaeological materials	Numerical ages
Palaeomagnetism – Polarity reversals, Polarity excursions, Secular variation	Direction of remnant magnetic field	2.5 Ka BP – 1 Ma BP	Magnetic minerals	Sea-floor sedimentation, cooling of volcanic or archaeological samples	Correlation (numerical age estimates possible using master curves)
Amino Acid Racemization (AAR)	D/L ratio	100 a BP – 2 Ma BP	Fossil materials containing protein breakdown products e.g., bones, teeth, shells, peats, etc.	Palaeoclimates and death of the organism	Relative age (conversion of numerical age is possible by correlation with materials of known age)
Weathering Pedogenesis	Sedimentary character	1 – 10 Ka BP	Soils, stratified units, glacial deposits	Soil formation, glacial / interglacial history, Palaeoclimate	Relative age and correlation (limited)

subsystem was isolated from the global equilibrium state can be calculated by knowing the rate of decay and the present radiocarbon activity in the subsystem.

The sort of samples that can be dated with radiocarbon dating technique are, wood, bone (protein fraction or carbonate fraction), charcoal, shells, peat, mortar, lime burials, seeds, ivory, paper, textiles, sediments, soils etc. The measurement of the remaining radioactivity is done either by using ultra low-level beta counting technique or by using accelerator mass spectrometry (AMS). Although a precision of 1% or less is achievable with the modern techniques, one of the principle uncertainties in the age is specification of initial ^{14}C activity. Atmospheric ^{14}C activity varied in the past due to reasons like geomagnetic variations, solar activity, reservoir effect, in-situ production, fossil fuel effect, nuclear weapon testing, etc. An exact estimate of initial of ^{14}C activity cannot be made leaving a large uncertainty in the age determination. The other types of uncertainties are associated with sample contamination. For example, contamination with modern humic acids in sediments and soils samples, lignin contamination in extraction of sufficient amount of cellulose from wood samples, possibility of carbon exchange in calcium carbonate of shells, possible contamination of limestone of marine origin in the dating of stalagmites and other carbonate deposits cause errors.

Uranium Series Dating: Uranium Series disequilibrium dating technique can be applied to a wide variety of materials such as speleothems, corals, mollusks, carbonate deposits (travertines, calcretes, evaporates, etc.), bones and peats. Leaching and precipitation of soluble and insoluble members of the U-series are very common and give rise to two groups of U-series disequilibrium dating method. The first group is based upon the decay of unsupported daughters of the U-series. The second group is based on the accumulation of decay products in the systems where the parent isotope has been deposited without any daughters or with a known daughter deficiency. Ages are then determined from the extent of equilibrium restoration by the accumulation of decay products (Williams et al., 1993). For Quaternary dating, intermediate nuclides of the series with relatively short half-lives are employed. The assumption on which the dating of all U-series is based are: (i) the dating material has been part of a chemically closed system since formation involving no loss or gain of any isotope other than radioactive decay and (ii) at the time of formation the isotope ratio used for the age determination was either zero or a known amount. Two additional assumptions are required if the concentrations of isotopes in deposits are used rather than isotopic ratios: (i) the supply of radioisotopes must have been constant through time and (ii) the ratio of radioisotopes to transportation mechanism has been constant. These assumptions are hardly fulfilled in soils and hence leave large uncertainty in age assigned to the stratum.

Electron Spin Resonance: It is closely related technique to TL / OSL technique discussed in substantial detail in the following section. The technique in principal can be used for all those materials, which are suitable for TL / OSL dating. Natural radioactive decay of uranium, thorium and potassium in the sample and or in its environment ionize or damage the crystals to generate free electrons that have accumulated / trapped in the crystal lattices of minerals over time. The technique directly measures these radiation-induced paramagnetic electrons trapped in crystal defects in the samples. These electrons can be excited through exposing to high-frequency electromagnetic radiation in a strong magnetic field and their resonance can be detected. When the trapped electrons are in resonance, electromagnetic power is absorbed in proportion to the population of trapped electrons. Therefore, the absorption is the reflection of trapped electron density as well as of age (period) during which these electrons were trapped.

The equipment employed for ESR dating is highly expensive. The technique has a low sensitivity and hence lower age limit is not as low as that obtainable by TL/OSL methods. However, it has been shown that the technique can date sample over 10^{6-7} years. The technique is yet to get established to date sediment deposited in fluvial environment.

5.2 LUMINESCENCE DATING

In luminescence process, materials show luminescence due to their de-excitation from higher energetic atomic and molecular state to lower energetic state. In normal luminescence process the de-excitation process take place within 10^{-8}s from the start of excitation. The electronic transitions in such a process are direct and are allowed as per the normal selection rules. There also exists another category, the phosphorescence or delayed luminescence in which luminescence can be seen for several seconds (in some cases even to several thousands of years) from the time of ceasing of excitation. Thermally or optically stimulated luminescence process is also a kind of phosphorescence exhibited by dielectric crystals such as NaCl, $ZnSO_4$, quartz, feldspars, garnets etc. Exposing to ionizing radiation like X-rays, α-rays, β-rays, γ-rays, etc can excite these materials. The ionization causes creation of avalanche of free electrons (and corresponding holes), which diffuse in the crystal lattice. In the energy band diagram (Fig. 5.1), free electrons are shown in conduction band and holes in valance band. Most of the free electrons return back to their ground state within 10^{-8}s by direct transition (recombining with the hole) giving prompt luminescence. The remaining fraction of electrons and holes in the process of their diffusion gets trapped at lattice defect sites. The lattice defect sites are point imperfections, where discontinuity in crystal geometry occurs due to reasons like vacancy of host lattice ion or due to presence of impurity ion etc. More the exposure to ionizing radiations more will be the trapped charge concentration. Hence, the trapped charge concentration is measure of absorbed radiation dose. The time over which charges (electrons/holes) remain trapped in the defect centre depends upon the electrostatic binding energy between charge and the centre. Higher the binding strength longer is the trapped life. In the band-energy diagram, the energy state associated with the traps is shown as metastable state in the energy gap between conduction band and valence band. Direct de-excitation of electrons from metastable state to ground state is not allowed as per the selection rules. The mode of de-excitation is only through conduction band. Therefore, larger the relative gap between metastable state and conduction band (valence band for holes) higher is the energy required to remove charge from the metastable state and hence longer is the life time of charge to remain trapped in the defect centre at a given temperature. Dielectrics show spectrum of traps with charge retention time varying from seconds to several thousands of years. Traps that can retain charge over geological time scales are important in dating studies. Rapid de-excitation is possible by thermal or optical stimulation of charges. The stimulation raises charges to conduction band from where direct transition to lower energy state/ground. The de-excitation is associated with electron-hole recombination and emission of light. The intensity of emitted light depends upon number of electron-hole recombinations and wavelength of emitted light is characteristic of electron-hole recombination centre. Higher the exposure to radiation higher will be the trapped charge concentration and higher will be the intensity of light emission on thermal or optical stimulation. Thus, higher will be the luminescence and in turn age. Thermally or optically stimulated luminescences are abbreviated as TSL or TL and OSL, respectively. OSL is also sometimes referred as photo-stimulated luminescence and abbreviated as PSL. Depending upon spectral band used in photo-stimulation, it is termed as BGSL if stimulation is in blue-green region, GLSL if stimulation is in green region, IRSL if stimulation is done using infrared source.

The dating of geological and archeological sediment has become easier with the advent of TL/OSL technique as the mineral grains that form sediment are directly dated. The geochronological application of TL/OSL dating stems from the following facts:

1. Natural ubiquitous minerals such as quartz, feldspars, zircon etc. are good TL/OSL phosphors. These minerals contain traps deep enough to retain trapped charges over geological time scales.
2. Exposure to sunlight, which normally mineral grains receive during their transport, and also exposure before getting buried, removes all the previously stored trapped charges.

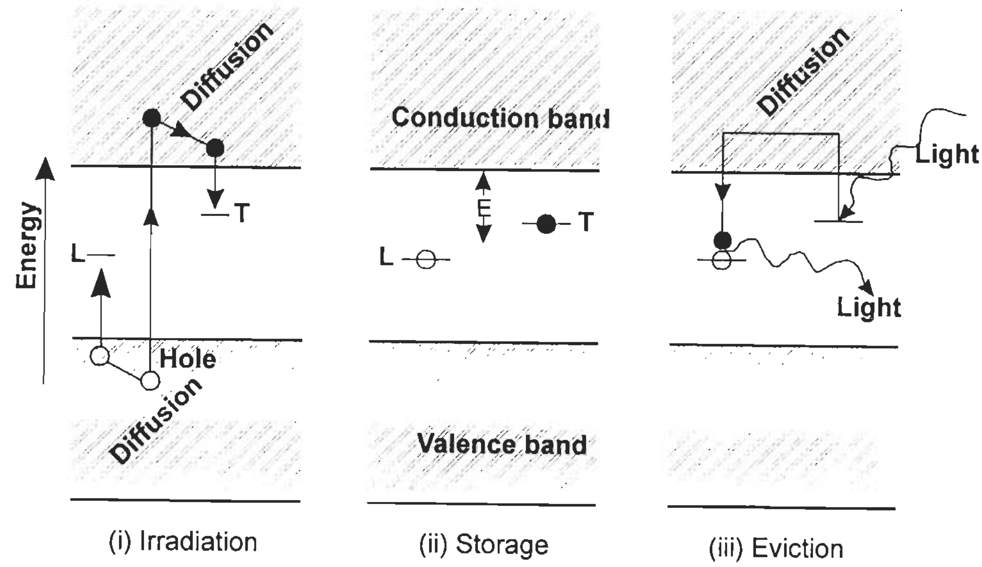


Fig. 5.1 OSL processes explained through energy-level diagram (after Aitken, 1998); (i) Ionization due to irradiation through ambient flux of nuclear radiation, with trapping of electrons (T) and holes (L) at defects; (ii) Storage during antiquity; (iii) By stimulating light of appropriate wavelength onto the sample, electrons evicted and some of them reach luminescence centers, and in the process of combining emit light.

3. On burial, exposure to sunlight ceases and fresh signal builds up in the form of increased trapped charge concentration with time due to exposure from ambient radioactivity. The ambient radioactivity act as a constant source of irradiation by virtue of the presence of long lived radio-isotopes ^{238}U, ^{232}Th, and ^{40}K having their half lives over 10^9 years. With this constant radiation the trapped charge concentration increases continuously until the sample is excavated.
4. In the measurement in laboratory, the observed TL/OSL signal is related to the trapped charge concentration and hence the absorbed radiation dose. As the ambient radioactivity acts as a constant radiation source, the absorbed radiation dose on normalization with ambient radiation rate gives the time spent by mineral in the deposit since its burial i.e. the sample age.

The luminescence age equation is therefore,

$$Age = P / (aD\alpha + D\beta + D\gamma + Dc)$$

Where 'a' is the alpha efficiency factor; D's are the component dose rates of different radiation types; 'P' is the paleodose i.e. the luminescence acquired during burial, which is also termed 'equivalent dose' (ED or D_E) as the equivalent laboratory beta dose can induce luminescence identical to that in the natural sample. Therefore, a dating experiment requires two types of measurements: estimation of dose rate and paleodose.

5.3 SAMPLING AND SAMPLE PREPARATION

In the present study, optically stimulated luminescence (OSL) dating technique has been used for dating soils that are formed from parent material deposited in fluvial, colluvial and mangrove environments. A typical soil pedon is a three-dimensional body of sediment matrix sub-divided into horizons A, B and C. In the soil profile, entire solum matrix is presumed to be developed from C-horizon. The alterations that take place in parent material due to eluvial and illuvial processes develop it into A and B-horizons respectively. The bioturbation in A-horizon keeps its surface sediment matrix actively mixed with its underneath particles clipping its growing OSL signal to a small level indicative of mean burial age of these particles. The percolation of finer particles from A to B-horizon not only reduces its age but can also brings along ^{232}Th with it changing the ambient radioactivity of both A and B-horizons. Similarly, percolation of dissolved ^{238}U through infiltrating water can also lead to change in dose rate of A and B-horizons. The horizons, which are considered to be least affected by pedogenic processes, are C and BC horizons. The ages obtained from these horizons are expected to yield true sediment deposition age. Therefore, in the present study for luminescence dating, samples were collected from C or BC-horizons only. Considering the slope factors it is expected that the sediment constituents might have been transported to a small distance before burial and have therefore a shorter exposure to sunlight for bleaching. Such sediments can only be dated by their fast bleaching OSL and particularly IRSL components.

Samples were collected in metal cylinders of 5 cm (dia.) X 15 cm (length), by pushing them into the C/BC-horizons of the soil profiles. Sample preparation and measurements were carried out under subdued red light to avoid photo bleaching of luminescence signals. The top and bottom 1 – 2 cm portion of the samples were discarded as they might be sun bleached during sampling and this fraction was used in estimating ^{238}U, ^{232}Th and ^{40}K content. The middle core was then sequentially treated with 1N HCl to remove carbonates, 30% - 50% H_2O_2 to dissolve the organic fraction and 0.01N Na-oxalate for deflocculation and each chemical treatment followed by ultrasonic treatment to remove suspended clay fraction. The samples were then washed in distilled water and transferred into an acetone medium for grain size separation and disc preparation. The 4 – 11 μm size fraction was separated from the bulk sample suspended in 6 cm high acetone medium following Stokes' settling time of typically 1.5 minutes and 15 minutes. The separated grain size fraction was then dispersed in acetone and equal volumes of this suspension were pipetted onto small flat bottomed glass tubes, each containing an aluminium disc (9.6 mm diameter) at their bottom. After drying the solution in an oven at a temperature of ~ 45^{0}C, the discs containing thin layer of fine grains were taken out and transferred into sample holders. 50 – 60 discs from each sample were prepared.

5.4 OSL MEASUREMENTS

All measurements were carried out on TL/OSL reader (Daybreak 1150 Automated TL System). The instrument is equipped with OSL sources for photoluminescence measurement as well as heating arrangement to measure thermoluminescence. The samples under consideration were investigated by IRSL technique. The IRSL source is composed of 10 IR diodes connected in array emitting light at 880nm wavelength, delivering ~ 45 mW / cm^2 power at the sample position. Power supply to optical sources is controlled to stabilize the beam intensity. Source intensity fluctuation at the sample position is less than 1%. Sample position, heating control and optical excitation timings are controlled through inbuilt software interfaced with the computer. The sample luminescence is filtered using Schott BG – 39 and Corning 7 – 59 filter combination (detection window: 330 – 480 nm; Godfrey-Smith et al., 1996, in Krbetscek et al., 1997) in order to screen the scattered luminescence, mineral selectivity and to optimize signal to noise ratio. The filters are used before the photomultiplier tube. The photomultiplier tube (EMI 9235 QA) with an associated electronics for low-level photon counting is used for detection of IRSL emission. For beta irradiation, 'Daybreak-801 multiple sample irradiator' having $^{90}Sr/^{90}Y$ source of 100 millicurie strength delivering dose at the rate of 2.60 Gy/min for fine grained polymineralic samples was used.

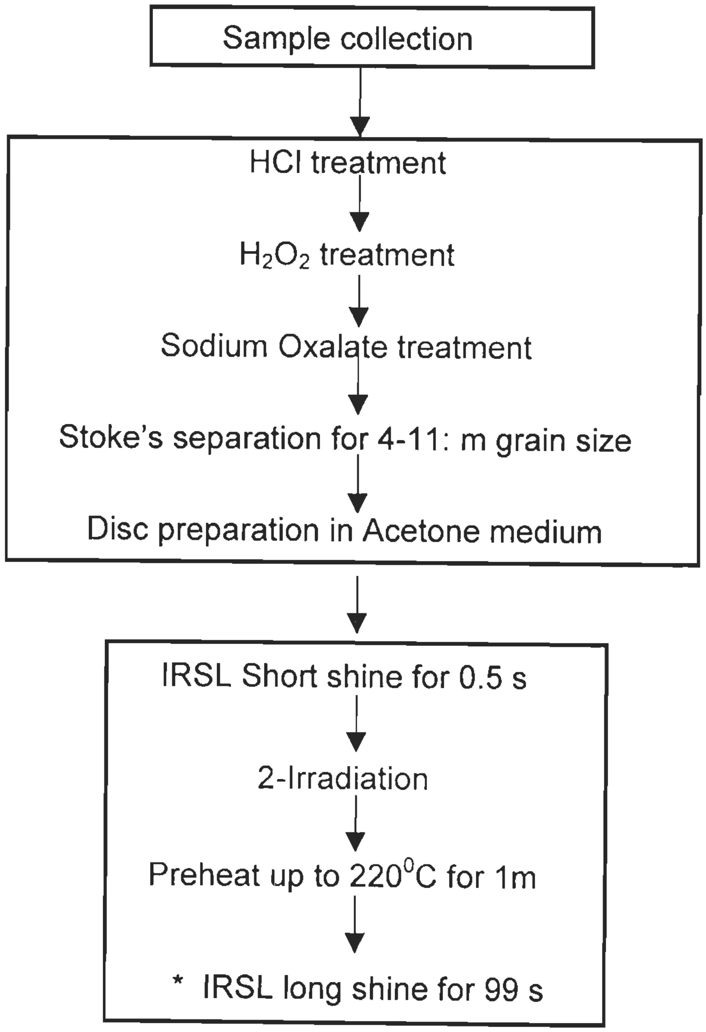
The experimental protocol for fine grain polymineralic aliquots through IRSL technique is designed following published protocols (Wintle, 1997; Aitken, 1998; Singhvi and Wintle, 1999). The protocol includes consideration of several factors as estimation of paleodose and dose rate. A flowchart of the experimental procedure is given in Table 5.2.

To remove / minimize the scattering in luminescence output and to avoid signals from unstable traps 'Normalization' and 'Preheating' techniques are adopted and are briefly described below.

5.4.1 Normalization

Different aliquots of the same sample can produce scatter in luminescence output. This scattering in luminescence arises because of the variation in the number of luminescence emitting grains in different aliquots or due to the variability in the luminescence properties of the grains (Franklin and Hornyak 1990; McFee and Tite, 1994). Thus, normalization between discs is required for all the analyses. Fresh discs were given infrared stimulation for 0.5 sec and the integrated IRSL counts over this time were used for normalization.

Table 5.2 Flowchart of the experimental procedure.



* Filters – BG-39; Corning 7-59

5.4.2 Preheating

Signals, in the case of geological samples, do not arise from traps with their mean lives less than the sample age as they get decayed out during this storage period. The signal arising from such traps is termed as unstable signal. However, under laboratory exposure the unstable signal remains intact, as such a long storage period is not admissible in laboratory practices. The unstable signal can, however, be removed by heating the material to an equivalent temperature for appropriate time. The procedure of thermal wash to remove unstable signal is sometime referred as preheating. Preheating of each disc at 220^0C for 60 seconds was done prior to each measurement to empty unstable traps that are existing or populated artificially during laboratory irradiations.

5.4.3 Paleodose Estimation

There are two approaches in estimating paleodose – the additive dose method and the regeneration method. Following the additive dose method, for constructing growth curve, 5 –6 'natural' aliquots and 4 sets of aliquots (each containing 4 discs) were irradiated to increase dose levels and their luminescences were measured. Then, the growth curve is extrapolated to read off the paleodose 'P' as the intercept on the dose axis. If the growth curve is linear – this method provides with good estimation. But when the growth curve is sub linear (as with older samples) it might provide erroneous measurement. In the regeneration method, a group of 'natural' OSL is measured and 4 – 5 sets of aliquots are bleached to zero level and artificially dosed to construct the growth curve. Then paleodose is read out through interpolation of natural luminescence. The advantage of this method over additive dose method is that uncertainties due to nonlinearity are reduced. But the major disadvantage is that there may be change in sensitivity between natural OSL and the regenerated OSL. Additive dose method is applied in the present study. The shine down curves (Figs. 5.2, 5.3) were taken for 99 seconds at room temperature. Curve fitting is used according to the luminescence output. To minimize the error in extrapolating the additive growth curves (Figs. 5.2, 5.3) for estimating the equivalent dose, doses were chosen in order to obtain at least a threefold increase in luminescence intensity to natural luminescence level. Equivalent dose plateau was constructed for each sample (Figs. 5.2, 5.3). Equivalent dose was estimated taking average of the ED's within the plateau region. All data reduction and analyses were done using standard TL APPLIC software (version 3.3).

5.4.4 Dose – Rate Estimation

Estimation of dose rate or annual dose requires measurement of the individual concentrations of radionuclides, ascertaining the status of their

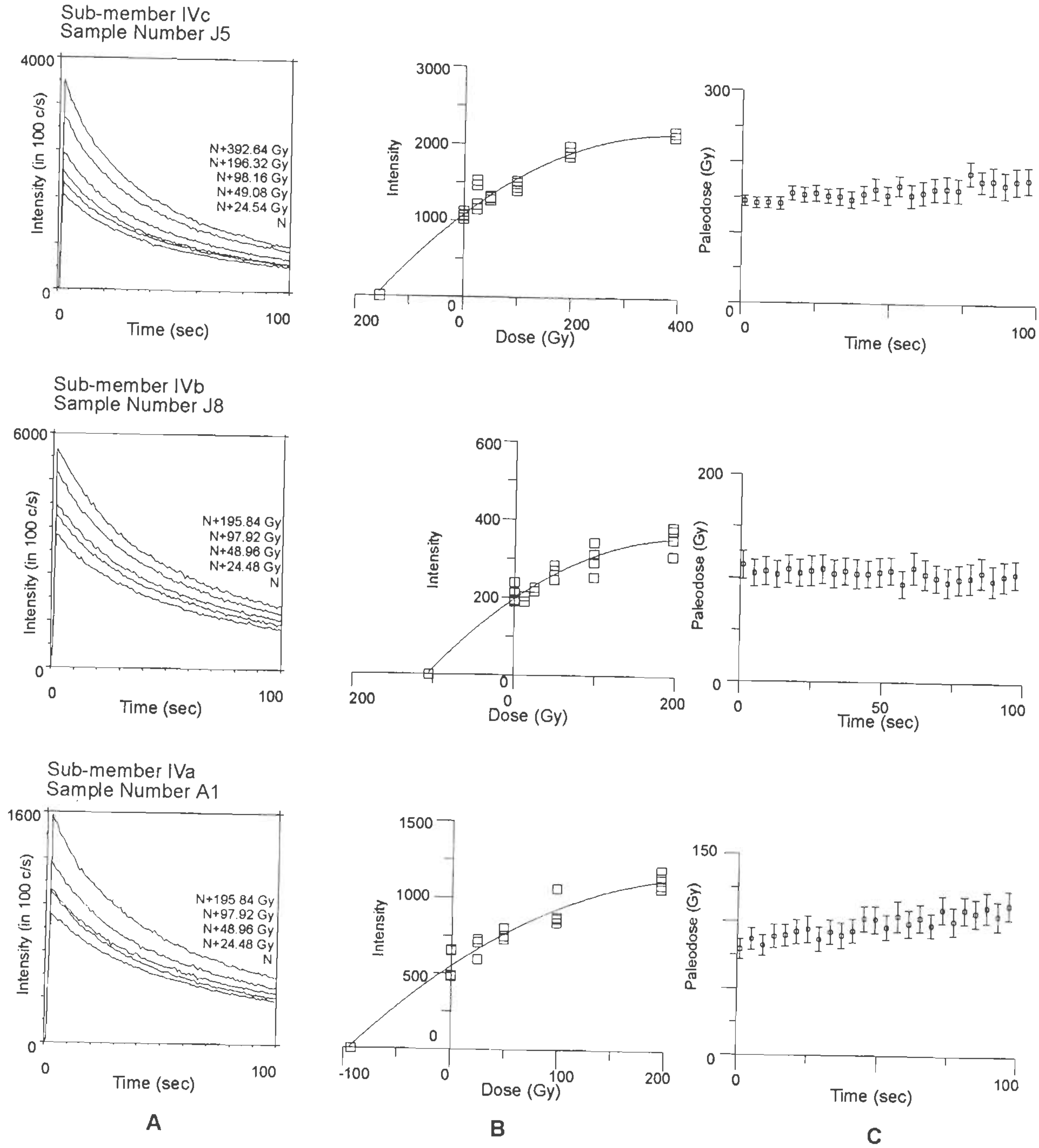


Fig. 5.2 (A) Typical IRSL shine down curves; (B) IRSL vs. dose growth curves; (C) Paleodose shine plateaus.

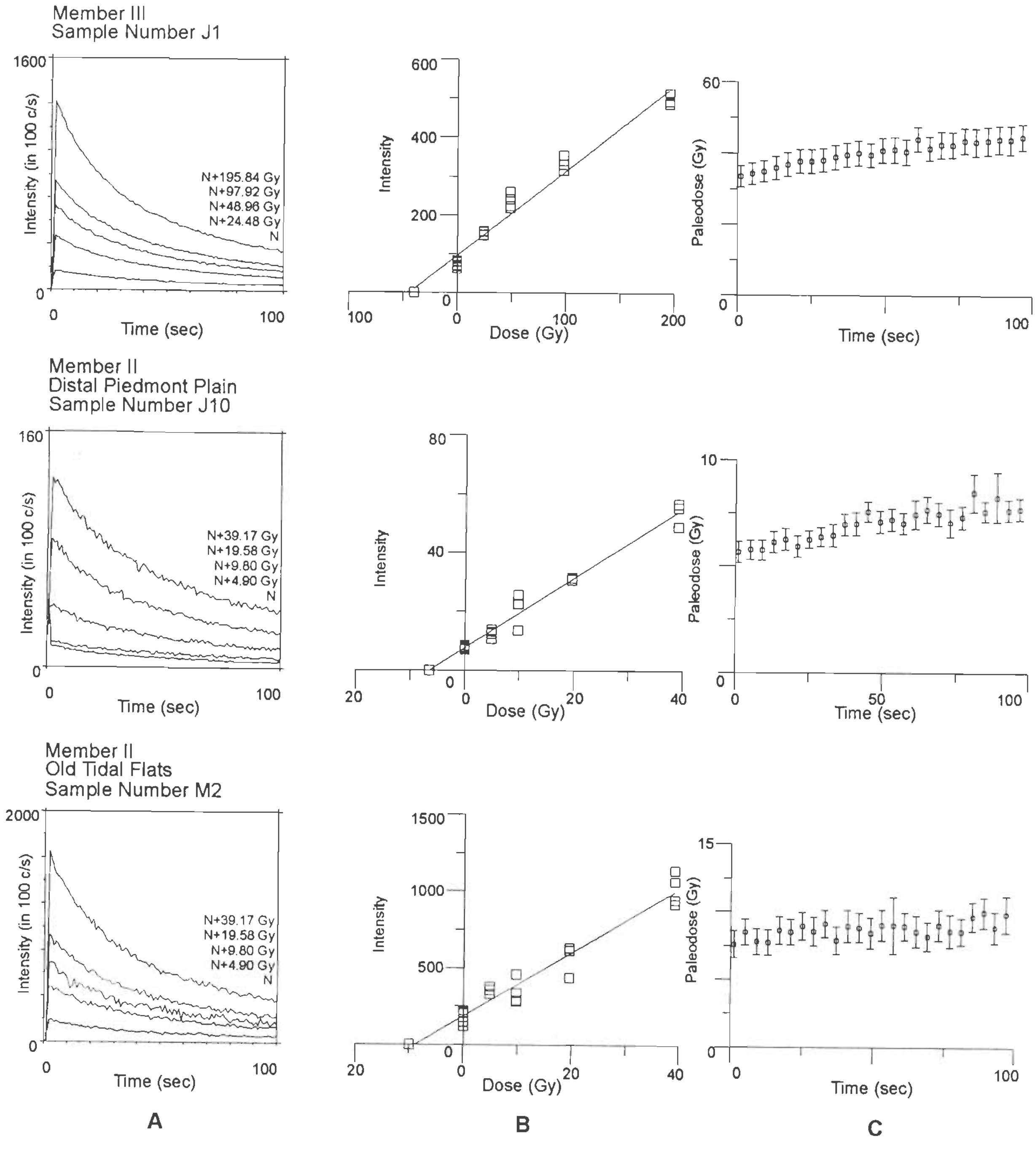


Fig. 5.3 (A) Typical IRSL shine down curves; (B) IRSL vs. dose growth curves; (C) Paleodose shine plateaus.

radioactive equilibrium and their alpha efficiency. The ^{238}U and ^{232}Th were measured using thick source alpha counter. The sample was crushed to about 10 μm grain size and then evenly spread in a thick layer on a ZnS (Ag) screen placed at the base of a circular perspex container. Equal counts were assumed for ^{238}U - ^{232}Th series and the series were also assumed to be in radioactive equilibrium. The intensity of alpha particle arising from samples depends on the concentration of ^{238}U and ^{232}Th as ^{40}K does not emit alpha particle. Each alpha particle reaching the zinc sulfide screen produces a flash of light, which is counted by a photomultiplier tube facing the base of the screen. Each flash is recorded as an alpha count. All the measurements were done using Daybreak 583 alpha counter. Background (BG) was measured before measuring each sample and BG counts were subtracted from the signal. For ^{40}K – estimation, 0.5 gm sample was taken, powdered and digested. ^{40}K contents of the samples were then estimated by ICP – AES (Induced Coupled Plasma – Atomic Emission Spectrometry) at the Institute Instrumentation Centre, Indian Institute of Technology Roorkee.

In addition to the estimation of radionuclides, moisture content of the samples was also calculated. Water attenuates the radiation flux effectively. Therefore, the samples receive less radiation / excitation from the radiation flux when they are wet as compared to dry condition. This measured moisture content is assumed to be constant during the burial period, though it is not the reality and this is a factor that causes some errors. Moisture content for dry and moist samples were taken as 10 ± 5% and 15 ± 5%, respectively.

Cosmic ray fluxes also contribute a minute fraction in the dose rate. Cosmic ray flux is latitude, altitude and depth dependent. Latitude and altitude variations can be accounted but the depth is time – varying function and hence an average depth is used for computation. Cosmic ray contribution to the dose rate was assumed as 150 ± 30 μGy/Ka.

The alpha efficiency factor 'a' is another important factor in calculating the dose rate for fine grains. The 'a' – value was calculated by comparing the luminescence induced by alpha irradiation to that induced by beta irradiation.

5.4.5 Age Estimation

Age estimation requires measurements of paleodose and dose-rate. Paleodoses of the samples were estimated using TL APPLIC software. To estimate the dose-rates, the concentrations of ^{238}U, ^{232}Th, ^{40}K and the a-value were calculated. Determining the above factors, the dose rate estimation and computation of the ages of the samples along with the errors were done using Grun soft ware for TL / OSL age calculation (Appendix III).

5.5 RESULTS

Samples have been collected and analyzed from the six soil-geomorphic units out of eight soil-geomorphic units identified in the area. Samples have not been analyzed from the River floodplains and Active tidal flats units, as active sedimentation and erosional processes are going on in these units. A total of sixteen samples have been dated. Table 5.3 provides the experimental data including paleodose, dose rate and age of the samples.

The following observations are made from the estimated dates:

1. The IRSL dates of different samples from the Jaldi and the Maiskhali structures are stratigraphically consistent.
2. All the samples showed an extended age plateau with the exception of M1, J3 and J7 samples. At higher time, the ED plateau showed marginal increase in trend. This might be because of contribution of IRSL derived from hard to bleach traps, which carry relict IRSL components, i.e. the last exposure before deposition not having been sufficient for complete zeroing of such traps.
3. In age calculations, all the samples show error ranging between 15 – 25% excluding 2 samples (J3 and J11), which show error up to 29%. When the errors in ED are counted, the samples show errors ranging between 5 – 25% (Fig. 5.4). The errors are, in general, higher in lower aged samples. For samples (excluding M1) with age more than about 2000 years, the errors in ED are in the range of 10-15%.

Table 5.3: Results of luminescence dating studies.

Morphostratigraphic sequence	Soil-geomorphic unit	Sample No.	Horizon	Depth (cm)	Elevation (m)	^{238}U conc. (ppm)	^{232}Th conc. (ppm)	^{40}K conc. (%)	Dose rate (μGy/a)	ED (Gy)	Age
Sub-Member IVc	Mainland Higher Hillocks	J5	C	85	10	4.097 ± 1.248	10.369 ± 4.865	1.636 ± 0.08	4402 ± 786	153.10 ± 11.29	34779 ± 6718
		J7	C	110	8	3.711 ± 1.156	8.251 ± 3.933	0.93 ± 0.05	3356 ± 666	101.18 ± 9.63	30145 ± 6633
Sub-Member IVb	Mainland Lower Hillocks	J3	C	130	12	2.805 ± 1.32	14.44 ± 5.012	1.372 ± 0.07	4115 ± 807	103.32 ± 19.43	25104 ± 6821
		J8	C	110	15	2.882 ± 1.349	15.154 ± 4.607	1.966 ± 0.10	4779 ± 803	111.10 ± 14.94	23250 ± 5003
Sub-Member IVa	Island Hillocks	M1	C	110	35	4.551 ±0.999	12.802 ±5.513	1.27 ±0.06	4504 ± 790	68.48 ±16.03	15207 ± 4447
		A1	C	100	45	2.043 ±1.253	19.733 ±5.234	2.14 ±0.11	5129 ± 837	91.10 ± 8.90	17760 ± 3377
Member III	Proximal Piedmont Plains	J1	C2	175	3	4.736 ± 0.915	27.713 ± 8.648	1.44 ± 0.07	6407 ± 1123	39.15 ± 3.33	6111 ± 1190
		J2	C	130	4	4.685 ± 1.291	7.769 ± 4.405	1.778 ± 0.09	4462 ± 764	35.12 ± 3.39	7871 ± 1546
		M3	C	110	3	4.415 ± 1.041	5.986 ± 3.518	1.476 ± 0.07	3881 ± 621	28.51 ± 2.81	7348 ± 1381
		M4	B2	90	3	3.605 ± 1.388	13.688 ± 4.762	1.348 ± 0.07	4318 ± 810	43.02 ±3.22	9961 ± 2011
		A2	BC	85	3	2.689 ±1.282	13.679 ±4.366	1.75 ±0.09	4337 ± 755	31.85 ±1.54	7344 ± 1326

Table 5.3: Results of luminescence dating studies (Contd.).

Morphostratigraphic sequence	Soil-geomorphic unit	Sample No.	Horizon	Depth (cm)	Elevation (m)	^{238}U conc. (ppm)	^{232}Th conc. (ppm)	^{40}K conc. (%)	Dose rate (µGy/a)	ED (Gy)	Age
Member II	Distal Piedmont Plains	J4	C	85	1.5	5.032 ± 0.185	15.632 ± 6.521	1.34 ± 0.07	5069 ± 814	6.19 ± 0.78	1221 ± 249
		J10	C	120	1.5	2.024 ± 0.694	9.736 ± 2.39	1.344 ± 0.07	3258 ± 438	6.55 ± 0.50	2010 ± 311
		J11	C	100	1.5	5.466 ± 1.036	10.193 ± 5.42	1.442 ± 0.07	4408 ± 747	5.11 ± 1.09	1160 ± 315
	Old Tidal Flats	J6	B1C	100	1.5	2.673 ± 1.11	20.20 ± 5.254	2.6 ± 0.13	5464 ± 784	2.64 ± 0.44	483 ± 105
		M2	Cg	100	1.5	5.513 ±1.202	10.831 ±5.022	2.4 ±0.12	5321 ± 779	8.74 ± 1.16	1642 ± 324

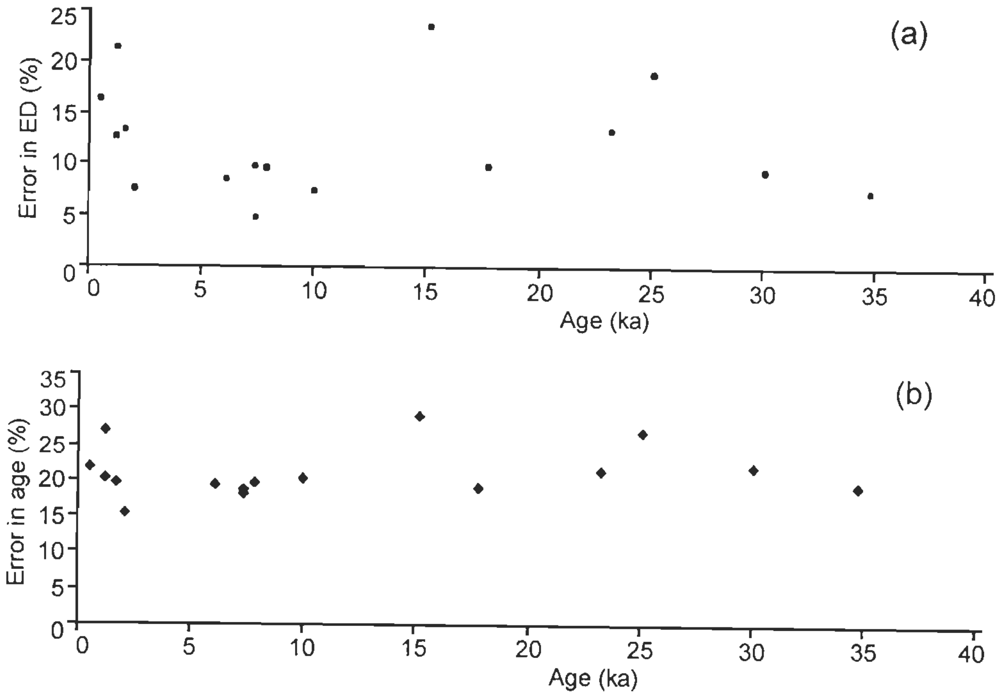


Fig. 5.4 Scattered points plot (a) age vs. error in ED and (b) age vs. error, in the samples analyzed through IRSL technique.

4. IRSL ages obtained for the soils of different soil-geomorphic units are: (i) Old tidal flats– 0.5 – 1.6 ka, (ii) Distal Piedmont Plains– 1 – 2 ka, (iii) Proximal Piedmont Plains– 6 – 10 ka, (iv) Island hillocks– 15 – 18 ka, (v) Mainland Lower hillocks– 23 – 25 ka, (v) Mainland Higher hillocks– 30 – 35 ka. It has been assumed that the age of River floodplains and Active tidal flats soils are less than 500 yrs. These ages helped to identify four members I to IV of Luminescence Morphostratigraphic Sequence with ages as <500 yr, 0.5 – 2 ka, 6 – 10 ka and >15 ka, respectively. Member IV is further divided into Sub-members IVa (15-18 ka), IVb (23-25 ka) and IVc (30-35 ka), as these represent distinctive events, as shown later.

5.6 RESUME

Correct stratigraphic order of the ages of terraces within individual areas suggest that IRSL dating technique is useful and ages of main soil-geomorphic units suggest that major geomorphic features in the area evolved during the Late Pleistocene to Holocene Period.

Chapter 6

PEDOGENIC PROCESSES AND CONTROLS ON DEVELOPMENT OF SOILS AND LANDFORM

6.1 INTRODUCTION

Limited studies of soil-geomorphic relationships of undulating areas are available (Gerrard, 1992) and those from undulating coastal regions are even less common (Moody and Graham, 1995). The undulating coastal region of Cox's Bazar, Bangladesh offers an excellent site for such studies. The study area includes a part of coastal region of north-south trending Fold Belt of Bangladesh, which is in turn a part of Arakan-Yoma Geoanticline / Indo-Burman Ranges, which were produced due to the collision between Indian and the Burmese continental plates. Collision started at about Eocene and the process is still continuing (Reimann, 1993). World wide Quaternary palaeoclimatic and sea level changes must have affected the region, as the area borders the coastline. The region is marked by tropical climate and characteristic pedogenic processes must be acting in this area. As soils represent episodes of land surface stability with little or no deposition (Catt, 1992) these can be used for inferring landscape evolution. Keeping these points in view, the present study was carried out with the following objectives:

(i) Delineation of different soil-geomorphological units using Landsat images, toposheets, available soil-resource maps, field checks and laboratory data.

(ii) To prepare a Morphostratigraphic Sequence based on Luminescence Dating of soils for the study area.

(iii) To elucidate the role of different pedogenic processes, neotectonic activities (folding) and Late Quaternary sea level fluctuations in the development of the soils and landscape of the area.

(iv) To find out the variation in the relative rate of uplift of the region due to folding during the Late Quaternary Period.

6.2 GENERAL FEATURES OF THE STUDY AREA

The study area, Jaldi and Maiskhali structures, constitute a part of Fold Belt of Bangladesh. The Jaldi structure lies on the main land and the Maiskhali island comprises the Maiskhali structure. The Jaldi and Maiskhali structures are box shaped anticlines trending N18^{0}W and N10^{0}W, respectively. The Sangu and Matamuhuri rivers mark the boundary of the Jaldi structure in north and south, respectively. These are the main streams in the area and debouch from the eastern hills and flow westward to reach the Bay of Bengal. Seasonal, ephemeral streams, and streamlets of consequent type and dendritic pattern are present in the hilly regions and small braided streams drain the Piedmont Plains. The area represents an undulating, irregular topography and comprises hills and valleys, piedmont plains, tidal flats and minor river flood plains. The highest elevation is about 110 m. The higher hillocks have an average elevation of 100 m and the lower hillocks have an average elevation of 30 – 40 m. The streams are entrenched in the hillocks and in the proximal portion of the Piedmont Plains.

The Maiskhali island is separated from the main land by the tidal Maiskhali channel. The eastern half of the island comprises the Maiskhali anticline and the western half is composed of narrow piedmont plains, tidal flats and beaches. Maximum elevation of Maiskhali hills is about 90 m with an average elevation of 60 – 65 m. The Maiskhali anticline is considered to be fault-bounded on all sides (Khan and Arefin, 1999). Incised streams of dendritic pattern mark the hillocks and the piedmont plains. The tidal flats and beaches are marked by small ephemeral, branching tidal and braided channels, respectively.

The investigated area is a zone of heavy rainfall and a small range of mean annual temperature. Four well-marked seasons i.e. pre-monsoon (summer), monsoon (rainy), post-monsoon and dry (winter) can be recognized. The temperature gradually rises from February and rapidly from

March onward till May. The temperature starts declining from June onwards and sharply from November onwards. The temperature rarely goes over 32^{0}C and below 13^{0}C. Rainfall is usually in the range of 280 cm to about 350 cm annually. There is an excess of rainfall over evaporation annually and particularly in the rainy season.

The distal parts of Piedmont Plains are occasionally flooded and the tidal flats and river flood plains are deeply flooded every year. The depth of ground water in the hill ranges is variable due to undulating topography. In the Piedmont Plains, tidal flats and river flood plains, the ground water is at a depth of about 50 m.

6.3 INVESTIGATION PROCEDURE

Topographic maps, Landsat TM images (bands 2, 3 & 4), available soil resource maps and field checks were used to delineate geomorphic units in the study area. As the soils on these geomorphic units were fairly uniform and their properties varied within a narrow range, these have been called soil-geomorphic units (Fig. 2.2).

Fieldwork was carried out along three traverses. A total of seventeen pedons were studied in order to cover these different soil-geomorphic units. Several other places were also checked through auguring to find out the continuity of the units. The depth/ thickness of different horizons and subhorizons of each pedon and their morphological characteristics were recorded in the field. Then bulk (disturbed) and in-situ (undisturbed) samples were collected from different horizons.

Out of 17 pedons studied in the field, 15 were selected for detailed laboratory investigations such as grain-size analysis, clay mineralogy, micromorphology and optically stimulated luminescence dating of soils. Soil samples were analysed for grain size distribution following the method of Galehouse (1971). Clay fraction (<2 μm) of the soil samples was used to find out the vertical and spatial distribution of clay minerals by X-ray diffraction analysis. Clay minerals were identified following the procedure described by

Wilson (1987) and their semi-quantitative estimation was done following the method of Klages and Hopper (1982).

In-situ (undisturbed) soil samples were collected in metal boxes for micromorphological studies. The samples were impregnated with crystic resin and large (60 X 40mm) thin-sections were prepared according to the procedure described by Jongerius and Heintzberger (1963) and Miedema et al. (1974). A total of 48 soil thin-sections were described in detail (Appendix II) following mostly the terminology of Bullock et al. (1985).

The ages of different soil-geomorphic units were determined by Infrared stimulated luminescence (IRSL) technique. For this purpose fine grain polymineralic aliquots were used using additive dose method following standard protocols (Wintle, 1997; Aitken, 1998; Singhvi and Wintle, 1999).

6.4 SOIL-GEOMORPHIC UNITS

Soil-geomorphic units identified in the area are: Top surfaces of Mainland Higher and Lower Hillocks (Jaldi Anticline), Top surfaces of Island Hillocks, Proximal and Distal Piedmont Plains, Old Tidal Flats, River Floodplains and Active Tidal Flats. Remote sensed (Landsat image) characters and physiography of the soil-geomorphic units are given in Table 2.1. Tops of hill surfaces are underlain by a few metres of flat-lying sediments overlying the Older Tertiary Formations unconformably and constitute strath terraces.

6.5 LUMINESCENCE MORPHOSTRATIGRAPHIC SEQUENCE OF THE STUDY AREA

In the present study, samples were collected from the C/BC horizons from the typical pedons of the different soil-geomorphic units and were dated by Infrared stimulated luminescence (IRSL) dating technique. The ages from the samples indicate the time of deposition (last burial episode) and approximate maximum ages of the soils. IRSL ages obtained for the soils of different soil-geomorphic units are: (i) Old tidal flats– 0.5 – 1.6 ka, (ii) Distal Piedmont Plains– 1 – 2 ka, (iii) Proximal Piedmont Plains– 6 – 10 ka,

(iv) Island Hillocks– 15 – 18 ka, (v) Mainland Lower Hillocks– 23 – 25 ka, (vi) Mainland Higher Hillocks– 30 – 35 ka. It has been assumed that the age of River floodplains and Active tidal flats soils are less than 500 yrs. These ages helped to identify four members I to IV of Luminescence Morphostratigraphy with ages as <500 yrs, 0.5 – 2 ka, 6 – 10 ka and >15 ka, respectively. Member IV is further divided into Sub-members IVa (15-18 ka), IVb (23-25 ka) and IVc (30-35 ka), as these Sub-members represent distinctive events, as shown later.

A landscape can be classified into three major zones based on slope and elevation: zone where material is being eroded (sloughing zone), zone where material is being deposited (accreting zones) and zone which is neither losing nor gaining materials (Gerrard, 1992) i.e. zone of pedogenesis. In the present study, the River floodplains and Active tidal flats in Member I are parts of 'accreting zone'. The Proximal Piedmont Plains with Member III soils form 'zone of pedogenesis'. The Distal Piedmont Plain and Old Tidal Flats are a couple of meters above the adjoining regime of deposition and receive sedimentation due to exceptional flooding of stream or tides and form a transitional zone between accreting zone and zone of pedogenesis. The Mainland Higher Hillocks, Mainland Lower Hillocks and Island Hillocks with Member IV soils belong to the 'sloughing zone'.

6.5.1 Variation in Soil Characteristics Among the Different Members of Morphostratigraphic Sequence

Some systematic changes in the morphological, physical, clay mineralogical and micromorphological characteristics of soils are observed among soils of the different Members. These changes are discussed below.

6.5.1.1 Soil morphology

A/C type of horizonation or a minor profile development is observed in Member I soils. Member II soils show a strong to moderate degree of ped development with a solum thickness of 65 – 120 cm and thickness of B-horizon is 45 – 95 cm. The soils of Members II and I have olive gray to gray coloured gleyed horizons, at some places, due to hydromorphic conditions caused by poor drainage. Member III soils show a relatively higher development in terms of solum (100 – 142 cm) and B-horizon thickness (60 – 118 cm) as compared to that of Member II soils, but the degree of ped development is less as compared to that of Member II soils. Ferro-manganese concretions are observed throughout the profiles in the Members II and III soils. Fe- oxide mottles are common in Members III – I soils.

Member IVb soils have the best development in terms of thickness of solum and B-horizons and degree of pedality among Member IV soils. The thicknesses of solum and B-horizon vary between 85 - >140 cm and 70 - >120 cm, respectively, with strong to moderate and medium to fine subangular blocky ped development in the B-horizons. Member IVa and IVc soils show a solum thickness of 70 -110 cm and the thickness of B-horizon is 50-80 cm, with common moderate and coarse to medium subangular blocky ped development in the B-horizons. Ferro-manganese concretions occur sporadically in Member IV soils.

On the basis of solum thickness, thickness of B-horizon and degree of pedality in the B-horizon soils the degree of soil development in the different members of the Morphostratigraphic sequence are ranked in the order: Sub-member IVb and Member II > Sub-member IVc > Sub-member IVa > Member III > Member I (Fig. 6.1).

According to Soil Survey Staff (1992) classification most soils of the Member I are Typic Fluvaquents, Typic Haplaquents, Typic Psammaquents and Typic Haplaquepts. Members II and III soils are mostly Typic Haplaquepts. Sub-member IVa soils are, in general, Typic Dystrochrepts. Typic Hapludults and Typic Dystrochrepts mark the Sub-member IVb. Soils of Sub-member IVc are mostly Dystric Eutrochrepts – Typic Dystrochrepts.

6.5.1.2 Textural variation

Member I soils have not been taken into account for any laboratory analysis as they are very weakly or not pedogenised at all and strong active

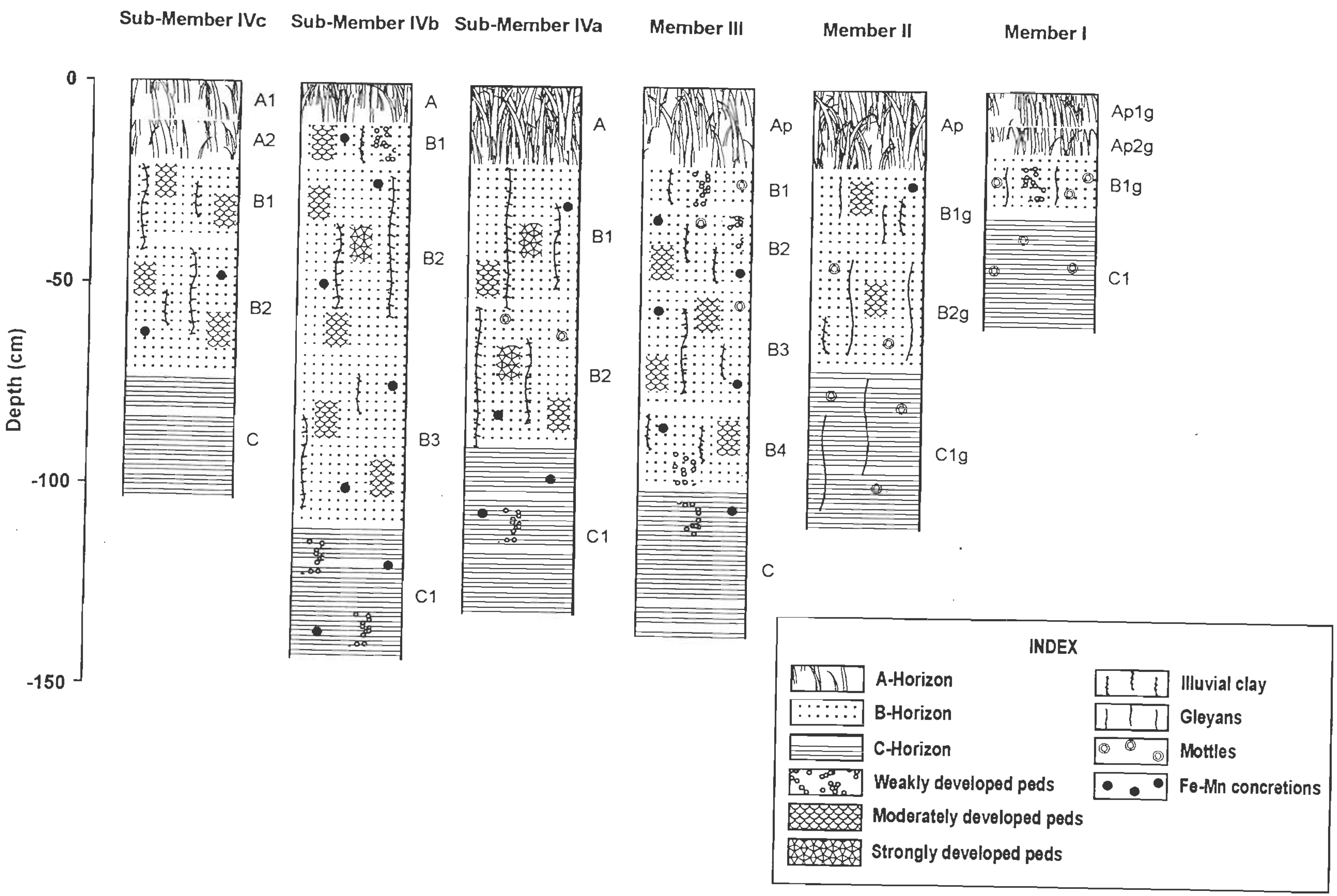


Fig. 6.1 Morphological features of the Member I to Member IV soils of the Morphostratigraphic Sequence of the area.

sedimentation processes are going on in the units of the member. Grain size analysis of soils of different members exhibits a wide variety of textures ranging from sand, sandy loam, silty clay loam to clay.

Increase of clay content in the B-horizon over A or C-horizon is taken as pedogenic clay, which is attributed to the translocation of clays from the upper to the lower horizons. Degree of translocation was determined by calculating Clay Accumulation Index (CAI) after Levine and Ciolkosz (1983).

Within Member IV soils Sub-member IVb soils show the highest clay accumulation index i.e. 827-1500 as compared to IVa (350) and IVb (220) Sub-member soils. Member III soils have an indeed of 180-130. The Distal Piedmont Plain and Old Tidal flat soils of Member II show surprisingly high CAI values (1100-1300). There is no pedogenic clay in Member I soils. The pedogenic clay distribution is systematic and follows the field observations of soil development.

6.5.1.3 Clay mineralogy

The major clay minerals of the soils of the study area are illite, kaolinite, vermiculite and chlorite with traces of smectite, illite-vermiculite, illite-smectite and kaolinite-smectite. Illite is the most dominant clay mineral in all the members of Morphostratigraphic Sequence. Next in abundance is kaolinite. All the soils have a higher kaolinite content as compared older sedimentary rocks (< 15%) (Hossain et al., 1999) exposed in the area (Bokabil, Tipam and Dupi Tila formations, Mid Pliocene to Late Quaternary age), but no significant pattern in occurrence of clay minerals with differences in age is observed in various soils. Kaolinite concentration is higher at Ap-horizons in all the soils of the Members II and III. This might be due to anthropogenic activities related to intense cultivation on these soils. Repeated flooding during rice cultivation probably leads to illuviation of finer sized clay (and other) minerals to lower horizons, leading to higher concentration of kaolinite in the Ap horizon. Illite and kaolinite contents generally exhibit antipathetic relationship in Members III- IV. Kaolinite abundance in soils of the present area is much higher than soils of the Upper and Middle Gangetic Plains.

Clay mineralogy of Bokabil, Tipam and Dupi Tila formations has been studied by Hossain et al. (1999) and these formations contain significant amounts of kaolinite (<15%). As at present only West Bengal soils in the Lower Gangetic Plains with hot humid climate contain similar amounts of kaolinite (Singh et al., 1998) and Middle and Upper Gangetic soils with subhumid to semiarid climate show only minor amounts of kaolinite (Mohindra and Parkash, 1990; Srivastava et al., 1998). Thus up to about 15% of kaolinite in Middle Miocene to Pleistocene formations suggest probably an overall hot humid climate prevailed in the present area during this period.

Micromorphological observations of alteration of biotite and feldspars and the presence of Illite-vermiculite Illite-smectite Kaolinite-smectite mixed layer minerals, well developed soils and significant amounts of kaolinite (18-25%) and antipathetic relationship of illite and kaolinite in the Member IV soils suggest that a significant amount of kaolinite has formed due to mineral transformation. Similar criteria suggest minor neoformation of kaolinite in Member III soils. The tentative scheme of clay mineral transformations in the soils might be: Biotite → Chlorite or Illite-vermiculite → Vermiculite → Kaolinite and K-feldspar → Illite → Illite-smectite → Kaolinite-smectite → Kaolinite.

The clay mineral distribution in younger Members II and I soils is very similar to soils of Members III and IV. As soils are weakly developed and mineral alteration is negligible in these members, high percentage of kaolinite in these soils probably reflect the clay mineral composition of parent materials, which were in turn derived from erosion of members III and IV soils and the older formations of Dupi Tila, Tipam and Bokabil.

Thus the clay mineral composition of the older soils (Members III and IV, > 6 ka) is controlled by mineral transformation. Clay mineral composition of the younger soils (Members I and II, < 2 ka) reflects essentially clay mineral composition of the parent material, which in turn is determined by clay mineral composition of the provenance.

6.5.1.4 Micromorphology

Micromorphological studies revealed distinct variations in the features such as grade of pedality, degree of alteration of minerals, development of cutans, smoothness / roughness of void surfaces, development of b-fabrics and formation of concretions and mottles in soils of different members of Morphostratigraphic sequence. A summary of the micromorphological characteristics of the B-horizon soils from different members of the Morphostratigraphic sequence is given in Table 6.1.

The grade of pedality is variable in the soils of different morphostratigraphic members. Field observations showed that Member I soils show weak or rarely any development. Member II soils show moderate to strong subangular ped development and the degree of pedality is higher to that of Member III soils. Among the Member IV soils, Sub-member IVb has a higher degree of pedality as compared IVc and IVa Sub-member soils.

Member II and I soils show no alteration or very feeble alteration of minerals (feldspars and biotites). Weak alterations of minerals are observed in the soils of Member III. Degree of alteration of minerals is strong in the Member IV soils. The thickness and abundances of argillan and ferriargillan coatings of Member II soils (50 – 300 μm thick) are greater than Member III – IV soils (30 – 200 μm thick).

The finer fraction of the soil materials shows mosaic- and stipple-speckled, parallel-, cross- and random- striated, and undifferentiated b-fabrics. Mosaic- speckled and undifferentiated b-fabrics are dominant in the Member IV soils, whereas parallel-, cross- and random- striated and stipple-speckled b-fabrics are common in the Member III and II soils. The degree of development and abundances of b-fabrics are similar in the different sub-members of Member IV soils, whereas Member III and II soils show relatively strong development of b-fabrics compared to Member IV soils. Ferro-manganese concretions and mottles are very common in Member III and II soils. Member IV soils show only a few ferro-manganese concretions and mottles. However, in these soils micromass is invariably impregnated with yellowish brown (Goethite) and reddish brown (Hematite) iron oxides.

Table 6.1 : Summary of micromorphological characters of B-horizons from different Morphostratigraphic members / sub-members.

Morphostratigraphic members, Soil-Geomorphic Units, Profile No.(s)	Pedality	Type of voids and void surfaces	C/f ratio and c/f related distribution	Cutans	Development of b-fabrics	Degree of alteration of minerals	Concretion and mottles
Sub-Member IVc Mainland Higher Hillocks J5 & J7	Moderate, subangular blocky peds	Subrounded, channel, irregular and vughy voids; smooth to undulating	10:90 to 20:80; porphyric	Argillan and ferriargillan hypo-coating (30-200μm thick)	Common moderate development of Mosaic- and stipple speckled and undifferentiated with weak cross-, parallel- and random striated	Pellicular alteration of feldspars and biotites and parallel linear alteration of biotites	Sporadic moderately to strongly impregnated Fe-Mn oxide nodule and Fe-oxide mottles
Sub-Member IVb Mainland Lower Hillocks J3, J8 & J9	Strong to moderate, subangular blocky peds	Subrounded, channel, planar irregular and vughy voids; undulating	2:98 to 25:75; porphyric	Argillan and ferriargillan hypo- and quasi-coatings (30-200 μm thick)	Common moderate development of Mosaic- and stipple speckled and undifferentiated with weak cross-, parallel- and random striated	Pellicular, parallel, cross and irregular linear alteration of feldspars and biotites	Sporadic weakly to strongly impregnated, orthic Fe-Mn oxide nodule and Fe-oxide mottles
Sub-Member IVa Island Hillocks M1	Moderate, subangular blocky peds	Subrounded, channel, irregular and vughy voids; smooth to undulating	10:90 to 20:80; porphyric	Argillan and ferriargillan hypo-coating (30-100μm thick)	Common moderate development of Mosaic- and stipple speckled and undifferentiated with weak cross-, parallel- and random striated	Pellicular alteration of feldspars and biotites and parallel linear alteration of biotites	Sporadic moderately to strongly impregnated Fe-Mn oxide nodule and Fe-oxide mottles

Table 6.1 : Summary of micromorphological characters of B-horizons from different Morphostratigraphic members / sub-members (Contd.).

Morphostratigraphic members, Soil-Geomorphic Units, Profile No.(s)	Pedality	Type of voids and void surfaces	C/f ratio and c/f related distribution	Cutans	Development of b-fabrics	Degree of alteration of minerals	Concretion and mottles
Member III **Proximal Piedmont Plains** J1, J2, M3 & M4	Weak, subangular blocky peds	Subrounded, channel, irregular and vughy voids; rough to smooth	10:90 to 30:70; porphyric	Argillan and ferriargillan hypo-coating (50-200μm thick)	Moderate development of cross-, parallel- and random striated and porostriated b-fabrics	Weak Pellicular alteration of feldspars and biotites and parallel linear alteration of biotites	Weakly, Moderately to strongly impregnated, orthic (few) Fe-Mn oxide nodule and Fe-oxide mottles
Member II **Distal Piedmont Plains** J4. J10 & J11	Weak to moderate, subangular blocky peds	Subrounded, channel, planar and vughy voids; smooth to undulating	2:98 to 20:80; porphyric	Argillan and ferriargillan hypo-coating (50-300μm thick)	Moderate development of cross-, parallel- and random striated and porostriated b-fabrics	Very weak linear alteration or no alteration of feldspars and pellicular alteration of biotites	Moderately to strongly impregnated Fe-Mn oxide nodule and Fe-oxide mottles
Member II **Old Tidal Flats** J6 & M2	Moderate to strong, subangular blocky peds	Channels, planar, subrounded and irregular voids; undulating to smooth	2:98 to 10:90; porphyric	Argillan and ferriargillan hypo- and quasi-coatings (50-300 μm thick)	Moderate development of cross-, parallel-striated and porostriated b-fabrics	No alteration or very weak pellicular alteration of feldspars and biotites	Weakly to moderately impregnated, orthic Fe-Mn oxide nodule and Fe-oxide mottles

6.6 DEVELOPMENT OF LANDFORMS AND SOILS – DISCUSSION

6.6.1 Pedogenic Processes

Duchaufour (1982) described three phases of weathering / pedogenesis in hot, humid climates characterised by increasing magnitude of alteration of primary minerals, loss of combined silica and an increasing amount of neoformed clay minerals. With increasing intensity of weathering, the phases are: (i) Fersiallitisation phase is characterized by partially inherited and partially neoformed clays with a dominance of 2:1 clays and a Bt-horizon. Free iron oxides are formed and soils may be rubified. (ii) Ferrugination phase is characteristic of more neoformed 1:1 clays than 2:1 clays, exchange capacity between 16 – 25 mEq/ 100 g clay, silt: clay ratio >0.2, moderate clay illuviation, and incomplete weathering of feldspars and micas. Two subphases – ferruginous soils and ferrisols – are distinguished on the basis of absence or presence of a distinct horizon containing large amount of red, dehydrated ferric iron, respectively. (iii) Ferrallitisation phase marked by complete weathering of primary minerals (except quartz), abundant 1:1 neoformed clays, frequent occurrence of gibbsite / hematite, silt: clay ratio < 0.2, exchange capacity less than 16 mEq/ 100 g clay, and negligible clay illuviation.

Important pedogenic processes responsible for the formation of the soils of the area can be explained in terms of phases of weathering (Duchaufour, 1982) along with palaeoclimatic implications, as discussed below.

Integration of field and laboratory data indicates that the soils of the study area can be broadly divided into three groups: (a) Poorly developed Member I soils, (b) Moderately developed Members II and III soils and (c) Strongly developed Member IV soils and their formation by distinctive pedogenic processes are discussed below.

(a) Poorly developed soils (Member I)

These are the least developed soils in the area showing A/C horizonation or only minor development of B-horizons. Active sedimentation is going on in these units. Biotite and muscovite minerals are almost fresh. Hydromorphism is going on indicated by diffused mottling.

(b) Moderately developed soils (Members II and III)

The Member III soils developed during the whole Holocene period, whereas the Member II soils developed during the Late Holocene period. These soils developed under an overall hot humid to subhumid climate prevailing in the area.

Member III soils have a better development in terms of solum and B-horizon thickness as compared to those of Member II soils. But the degree of pedality in the soils of Member III is lesser than that of Member II. Pedogenic clay content is higher in the Member II soils. Argillan and ferriargillan coatings are thicker and more abundant in Member II soils relative to those of Member III soils. The coatings in the Member II soils also include gleyans. Due to fine grained nature of gleyans, it is difficult to differentiate them from argillans in some cases even under a microscope. Hydromorphism is active in these units as indicated by Fe-Mn oxide concretions and Fe-oxide mottles. Weak to very weak alteration of minerals are observed in the soils of both the members with a relatively stronger alteration in the Member III soils. Clay mineralogy of the Members III and II soils are similar to that of Member IV soils. But, as soils are moderately developed and mineral alteration is negligible in these members, the clay mineral composition is dominantly inherited from the parent material derived from erosion of Member IV soils and rocks exposed in the Hills with minor neoformation of clays in the member III soils. The weak alteration of minerals and dominance of 2:1 clays and considerable amount of free iron oxide in the form of Fe-Mn oxide concretions and Fe-oxide mottles suggest that the soils of Member III and II are at the initial stage of weathering i.e. in the fersiallitisation stage of weathering / pedogenesis (Duchaufour, 1982).

(c) Strongly developed soils (Member IV)

Strong alteration of minerals, the yellowish brown to reddish brown colour of the micromass, dominance of 2:1 and 1:1 clays (illite and kaolinite) suggest that these soils have undergone a ferrugination stage of weathering / pedogenesis (Duchaufour, 1982).

Soils of Member IV exhibit degradation of argillans and ferriargillans marked by poor birefringence, indicating a significant change in conditions of pedogenesis. The presence of a few orthic Fe-Mn oxide concretions and diffused Fe-oxide mottles suggest their recent formation and general 'relict' nature of these soils.

6.6.2 Role of Parent Materials and Physiography

Member III and I soils form the zone of pedogenesis and accretion, respectively, and the Member II soils represent the area between the two and receive fine sediments due to exceptional flooding or tidal surges. Field morphology including pedality, micromorphological features as cutans and amount of pedogenic clay in B-horizons suggest Member II soils show a higher degree of development as compared to Member III soils. Addition of fines during the pedogenesis leads to development of cumulative profiles with overthickened A-horizons and higher content of fines in the B-horizon in some cases (Birkeland, 1984, p. 184). The thickness of A-horizons in Member II soils is comparable to those in the Member III soils, so this factor is insignificant. Probably very fine nature of the parent material (clay) in Member II soils gives it higher soil development as compared to the older Member III soils with a coarser parent material.

Among the Member IV soils, IVb has the best development in terms of solum, pedality in the B-horizons and pedogenic clay content. Sub-members IVa and IVc soils are from the narrow tops of the highest hillocks of the area, whereas IVb soils are from relatively broader and lower altitude hillocks (Mainland Lower Hillocks). Lower soil development of IVa and IVc Sub-member soils is probably due to their representing the top element of catena and being marked by lateral movement of eluviated materials, whereas similar process is probably acting only in a minor way on the Mainland Lower Hillocks, giving their soils higher degree of development.

6.6.3 Role of Sea Level Changes

The sea level curve during the Quaternary for the region is yet to be established. Here results of Chappell (1994) and Shackleton (1987) regarding eustatic sea level changes and geomorphological evolution of the region are correlated.

Chappell's (1994) work shows that during the Late Pleistocene (~ 40 ka to 18 ka) sea level fluctuated several times with some stillstands. During 35 ka – 30 ka and 23 ka – 20 ka, the eustatic sea level was stationary at about 85 m and 108 m below the present mean sea level. The sea level continued its downward trend till the Last Glacial Maximum (LGM), when the eustatic sea level was about 120 m below the present mean sea level and the coastline was some hundreds of kilometres southward from the present coastline. After the LGM with the onset of humid monsoon climate, the sea level started rising and the coastline of Bay of Bengal started shifting northward. During 7 – 6 ka, sea transgressed (Banerjee and Sen, 1987) and sea level rose to 6 – 10 m above present sea level (Merh, 1992). Tarafder and Monsur (1999) reported two drops of Holocene sea level around 2.3 and 1 ka.

Eustatic stillstands at 35 – 30 ka and 23 – 20 ka, may have affected the palaeodrainage in the study area, made streams to migrate laterally and to form fluvial terraces of Mainland Higher Hillocks and Lower Hillocks (Jaldi anticline). The age of the Mainland Lower Hillock terrace is a little higher than the corresponding eustatic stillstand. This may be due to the fact that timing of stationary sea level in the study area may be slightly different from that in the eustatic curve. These phases saw the deposition of the parent materials for the soils of the Sub-members IVb and IVc.

The LGM (18 – 15 ka probably) was probably marked by local stillstand of sea and was responsible formation of Island Hillock terrace (Maiskhali island). Between the lowering and rise of sea level before and after LGM, the presence of a stillstand at LGM is highly probable. Deposition of Piedmont zone started at 10 ka and it peaked at 7 ka that coincided with a major transgression in the area. Later a regression at about 1.5-2.0 ka led to the formation of Old Tidal Flats, similar to a regression observed by Tarafdar and Monsur (1999) in nearby Kutubdia island.

6.6.4 Role of Tectonics

The tectonics of the investigated Jaldi and Maiskhali structures is tied with the development of the Arakan-Yoma Geoanticline or Indo-Burman Ranges, which came into existence due to collision of Indian plate with Burmese plate by the middle Eocene (Curray et al., 1979; Mitchell, 1981; Reimann, 1981; Rangarao, 1983). These movements compressed Neogene sediments into linear elongated (N-S trending) folds (Bender, 1983; Reimann, 1993). The intensity and amplitude of folding is highest in the east and decrease westwards. This neotectonic activity is still continuing, affecting the structure and geomorphology of the area.

Calculation of uplift rates from ages of and heights of terraces / surfaces for the present area is beset with the major problem of fluctuating eustatic sea level during the Quaternary Period. When the sea level falling (e.g. 35 – 18 ka), any such calculated rate of uplift will be higher than the actual rate of uplift. Similarly such calculated rate of uplift for the period of 18 ka – present marked by a general rise of sea level, will be on the lower than the actual one. Also, it is realised that the study area is subjected to folding and it is causing uplift of anticlinal regions (hillocks) and subsidence of synclinal regions (valleys) and subsidence in synclines is difficult to account for in these calculations. So, the calculated uplift rates are only tentative in nature.

The uplift rate as estimated from the samples of the Maiskhali structure during the period between 18 ka up to 8 ka is about 4.5 mm/yr (Fig. 6.2) and afterwards (8ka –present) the rate of uplift is retarded to about 0.37 mm/yr. The over all uplift rate (18 ka – present) is 2.43 mm/yr. Assuming that the material overlying the nose is the same as that overlying the crest of the Jaldi anticline, the dated samples from the nose of the anticline can be used to calculate the rate of the anticlinal uplift, which comes as 7.9 mm/yr during the period 35 – 25 ka. The relative uplift rate for the Mainland Lower Hillock (Jaldi structure) is calculated as 1.5 mm/yr for the period 25 ka – present. The

Maiskhali structure is separated from the Mainland by a N-S trending fault and that block uplifted at a higher rate as compared to the Mainland during the period 18 – 8 ka.

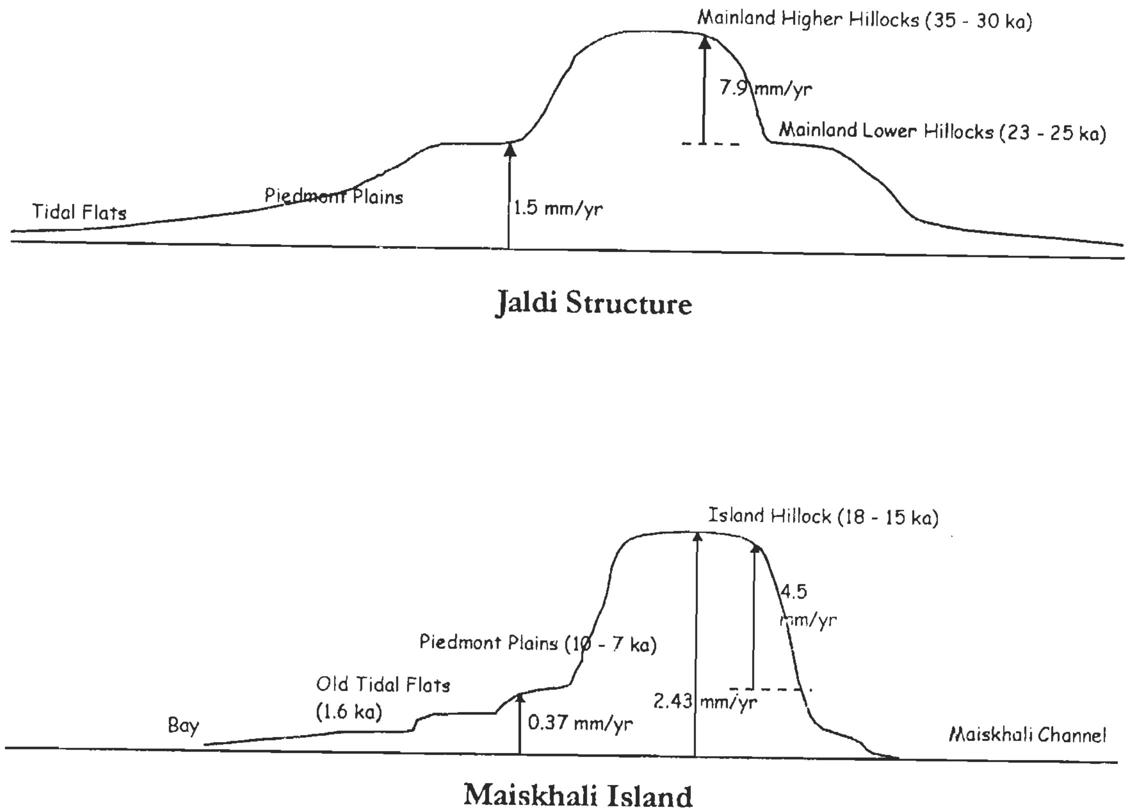


Fig. 6.2 Schematic diagram representing tentative rates of uplift of terraces in the region.

6.6.5 Role of Palaeoclimatic Changes

The Late Quaternary Period has been marked by varied climates. The temperature pattern over northern Tibet may be the key driving force of the southwest monsoon, which in turn affects the climate over the Indian subcontinent (Rangarajan and Sant, 2000; Sirocko et al., 1993; Sirocko, 1996). A warm and humid climate was prevailing around 40 ka (Vishnu-mittra and Sharma, 1984) and seems to have continued till 30 ka. A stable arid climate and weaker southwest monsoon were prevailing in the region during the late glacial period up to around 19 ka. From 19 ka to 16.5 ka, temperature increased in the Tibetan Plateau (Rangarajan and Sant, 2000) and there was an abrupt increase in the southwest monsoon and precipitation between 16.5 ka to 13.5 ka that favoured an increased humidity on land. A decrease in temperature in Tibet during the 13.5 ka – 10 ka resulted in the weaker monsoon and relatively a more arid phase (Sirocko et al., 1993; Sirocko, 1996; Rangarajan and Sant, 2000). During Early and Middle Holocene between 10 ka to 3.4 ka, the climate was in a moist phase and southwest monsoon strengthened again. Since 3.4 ka, a more arid climate as compared to Middle Holocene has been prevailing, but locally it also shows moist phases in the region. Thus climate fluctuated from subhumid to semiarid from about 40 ka to about 16.5 ka. Since 16.5 ka, climate has varied between hot humid to sub-humid with small periods of aridity.

The thick argillans and ferriargillans present in Member IV soils, characteristics of subhumid to semiarid phase, were probably formed during the subhumid to semiarid phase. The presence of few orthic Fe-Mn oxide concretions and diffused Fe-oxide mottles indicate their probable formation during the later hot humid to subhumid Phase. This humid phase caused degradation of argillans and ferriargillans and their poor birefringence in Member IV soils.

6.7 CONCLUSIONS

Major conclusions are:

(1) Eight soil-geomorphic units were recognised and grouped into four morphostratigraphic members (Member I to Member IV, Member IV divided into Sub-members – IVa, IVb, IVc; with Sub-member IVc being the oldest).

(2) The ages of different members of Morphostratigraphic sequence are Member I: <500yrs; Member II: 0.5 – 2 ka; Member III: 6 – 10 ka; Sub-member IVa: 15 – 18 ka; Sub-member IVb: 23 – 25 ka and Sub-member IVc: 30 – 35 ka.

(3) Sea level has fluctuated several times with some stillstands during the Late Pleistocene and Holocene Period. These stillstands produced five terraces in the region – the top surfaces of Mainland Higher and Mainland Lower Hillocks in the Jaldi anticline; the top of the Island

Hillocks, the surfaces of the Piedmont Plains and the Old tidal flats in the Maiskhali island.

(4) The soils formed during the Late Pleistocene Period (Member IV) show strong weathering of ferrugination stage. The soils developed in the Holocene Period (Members III and II) showed a fersiallitisation stage of weathering. The younger soils (Member I) have been affected by hydromorphism.

(5) The Maiskhali structure has been uplifted as a structural block during 18 – 8 ka with a tentative rate of uplift of about 4.5 mm/yr and afterwards (8ka –present) the rate of uplift is retarded to about 0.37 mm/yr with an over all uplift rate of about 2.43 mm/yr. The tentative uplift rate for the Mainland Higher Hillocks (Jaldi structure) is about 7.9 mm/yr during the period 35 – 25 ka and the uplift rate for the Mainland Lower Hillocks (Jaldi structure) is calculated as 1.5 mm/yr for the period 25 ka – present.

(6) Pedogenesis of the soils of the area has been controlled mainly by the duration (time), parent material composition, climatic variation, geomorphology of the area, neotectonic activity (folding) and fluctuating sea level with stillstands.

REFERENCES

Ahmed, S. T., 1968. *Cenozoic Fauna of the Cox's Bazar Coastal Cliff.* Unpubl. M. Sc. Thesis, Univ. of Dhaka, Dhaka, 68pp.

Aitken, M. J., 1998. *An introduction to optical dating.* Oxford University Press, Oxford, 267pp.

Alam, M., 1972. Tectonic classification of Bengal Basin. *Geol. Soc. Am. Bull.*, 83, 519 – 522.

Alam, M., 1989. Geology and depositional history of Cenozoic sediments of the Bengal Basin of Bangladesh. *Palaeogeogr. Palaeoclim. Palaeoecol.*, 69, 125 – 139.

Alam, M., 1997. Bangladesh. In: Moores, E. M., and Fairbridge, R. W. (Eds.), *Encyclopedia of European and Asian Regional Geology.* Chapman and Hall, London, 64 – 72.

Alam, M. S., 1998. Palaeoclimatic impact on the flood basin accretion and palaeosol development in northwestern Bangladesh. *Journal of Nepal Geological Society*, 18, 227 – 238.

Alam, M., Alam, M. M., Curray, J. R., Chowdhury, M. L. R. and Gani, M. R., 2003. An overview of the sedimentary geology of the Bengal Basin in relation to the regional tectonic framework and basin-fill history. *Sedimentary Geology,* 155, 179 – 208.

Anandaraj, N. and Seralathan, P., 2002. Geochemical characteristics of the sediments of Kavaratti coral island, Lakshadweep, India. *National seminar on Coastal and Off-shore sedimentary basins and their resource potential,* Abstract, Visakhapatnam.

Bakhtine, M. I., 1966. Major Tectonic features of Pakistan. *Part II: Eastern province; Science and Industries*, 4 (2), 1 – 15.

Bakr, A. 1977. Quaternary geomorphic evolution of the Brahmanbaria-Noakhali area, Comilla and Noakhali Districts, Bangladesh. *Records of Geological Survey of Bangladesh.* 1(2). 48pp,Dhaka.

Banerjee, B. K., 1984. Post – Eocene biofacies, Palaeoenvironments and palaeogeography of the Bengal Basin, India. *Palaeogeogr. Palaeoclim. Palaeoecol.*, 45 (2), 49 – 74.

Banerjee, M. and Sen, P. K., 1987. Palaeobiology in understanding the change of sea level and coastline in Bengal Basin during Holocene period. *Ind. Jour. Earth Sci.*, 14(3-4), 307 – 320.

Bender, F., 1983. *Geology of Burma.* Beitraege zur Regionalen Geologie der Erde, Gebruder Borntraeger, Berlin – Stuttgart, 293pp.

Bhattacharya, A. and Banerjee, S. N., 1979. Quaternary geology and geomorphology of the Ajay-Bhagirathi Valley, Birbhum and Murshidabad District, West Bengal. *Ind. Jour. Earth Sci.*, 6 (1), 91 – 102.

Birkeland, P. W., 1984. *Soils and Geomorphology.* Oxford Univ. Press, New York, 372pp.

Biscaye, P. E., 1965. Mineralogy and sedimentation of Recent deep sea clay in the Atlantic ocean and adjoining seas and oceans. *Geol. Soc. Am. Bull.*, 76, 803 – 832.

Brammer, H., 1996. *The Geography of the Soils of Bangladesh.* University Press Ltd., Dhaka, 287pp.

Brammer, H., 1971. FAO Soil Surv. Proj. Bd., Soil Resources, Rome, AGL: SF/PAK6, *Tech. Report 3*, 211pp.

Brammer, H., 1964. An outline of the geology and geomorphology of East Pakistan in relation to soil development. *Pak. Jour. Soil Sci.*, 1 (1), 14 – 19.

Brammer, H. and Brinkman, R., 1977. Surface-water gley soils in Bangladesh, Environment, landforms and soil morphology. *Geoderma*, 17, 91 – 109.

Brewer, R., 1964. *Fabric and mineral analysis of soils*. John Wiley and Sons, Inc. New York. 470pp.

Brindley, G. W., 1961. Quantitative analysis of clay mixtures. In: Brown, G. (Ed.), *X-ray Diffraction and Crystal Structure of Clay Minerals*. Mineral Soc. London, 485 – 516.

Brinkman, R., 1970. Ferrolysis, a hydromorphic soil forming process. *Geoderma*, 3, 199 – 206.

Brinkman, R., 1977. Surface-water gley soils in Bangladesh: Genesis. *Geoderma*, 17, 111 – 144.

Brunnschweiler, R. O., 1966. On the geology of the Indoburman Ranges. *Geol. Soc. Austr. Jour.*, 13 (1), 127 – 194.

Brunnschweiler, R. O. and Khan, M. A. M., 1978. With Sherlock Holmes in the Bengal Basin. *Proc. Offshore South East Asia Conf.*, SEAPEX Sess., 7pp. Singapore.

Bullock, P., Fedoroff, N., Jongerius, A., Stoops, G. and Tursina, T., 1985. *Handbook for soil thin section description.* Waine Res. Publ., U. K., 152pp.

Catt, J. A., 1986. *Soils and Quaternary Geology – A Handbook for Field Scientists*, Monograph on Soils and Resources Survey No. 11, Oxford Univ. Press, New York, 267pp.

Catt, J. A., 1992. Quaternary Environments and their impact on British Soils and Agriculture. In: Gray, J. M. (Ed.), Applications of Quaternary Research. *Quat. Proc. No. 2, Quat. Res. Assoc.*, Cambridge, 17 – 24.

Chappell, J., 1994. Upper Quaternary sea levels, coral terraces, oxygen isotopes and deep-sea temperatures. *Journal of Geography*, 103 (7), 828 – 840.

Chowdhury, K. R. and Haque, M., 1997. Planktonic foraminifera from two gravity cores of the northeastern Bay of Bengal. *Bangladesh J. Geol.*, 16, 1 – 16, Dhaka.

Chowdhury, K. R., Haque, M. M., Nasreen, N., Hasan, M. R., 2003. Distribution of planktonic foraminifera in the northern Bay of Bengal. *Sedimentary geology,* 155, 393 – 406.

Chowdhury, K. R., Nasreen, N. and Islam, M. S., 1997. Planktonic foraminifera in a piston core from the continental slope of the Bay of Bengal. *Bangladesh J. Geol.*, 16, 17 – 29, Dhaka.

Chowdhury, S. Q., 1982. Palynostratigraphy of the Neogene sediments of the Sitapahar anticline (western flank), Chittagong Hill Tracts, Bangladesh. *Bangladesh J. Geol.* 1, 35 – 49.

Curray, J. R. and Moore, D. G., 1974. Sedimentary and tectonic processes in the Bengal Deep – Sea fan and Geosyncline. In: Burke, C. A. and Drake, C. (Eds), *The Geology of continental margins.* Springer – Verlag, New York, 617 – 627.

Curray, J. R., Moore, D. G., Lawver, L. A., Emmel, F. J., Raitt, R. W., Henry, & Kieckhefer, R., 1979. Tectonics of the Andaman Sea and Burma. In: Wutkkins, J. S., Montadert, L. and Dickerson, P. W. (eds.), *Geological and geophysical investigations of Continental Margins.* AAPG Mem., 29, 189 – 198.

Dasgupta, S. and Nandy, D. R., 1995. Geological framework of the Indo-Burmese convergent margin with special reference to ophiolitic emplacement. *Indian J. Geol.* 67(2), 110 – 125.

Duchaufour, P., 1982. *Pedology, Pedogenesis and Classification* (Translated by T. R. Paton). George Allen and Unwin, London, 448 pp.

Evans, P., 1932. Tertiary Succession in Assam. Trans. Min. Geol. Inst. India, 27, 155 – 260.

FitzPatrick, E. A., 1980. *The Micromorphology of soils*. Deptt. Of Soil Science, University of Aberdeen, Scotland.

Franklin, A. D. and Hornyak, W. F., 1990. Isolation of the rapidly bleaching peak in quartz TL glow curves. *Ancient TL*, 9, 29 – 31.

Frye, J. C. and Willman, H. B., 1960. Classification of the Wisconsinan stage in the Lake Michigan Glacial Lobe. *Illinois State Geol. Surv. Circ.*, 258, 1 – 16.

Galehouse, J. S., 1971. Sedimentation analysis. In: Carver, R. E. (Ed.), *Procedures in Sedimentary Petrology*. Wiley Interscience, London, 69 – 94.

Gani, M. R. and Alam, M. M., 2003. Sedimentation and basin-fill history of the Neogene clastic succession exposed in the southeastern fold belt of the Bengal Basin, Bangladesh: a high-resolution sequence stratigraphic approach. *Sedimentary Geology,* 155, 227 – 270.

Gani, M. R. and Alam, M. M., 1999. Trench-slope controlled deep-sea clastics in the exposed lower Surma group in the southeastern fold belt of the Bengal Basin, Bangladesh. *Sedimentary Geology,* 127, 221 – 236.

Geological Evaluation Division Petrobangla, 1975. Well completion report Jaldi – 3, unpublished.

Gerrard, J., 1992. *Soil-Geomorphology – An Integration of Pedology and geomorphology*. Chapman & Hall, London, 269pp.

Godfrey-Smith, D. I. And Cada, M., 1996. IR Stimulation spectroscopy of plagioclase and potassium feldspars, and quartz. *Radiat. Prot. Dosim.*, 66, 379 – 386.

Guha, D. K., 1978. Tectonic framework and oil and gas prospects of Bangladesh. *Proc. 4th Annual Conf. Bangladesh Geol. Soc.*, 65 – 75.

Habibullah, A. K. M., Greenland, D. J. and Brammer, H., 1971. Clay mineralogy of some seasonally flooded soils of East Pakistan. *Jour. Soil Sci.*, 23 (2), 179 – 190.

Hassan, M., 1986. *Stratigraphical and sedimentological studies on Quaternary deposits of the Lalmai Hills with relation to the Madhupur Tract and the adjoining floodplain*. D. Sc. Dissertation, The Free Univ. of Brussels, Pleinlaam-2, 1050 Brussels, Belgium (Unpublished).

Hiller, K., 1988. On the petroleum geology of Bangladesh. *Geol. Jb.*, D. 90, 1 – 30.

Hoque, M., Huq, A. T. M. F., Khandoker, R. A., Elahi, M. and Khan, A. A., 1982. Tectonic set up of Bangladesh and its relation to hydrocarbon accumulation (Phase I); Center for Policy Research, Dhaka University and UFSI (USA) Publication.

Hossain, K. M. I., Khan, M. S. H., Chowdhury, M. A. and Huq, N. E., 1999. Flushing ability of Basal shales: Implications for deep – seated hydrocarbon prospect in the Surma Basin, *Bangladesh. Bangladesh Geoscience Journal*, 5, 45 – 55.

Hossain, M. S. and Parkash, B., 1999. The role of neotectonics on the evolution of the Quaternary landforms and soils of Bangladesh. *Dhaka Univ. J. Sci.*, 47 (2), 201 – 208.

Islam, M. S. and Tooley, M. J., 1999. Coastal and sea-level changes during the Holocene in Bangladesh. *Quaternary International*, 55, 61 – 75.

Ismail, M., 1978. Stratigraphical position of Bogra limestone of the platform area of Bangladesh. *Proc. 4th Annual Conf. Bangladesh Geol. Soc.,* 19 – 26.

Johnson, B. L. C., 1957. A note on the Cropping System in relation to physiographic condition in East Pakistan: Winter 1955-57, F. A. O.

Jongerius, A. and Heintzberger, G., 1963. Methods in Soil Micromorphology; A technique for the preparation large thin sections. *Soil survey Paper No. 10, Netherland Soil Surv. Inst.*,Wageningen, 49pp.

Joseph, S. and Thrivikramaji, K. P., 2002, Rhizolithic calcrete in Tris, southern Tamil Nadu: Origin and paleoenvironmental implications. *National seminar on Coastal and Off-shore sedimentary basins and their resource potential,* Abstract, Visakhapatnam.

Khan, F. H., 1991. *Geology of Bangladesh*. The University Press Ltd., Dhaka, 207pp.

Khan, M. R. and Muminullah, M., 1980. *Stratigraphy of Bangladesh – Petroleum and mineral resources of Bangladesh*. Seminar and Exhibition, Min. Petrol. Miner. Res., Govt. of Bangladesh, 35 – 40.

Khan, S. R. and Arefin, K. M. S., 1999. Geological report on the effect of July 22, 1999 Earthquake in the Moheskhali Island, Cox's Bazar District, Bangladesh (Unpbl.). Government of the People's Republic of Bangladesh, GSB, Dhaka, 9p.

Klages, M. G. and Hopper, R. W., 1982. Clay minerals in northern plains coal overburden as measured by x-ray diffraction. *Jour. Soil Sci. Soc. Am.*, 46, 414 – 425.

Krbetschek, M. R., Gotze, J., Dietrich, A. and Trautmann, T., 1997. Spectral Information from minerals relevant for luminescence dating. *Radiation Measurements*, 27 (5/6), 695 – 748.

Kumar, S., Parkash, B., Manchanda, M. L., Singhvi, A. K. and Srivastava, P., 1996. Holocene landform and soil evolution of the western Gangetic Plains: Implications of neotectonics and climate. *Z. Geomorph. N. F.*, Suppl-Bd. 103, 283 – 312.

Kutzbach, J. E. and Street Perrott, F. A., 1985. Milankovitch forcing of fluctuations in the level of tropical lakes from 18 to 0 kyr B.P. *Nature*, 317, 130 – 134.

Levine, E. L. and Ciolkosz, E. J., 1983. Soil development in till of various ages in northern Pennsylvania. *Quat. Res.*, 19, 85 – 99.

Lietz, J. K. and Kabir, J., 1982. Prospects and constraints of oil exploration in Bangladesh. *Proc. 4th Offshore South East Asia Conf.,* Singapore, 1 – 6.

Lindsay, J. F., Holliday, D. W. and Hulbert, A. G., 1991. Sequence stratigraphy and the evolution of the Ganges – Brahmaputra Delta complex. *Am. Assoc. Pet. Geol. Bull.* 75, 1233 – 1254.

Master Plan Organization (MPO), 1987. *Geology of Bangladesh*. Technical Report No. 4. Ministry of Irrigation, Water Development and Flood Control, Govt. of People's Republic of Bangladesh, Dhaka, Bangladesh.

Matin, M. A., Fariduddin, M., Hussain, M. M. T., Khan, M. A. M., Boul, M. A. and Kononov, A. I., 1986, New concepts on the tectonic zonation of the Bengal Foredeep. *6th Offshore South East Asia Conf. and Exhibition*, 51 – 54.

McFadden, L. D. and Knuepfer, L. K., 1990. Soil geomorphology: The linkage of pedology and surficial processes. *Geomorphology*, 3, 197 – 205.

McFee, C. J. and Tite, M. S., 1994. Investigation into the thermoluminescence properties of single quartz grains using an imaging photon detector. *Radiation Measurement*, 23, 355 – 360.

Merh, S. S., 1992. Quaternary sea level changes along Indian coast. *Proc. Ind. Nat. Sci. Acad.,* 58 A (5), 461 – 472.

Miedema, R., Pape, Th. and Wall, G. J. Vand de, 1974. A method to impregnate wet soil samples, producing high-quality thin sections. *Netherland Jour. Agri. Sci.*, 22, 37 – 39.

Mitchell, A. H. G., 1981. Phanerozoic plate boundaries in mainland SE Asia, the Himalayas and Tibet. *J. Geol. Soc. London*, 138, 109 – 122.

Mohan, P. M. and Rajamanickam, G. V., 2000. Buried placer deposits along the east coast between Chennai and Pondicherry. Jour. *Geol. Soc. Ind.*, 56, 1 – 13.

Mohindra, R. and Parkash, B., 1990. Clay mineralogy of the Gandak megafan and adjoining areas, Middle Gangetic Plains, India. *Sciences Geologiques Bull.*, 43, 203 – 212.

Mohindra, R., Parkash, B. and Prasad, J., 1992. Historical geomorphology of the Gandak Mega Fan, Middle Gangetic Plain, India. *Earth Surf. Proc. And Land.*, 17, 643 – 662.

Monsur, M. H., 1995. Holocene sea – level and the marine transgressions of the eastern coast of the Bay of Bengal; *An introduction to the Quaternary Geology of Bangladesh.* City Press and Publications, Dhaka, 70pp.

Monsur, M. H., 1990. Stratigraphical and palaeomagnetical studies of some Quaternary deposits of the Bengal Basin, Bangladesh. Unpbl. Ph.D. Thesis, Vrije Universiteit Brussel, Belgium.

Monsur, M. H. and Kamal, A. S. M. M., 1994. Holocene sea-level changes along the Maiskhali and Cox's Bazar-Teknaf coast of the Bay of Bengal. *The Journal of NOAMI*, 11 (1), 15 – 21.

Monsur, M. H. and Paepe, R., 1992. Quaternary stratigraphy of the Barind area of the Bengal Basin, Bangladesh. *Ind. Jour. Earth Sci.*, 19 (2-3), 79 –84.

Moody, L. E. and Graham, R. C., 1995. Geomorphic and pedogenic evolution in coastal sediments, central California. *Geoderma*, 67 (3-4), 181 – 201.

Morgan, J. P. and McIntire, W. G., 1959. Quaternary geology of the Bengal Basin, East Pakistan and India. *Geol. Soc. Am. Bull.*, 70 (3), 319 – 342.

Nagappa, Y., 1959. Foraminiferal biostratigraphy of the Cretaceous-Eocene succession in the India-Pakistan-Burma region. *Micropalaeontology*, 5, 145 – 179.

Naqvi, S. N., 1964. The meteorological problems of the deltaic floodplains of East Pakistan, Humid Tropics Research. *Proc. Dhaka Symp., UNESCO*, 123 – 133.

Orient Geological Consultants, 1975. A Geological report on Maishkhali Structure, Chittagong, Bangladesh. A report submitted to the Bengal Oil Development Co. Ltd.

Oya, M., 1977. Applied geomorphological study on the selection of the proposed bridge site along the Jamuna river in Bangladesh. *Natl. Geogr.*, 12 (2), 101 – 113.

Paul, D. D. and Lian, H. M., 1975. Offshore Tertiary basins of Southeast Asia, Bay of Bengal to South China Sea. *Proc. 9th World Petroleum Congr.*, 3, 107 – 121.

Rajamanickam, G. V. and Tooley, M. J. (Eds.), 2001. *Quaternary Sea-level variation, shoreline displacement and coastal environment: Proceedings*. New Academic, Delhi, 259p.

Rangarajan, G. and Sant, D. A., 2000. Paleoclimatic data from 74KL and Guliya cores: New insights. *Geophysical Research Letters*, 27 (6), 787 – 790.

Rangarao, A., 1983. Geology and hydrocarbon potential of a part of Assam – Arakan Basin and its adjacent region; In: Bhandari, L. L., Venkatachala, B. S., Kumar, R., Swamy, S. N., Garga, P. and Srivastava, D. C. (eds.), *Petroliferous Basins of India. – Petroleum Asia J.*, 127 –158, Dehra Dun.

Rashid, H. E., 1977. *Geography of Bangladesh*. The university Press Ltd., Dhaka, 529pp.

Reimann, K.-U., 1993. *Geology of Bangladesh*. Beitraege zur Regionalen Geologie der Erde Band 20, Gebruder Borntraeger, Berlin – Stuttgart, 160pp.

Reimann, K.-U.,1981. Stratigraphie, regionale Geologie; In Schneider, H. H.: *Technische Zusammenarbeit*, Projekt Nr. 75,2034,9, Schlussbericht Phase II, 1.1.1070 – 31. 12. 1980; 42 – 50, Bundesanst, f. Geowiss. u. Rohstoffe, Hannover (Unpubl. Rep).

Rob, M.A. and Hoque, A., 1999. Studies on geomorphological environment of the Moheshkhali island of Bangladesh. *Oriental Geographer*, 43 (1), 1 – 12, Dhaka.

Salt, C. A., Alam, M. M., Hossain, M. M., 1986. Bengal Basin: current exploration of the hinge zone area of southwestern Bangladesh. *Proc. 6th Offshore Southeast Asia Conference,* Singapore, 55 – 57.

Schultz, L. G., 1960. Quantitative X-ray determination of some aluminous clay minerals in rocks. In: Swineford, Ada. (Ed.), *Clays and clay minerals*, Pergamon Press, New York, 216 – 224.

Sengupta, S., 1964. Possible subsurface structures below the Himalayas and the Gangetic Plains. *Int. Geol. Cong.*, 22nd Session (II), 334 – 351.

Shackleton, N. J., 1987. Oxygen isotopes, ice volume and sea level. *Quat. Sci. Rev.*, 6, 183 – 190.

Shamsuddin, A. H. M., Abdullah, S. K. M., 1997. Geological evolution of the Bengal Basin and its implication in hydrocarbon exploration in Bangladesh. *Indian J. Geol.,* 69, 93 – 121.

Singh, L. P., Parkash, B. and Singhvi, A. K., 1998. Evolution of Lower Gangetic Plain landforms and soils in West Bengal, India. *Catena*, 33, 75 – 104.

Singhvi, A. K. and Wintle, A. G., 1999. Luminescence dating of Aeolian and Coastal sand and silt deposits: Applications and implications. In: Goudie, A. S., Livingstone, I. and Stokes, S. (eds.), *Aeolian Environments, Sediments and Landforms*, John Wiley and Sons, Ltd., New York, 293 – 316.

Sirocko, F., 1996. The evolution of the monsoon climate over the Arabian Sea during the last 24,000 years. *Palaeoecology of Africa*, 24, 53 – 69.

Sirocko, F., Sarnthein, M., Erienkeuserg, H., Lange, H., Arnold, M. and Duplessy, J. C., 1993. Century-scale events in monsoonal climate over the past 24,000 years. *Nature*, 364, 322 – 324.

Soil Survey Staff, 1992. Keys to Soil Taxonomy. *SMSS Technical Monograph No. 19.* Pocahontas Press Inc. Blacksbury, Virginia.

Srivastava, P., Parkash, B. and Pal, D. K., 1998. Clay minerals in soils as evidence of Holocene climatic change, central Indo-Gangetic Plains, North-Central India. *Quat. Res.*, 50, 230 – 239.

Srivastava, P., Parkash, B., Sehgal, J. L. and Kumar, S., 1994. Role of neotectonics and climate in development of the Holocene geomorphology and soils of the Gangetic Plains between the Ramganga and Rapti rivers. *Sedimentary Geology*, 94, 129 – 151.

Tarafder, S.A. and Monsur, M. H., 1999. Geological evolution of the Kutubdia Island. *International seminar on "Quaternary development and coastal hydrodynamics of the Ganges delta in Bangladesh"*, Abstract, Dhaka.

Umitsu, M., 1993. Late Quaternary sedimentary environments and landforms in the Ganges Delta. *Sed. Geol.*, 83, 177 – 186.

Umitsu, M., 1987. Late Quaternary sedimentary environment and landform evolution in the Bengal lowland. *Geo. Rev. Japan*, 60 (2), 164 – 178.

Umitsu, M., 1985. Natural Levees and Landform evolution in the Bengal Lowland. *Geo. Rev. Japan*, 58 (2), 149 – 164.

U.S.D.A., 1966. *Soil Survey Manual*, Handbook No. 18, Oxford and IBH, New Delhi, 503pp.

Van Campo, E., 1986. Monsoon fluctuations in two 20,000-Yr B. P. Oxygen Isotope / Pollen records of Southwest India. *Quaternary Research*, 26, 376 – 388.

Vishnu – Mittre and Sharma, C., 1984. Vegetation and climate during the last glaciation in the Kathmandu valley, Nepal. *Pollen Spores*, 26 (1), 69 – 94.

Williams, M. A. J., Dunkerley, D. L., De Decker, P., Kershaw, A. P. and Stokes, T. J., 1993. *Quaternary environments*. Edward Arnold, London, 329pp.

Wilson, M. J., 1987. X-ray diffraction methods. In: Wilson, M. J. (Ed.), *A Handbook of Determinative Methods in Clay Mineralogy*. Batckie, Glasgow, 26 – 98.

Wintle, A. G., 1997. Luminescence dating: Laboratory procedures and protocols. *Radiation Measurements*, 27 (5/6), 769 – 817.

APPENDIX - I

Particle Size Distribution, Textural Class, pH & EC Values of Soil Profiles of Different Members of the Morphostratigraphic Sequence

Sample No.	Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural Class	pH	EC
				Sub-Member IVc				
J5/1	A1	0-10	70	22	8	SL	4.68	.013
J5/2	A2	10-20	67	20	13	SL	4.89	.001
J5/3	B1	20-40	67	23	10	SL	5.00	.001
J5/4	B2	40-70	87	9	4	S	5.22	.001
J5/5	C	70-100+	93	5	2	S	5.28	.001
J7/1	A	0-20	52	21	27	SCL	3.99	.017
J7/2	B1	20-65	53	18	29	SCL	4.10	.010
J7/3	B2	65-100	55	16	29	SCL	4.18	.007
				Sub-Member IVb				
J3/1	A	0-10	51	34	15	L	3.82	.020
J3/2	B1	10-20	54	31	15	SL	3.70	.018
J3/3	B2	20-60	51	31	18	L	3.75	.023
J3/4	B3	60-100	36	28	36	CL	3.96	.008
J3/5	C1	100-140+	28	33	39	CL	4.80	.001
J8/1	A	0-15	39	46	15	L	4.96	.016
J8/2	B1	15-46	19	47	34	SiCL	4.44	.002
J8/3	B2	46-60	10	48	42	SiC	4.51	.001
J8/4	BC	60-85	9	48	43	SiC	4.60	.001
J8/5	C	85-120+	7	54	39	SiCL	5.08	.003
J9/1	A	0-20	57	30	13	SL	4.60	.048
J9/2	B1	20-40	42	29	29	CL	4.50	.006
J9/3	B2	40-70	46	20	34	SCL	4.70	.001
J9/4	B3	70-90	46	26	28	SCL	4.70	.001
J9/5	B4	90-140+	67	15	18	SL	4.70	.001
				Sub-Member IVa				
M1/1	A	0-20	55	30	15	SL	4.20	.014
M1/2	B1	20-55	54	25	21	SCL	4.30	.003
M1/3	B2	55-90	44	31	25	L	4.35	.001
M1/4	C1	90-140+	67	15	18	SL	4.40	.001
				Member III				
J1/1	Ap1	0-12	57	33	10	SL	4.18	.093
J1/2	Ap2	12-24	60	30	10	SL	5.19	.029
J1/3	B1	24-42	68	22	10	SL	6.25	.009
J1/4	B2	42-70	67	23	10	SL	6.20	.004
J1/5	B3	70-142	47	32	21	L	6.58	.006
J1/6	C1	142-170	80	17	3	LS	5.00	.027
J1/7	C2	170-200+	82	15	3	LS	4.50	.048
J2/1	Ap	0-20	44	43	13	L	5.22	.020
J2/2	B1	20-30	52	23	25	SCL	5.80	.034
J2/3	B2	30-50	42	40	18	L	7.12	.014
J2/4	B3	50-80	44	41	15	L	6.98	.012
J2/5	B4	80-100	34	52	14	SiL	6.88	.014

Appendix – I (Contd.)

Sample No.	Horizon	Depth	Sand (%)	Silt (%)	Clay (%)	Textural Class	pH	EC
J2/6	C	100-140+	34	48	18	L	5.87	.012
M3/1	Ap1g	0-10	62	23	15	SL	5.47	.005
M3/2	Ap2g	10-30	65	20	15	SL	5.18	.002
M3/3	B1g	30-55	67	20	13	SL	4.58	.008
M3/4	B2g	55-90	72	15	13	SL	4.66	.008
M3/5	C1	90-120+	77	13	10	SL	4.28	.022
M4/1	Ap1g	0-10	39	52	9	SiL	5.85	.085
M4/2	Ap2g	10-30	40	47	13	L	6.10	.050
M4/3	B1	30-60	55	33	12	SL	6.56	.013
M4/4	B2	60-100+	65	25	10	SL	6.67	.016
Member II (Distal Piedmont Plains)								
J4/1	Ap	0-20	36	46	18	L	4.43	.022
J4/2	B1	20-65	28	41	31	CL	5.91	.007
J4/3	C	65-100+	14	39	47	C	5.18	.005
J10/1	Ap	0-15	25	62	13	SiL	4.48	.065
J10/2	B1	15-40	17	63	20	SiL	4.78	.03
J10/3	B2	40-75	25	52	23	SiL	5.83	.014
J10/4	B3	75-90	30	42	28	CL	6.33	.012
J10/5	B4	90-110	37	35	28	CL	6.16	.013
J10/6	C	110-140+	72	18	10	SL	5.18	.005
J11/1	Ap	0-15	50	35	15	L	4.59	.057
J11/2	B1	15-30	27	48	25	L	5.39	.029
J11/3	B2	30-90	33	36	31	CL	6.35	.010
Member II (Old Tidal Flats)								
J6/1	Ap	0-20	54	15	31	SCL	4.75	.175
J6/2	B1	20-80	1	55	44	SiC	6.57	.128
J6/3	BC	80-120+	5	51	44	SiC	6.80	.200
M2/1	Ap	0-20	46	38	16	L	3.80	.158
M2/2	B1g	20-40	12	60	28	SiCL	4.50	.048
M2/3	B2g	40-70	11	61	28	SiCL	5.15	.024
M2/4	Cg	70-110+	9	53	38	SiCL	4.17	.221

Remarks :
Textural class abbreviated as S = Sandy; SL = Sandy loam; L = Loam; SCL = Sandy clay loam; SiL = Silty loam; SiCL = Silty clay loam; SiC = Silty clay; CL = Clay loam; C = Clay

APPENDIX - II
Description of Typical Soil Thin Sections from the Different Members of the Morphostratigraphic Sequence

SUB-MEMBER IVc
Mainland Higher Hillocks
Sample No. J5/2
Location: Rupnagar, Satkania Depth: 10 – 20 cm Horizon: A2
Physiography: Summit of dome shaped low hill.
Microstructures

Moderately to weakly developed subangular blocky structures. Ped faces are separated by channels and are partially accommodating each other. Ped diameter ranging between 500 μm – 1.5 mm. Rounded to subrounded voids dominant along with few channels. Voids and channels are randomly distributed. The diameter of subrounded voids and the width of channels ranging between 100 – 550 μm. Void and channel walls are smooth to undulating. Estimated porosity is 20%.

Basic mineral components
c/f limit at 30 μm; the ratio of 20:80.
(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured feldspar (50%), quartz (40%) and muscovite and biotite (20%). About 90% of feldspar and quartz grains ranging between 100 – 450 μm in diameter. Slight pellicular alteration of feldspars and biotites are observed.

(b) Fine fraction

It consists of quartz, feldspar, clay aggregates and heavy minerals.

Groundmass

The c/f related distribution is single spaced porphyric. The micromass is yellowish brown to gray coloured. Mosaic-speckled, cross striated and random striated b-fabric is observed.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings are present along voids and channels. The thickness of hypo-coatings ranging between 30 – 100 μm.

Sample No. J5/3
Location: Rupnagar, Satkania Depth: 20 – 40 cm Horizon: B1
Physiography: Summit of dome shaped low hill.
Microstructures

Moderately developed subangular blocky structures. Ped faces are separated by channels and irregular shaped voids. Ped faces partially accommodating each other. Ped diameter ranging between 700 μm – 2 mm. Subrounded voids dominant along with few channels and irregular vughy voids. Voids and channels are randomly distributed. The diameter of subrounded voids ranging between 100μm – 1mm and the width of channels ranging between 100 – 550 μm. Few vughy voids are present having a diameter of ~2 mm. Void and channel walls are smooth to undulating. Estimated porosity is 20%.

Basic mineral components

c/f limit at 30 μm; the ratio of 20:80.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured feldspar (40%), quartz (40%) and muscovite and biotite (20%). Majority of the feldspar and quartz grains ranging between 100 – 700 μm in diameter. Pellicular alteration of feldspars and biotites are observed.

(b) Fine fraction

It consists of quartz, feldspar, clay aggregates and heavy minerals.

Groundmass

The c/f related distribution is single to double spaced porphyric. The micromass is yellowish brown to gray coloured. Mosaic-speckled and discontinuous stipple-speckled b-fabrics are observed.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings are present along voids and channels. The thickness of hypo-coatings ranging between 50 – 100 μm.

Sample No. J5/4

Location: Rupnagar, Satkania Depth: 40 – 70 cm Horizon: B2

Physiography: Summit of dome shaped low hill.

Microstructures

Moderately developed subangular blocky structures. Ped faces are separated by channels and irregular shaped voids. Ped faces are partially accommodating each other. Smallest ped diameter is about 500μm. Subrounded voids are dominant along with channels. Voids and channels are randomly distributed. The diameter of subrounded voids ranging between 100 – 700 μm and the width of channels ranging between 30 – 100 μm. Void and channel walls are smooth and at few places it is rough. Estimated porosity is 10%.

Basic mineral components

c/f limit at 30 μm; the ratio of 15:85.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured feldspars (45%), quartz (40%) and biotite and muscovite (15%). Majority of feldspar and quartz grains ranging in diameter between 100 – 450 μm. Pellicular alteration of feldspars and biotites are observed.

(b) Fine fraction

It consists of quartz, feldspar, heavy minerals and micaceous particles.

Groundmass

The c/f related distribution is single spaced porphyric. The micromass is yellowish brown to gray coloured. Mosaic-speckled and random striated b-fabrics are observed.

Pedofeatures

Ferruginous (ferriargillans) hypo-coating along channels and few voids are present. Irregular flow of ferruginous materials around the channels is noticed. The thickness of hypo-coatings ranging between 30 – 100 μm. Few strongly impregnated Fe-Mn oxide nodule of 150 – 650 μm diameter are present.

Sample No. J7/2

Location: Between Rupnagar & Bahigram, Satkania Depth: 20–65 cm
Horizon: B1 Physiography: Upper slope of very steep low hill.

Microstructures

Moderately developed subangular blocky structures. Channels separated peds. Ped faces are partially to completely accommodating each other. Ped diameter ranging between 700 μm - 2 mm. Channel voids are dominant along with subrounded voids and few vughy voids. Channel voids begins or ended with vughy voids. Channel and voids are randomly distributed. The width of channels ranging between 50 – 500 μm. The diameter of subrounded voids ranging between 100 – 700 μm with few vughy voids having a diameter upto 3 mm. Walls of channels and voids are undulating to smooth. Estimated porosity is 25 – 30%.

Basic mineral components

c/f limit at 30 μm; the ratio of 20:80.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured feldspar (55%), quartz (35%) and muscovite, biotite and heavy minerals (10%). Majority of feldspar grains ranging between 100 – 600 μm in diameter. Pellicular alteration of feldspars and biotites are observed.

(b) Fine fraction

It consists of quartz, feldspar, micaceous particles and heavy mineral grains.

Groundmass

The c/f related distribution is single spaced porphyric. The micromass is reddish brown coloured. Mosaic-speckled b-fabric is observed.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings along channels and voids are present. The thickness of hypo-coatings ranging between 50 – 200 μm. The thickness of hypo-coatings are underestimated due to diffuse and irregular movement of ferruginous materials through out the section. Few strongly impregnated Fe-Mn oxide nodules of ~2 mm diameter are observed.

Sample No. J7/3

Location: Between Rupnagar & Bahigram, Satkania Depth: 65 – 100 cm
Horizon: B2 Physiography: Upper slope of very steep low hill.

Microstructures

Weakly developed subangular blocky structures. Ped faces are not completely separated. Ped faces are partially or not accommodating each other. Ped diameter is ~1 mm. Subrounded voids are dominant along with few channels. Voids and channels are randomly distributed. The diameter of subrounded voids and the width of channels ranging between 100 – 700 μm. Walls of subrounded voids and channels are smooth to undulating. Estimated porosity is 20 – 25%.

Basic mineral components

c/f limit at 30 μm; the ratio of 20:80.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured quartz (55%), feldspar (30%) and muscovite, biotite and heavy minerals (15%). About 90% of the quartz and feldspar grains ranging between 100 - 550μm. Pellicular alteration of feldspars and parallel linear alteration of biotites are observed.

(b) Fine fraction

It consists of quartz, feldspar, micaceous particles and heavy mineral grains.

Groundmass

The c/f related distribution is single spaced porphyric. The micromass is reddish brown coloured. Mosaic-speckled b-fabric is observed.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings are present along voids and channels. The thickness of hypo-coatings ranging between 50 - 200μm. The thickness of hypo-coatings is underestimated due to diffuse and irregular movement of ferruginous materials through out the section.

SUB-MEMBER IVb

Mainland Lower Hillocks

Sample No. J3/2

Location: Dakhin Kanchana, Satkania Depth: 10 – 20 cm Horizon: B1
Physiography: Foot slope of low hill.

Microstructures

Moderately to weakly developed subangular blocky structures. Ped faces are partially accommodating each other. Smallest ped diameter is >1mm. Subrounded voids are dominant along with channels. Voids and channels are randomly distributed. The diameter of subrounded voids ranging between 150 – 650 μm and the width of channels ranging between 150 – 400 μm. Void walls are undulating. Estimated porosity is about 20 – 25%.

Basic mineral components

c/f limit at 30 μm; the ratio of 20:80.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral, fractured feldspar (50%), and quartz (30%), and muscovite and biotite (20%). Majority of feldspar and quartz grains ranging between 150 – 450 μm. The feldspars are highly fractured and pellicular alteration of feldspars is observed.

(b) Fine fraction

It consists of quartz, feldspars, micaceous particles and heavy minerals. Quartz grains are concentrated in fine fractions.

Basic organic components

Roots are present. Roots are impregnated with iron oxides. The width of roots are ~700µm.

Groundmass

The c/f related distribution is single to double spaced porphyric. The micromass is yellowish brown to gray coloured. Mosaic-speckled b-fabric is observed.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings are present along void and channels. Movement of ferruginous materials is observed. The thickness of hypo-coatings is ~200 µm. Ferruginous rings enveloping voids or clay matrix of ~2mm diameter are present; thickness of ring wall is about 100 µm. Few strongly impregnated Fe-Mn oxide nodule having a diameter of 2 mm are present and contain silt cappings on the top.

Sample No. J3/3

Location: Dakhin Kanchana, Satkania Depth: 20 – 60 cm Horizon: B2

Physiography: Foot slope of low hill.

Microstructures

Strongly to moderately developed subangular blocky structures. Ped faces are separated by channels and partially or completely accommodating each other. Smallest ped diameter is about 1mm. Subrounded voids are dominant along with few channels. Voids and channels are randomly distributed. The diameter of subrounded voids ranging between 150 µm – 1 mm with few subrounded voids have a diameter of 2 mm. The width of the channels ranging between 100 – 700 µm. Walls of voids and channels are undulating. Estimated porosity is 10 – 15%.

Basic mineral components

c/f limit at 30 µm; the ratio of 20:80.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured feldspar grains (50%), quartz (30%) and rest (20%) is composed of muscovite and biotite. About 70% of feldspar grains ranging in diameter between 150 – 450 µm. Pellicular and dotted alteration of feldspars is observed.

(b) Fine fraction

It consists of quartz, feldspar, micaceous particles and clay aggregates.

Groundmass

The c/f related distribution is single to double spaced porphyric. The micromass is yellowish brown, yellowish red to reddish brown coloured. The yellowish brown to reddish brown colour may be because of fine dispersed goethite, hematite and or Fe-gel. Mosaic-speckled b-fabric is observed.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings are present along voids and channels. Irregular movement of ferruginous materials is noticed. The thickness of hypo-coatings ranging between 100 – 150 µm. Ferruginous (ferriargillans) rings of ~2 mm diameter enveloped clay matrix or subrounded voids are present. Few strongly impregnated Fe-Mn oxide nodule of 300 µm - ~2 mm diameter are present.

Sample No. J3/4
Location: Dakhin Kanchana, Satkania   Depth: 60 - 100 cm   Horizon: B3
Physiography: Foot slope of low hill.
Microstructures

Strongly to moderately developed subangular blocky structures. Ped faces are separated by channels and accommodating each other. Peds ranging in diameter between 1 – 2 mm with a few up to 3 mm. Channel voids are dominant along with subrounded voids. Channels and voids are randomly distributed. The width of channels ranging between 100 - 600µm and the diameter of subrounded voids ranging between 100 - 500µm. Few vughy voids of >2mm diameter are also present. Walls of channels and voids are undulating to smooth. Estimated porosity is 15 – 20%.

Basic mineral components
c/f limit at 30µm; the ratio of 10:90.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured feldspar (45%), quartz (35%) and rest (20%) is composed of biotite and heavy minerals. Majority of feldspar and quartz ranging in diameter between 100 - 550µm. Pellicular alteration of feldspar grains is observed.

(b) Fine fraction

It consists of quartz, feldspar, micaceous particles and heavy minerals.

Groundmass

The c/f related distribution is single to double spaced porphyric. The micromass is yellowish brown yellowish red coloured. Cross striated and mosaic-speckled b-fabrics are observed.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings are present along channels and voids. Irregular movement of ferriargillans is observed. The thickness of hypo-coatings ranging between 100 - 200µm. Few strongly impregnated Fe-Mn oxide nodule of 2mm diameters are present.

Sample No. J3/5
Location: Dakhin Kanchana, Satkania   Depth: 100 – 140+ cm   Horizon: C1
Physiography: Foot slope of low hill.
Microstructures

Weakly developed subangular blocky structures. Ped faces are partially accommodating each other. Ped diameter ranging between 1–2 mm. Channel voids are dominant along with few subrounded voids. Channels and voids are randomly distributed. The width of channels ranging between 50 – 850µm and the diameter of the subrounded voids ranging between 100 - 850µm. Channel and void walls are undulating. Estimated porosity is 15%.

Basic mineral components
c/f limit at 30µm; the ratio of 5:95.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured feldspar and quartz (80%), muscovite and biotite (20%). The feldspar and quartz grains ranging in diameter between 100 - 550µm. Weak pellicular alteration of feldspars are observed.

(b) Fine fraction

It consists of quartz, feldspar, heavy minerals and few micaceous particles.

Groundmass

The c/f related distribution is open porphyric. The micromass is yellowish brown to gray and around the nodules the micromass is reddish. Cross striated and mosaic-speckled b-fabrics are observed.

Pedofeatures

Clay (argillans) and ferruginous (ferriargillans) hypo-coatings are present along channels and voids. The thickness of hypo-coatings ranging between 50 - 100µm. Few weakly to moderately impregnated, orthic, Fe-Mn oxide nodules of ~2mm diameters are present.

Sample No. J8/2

Location: Chunati, Lohagora Depth: 15 – 46 cm Horizon: B1
Physiography: Middle slope of steep low hill.

Microstructures

Moderately to weakly developed subangular blocky structures. Channels separate ped faces. Ped faces are partially accommodating each other. Ped diameter ranging between 500µm – 2 mm. Channel voids are dominant along with few subrounded to irregular shaped voids. Channels and voids are randomly distributed. The width of channels ranging between 50 - 300µm and the diameter of subrounded and irregular shaped voids ranging between 150 - 700µm. Walls of channels and voids are undulating. Estimated porosity is 10 –15%.

Basic mineral components

c/f limit at 30µm; the ratio of 5:95.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral, fractured feldspar(40%) and quartz (35%), micaceous particles and heavy minerals (25%). Majority of feldspar and quartz grains ranging in diameter between 100 - 450µm. Pellicular and cross-linear alteration of feldspars is observed.

Basic organic components

Fragments of roots are present. Portions of roots are impregnated with iron oxides. The width of roots are about 500µm and the lengths are 1– 2 mm.

Groundmass

The c/f related distribution is open porphyric. The micromass is yellowish brown to gray coloured. Parallel and cross striated b-fabrics are observed.

Pedofeatures

Clay (argillans) hypo-coatings are present along channels and voids. The thickness of hypo-coatings ranging between 100 – 200µm. Irregular movement of ferriargillans is noticed. Few moderately to weakly impregnated, orthic, Fe-Mn oxide nodules of 200 - 850μm diameters are present.

Sample No. J8/3

Location: Chunati, Lohagora Depth: 46 – 60 cm Horizon: B2

Physiography: Middle slope of steep low hill.

Microstructures

Moderately to strongly developed subangular blocky structures. Planar and channel voids separate peds. Ped faces are accommodating each other. Ped diameters ranging between 850μm – 2mm. Planar voids dominant along with channel and subrounded voids. Planar, channel and subrounded voids are randomly distributed. The width of planar and channel voids ranging between 30 - 500μm. The diameter of subrounded voids ranging between 100 - 700μm. Walls of planar, channel and subrounded voids are smooth to undulating. Estimated porosity is 15 – 20%.

Basic mineral components

c/f limit at 30μ; the ratio of 2:98.

Coarse fraction

Coarse fraction comprises anhedral to subhedral, fractured feldspar (50%) and quartz (30%), muscovite, biotite and heavy minerals (20%). Majority of feldspar and quartz grains ranging between 100 - 450μm. Weak pellicular alteration of feldspars is observed.

Groundmass

The c/f related distribution is open porphyric. The micromass is yellowish brown to reddish brown. Cross striated and mosaic-speckled b-fabrics are observed.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings along voids are present. Movement of ferriargillans is observed throughout the section. The thickness of hypo-coatings ranging between 100 - 150μm. Few Fe-oxide mottles of 150 - 600μm diameters are present.

Sample No. J8/4

Location: Chunati, Lohagora Depth: 60 – 85 cm Horizon: BC

Physiography: Middle slope of steep low hill.

Microstructures

Moderately developed subangular blocky structures. Channels separate peds. Ped faces are accommodating each other. Ped diameter ranging between 800μm – 2mm. Channel voids are dominant along with subrounded voids. Channels and voids are randomly distributed. The width of channels ranging between 30 - 400μm and the diameter of subrounded voids ranging between 100 - 700μm. Channel and void walls are undulating to rough. Estimated porosity is 20%.

Basic mineral components

c/f limit at 15μm; the ratio of 5:95.

Coarse fraction

Coarse fraction comprises anhedral to subhedral, fractured feldspar (45%) and quartz (40%), biotite, muscovite and heavy minerals (15%). About 95% of feldspar and quartz grains ranging between 30 - 350μm. Pellicular alteration of feldspars is observed.

Groundmass

The c/f related distribution is open porphyric. The micromass is reddish brown and yellowish brown to gray coloured. Cross striated and discontinuous stipple-speckled b-fabrics are present.

Pedofeatures

Clay (argillans) and ferruginous (ferriargillans) hypo-coatings are present along channels and voids. Movement / flow of ferriargillans are noticed. The thickness of hypo-coatings ranging between 30 - 150μm. Few Fe-oxide mottles of 100 - 600μm diameters are present.

Sample No. J8/5

Location: Chunati, Lohagora Depth: 85 – 120 cm Horizon: C
Physiography: Middle slope of steep low hill.

Microstructures

Weakly developed subangular blocky structures. Channels and planar voids separate peds. Ped faces are partially accommodating each other. Ped diameter ranging between 500μm – 2mm. Channel voids are dominant along with planar and subrounded voids. Channels, planar and subrounded voids are randomly distributed. The width of channel and planar voids ranging between 30 - 850μm and the diameter of subrounded voids ranging between 100 - 850μm. Walls of planar voids are smooth and those of channels and subrounded voids are smooth to rough. Estimated porosity is 20%.

Basic mineral components

c/f limit at 15μm; the ratio of 2:98.

Coarse fraction

Coarse fraction comprises anhedral to subhedral feldspar (50%) and quartz (35%), biotite, muscovite and heavy minerals (15%). About 95% of feldspar and quartz grains ranging in diameter between 30 - 300μm. Weak pellicular alteration of feldspars is observed.

Groundmass

The c/f related distribution is open porphyric. The micromass is reddish brown to yellowish brown and gray coloured. Parallel and cross striated b-fabrics are observed.

Pedofeatures

Clay (argillans) and ferruginous (ferriargillans) hypo-coatings and quasi-coatings are present along channels and planar voids. The thickness of hypo- and quasi-coatings ranging between 30 - 150μm.

Sample No. J9/2

Location: Chunati, Lohagora Depth: 20 – 40 cm Horizon: B1
Physiography: Upper slope of steep low hill.

Microstructures

Weakly to moderately developed subangular blocky structures. Channels separate ped faces. Ped faces are partially accommodating each other. Ped diameter is 1 – 2 mm. Channel voids are dominant along with few subrounded voids. Channels and voids are randomly distributed. The width of channels ranging between 50μm – 1mm and the diameter of subrounded voids ranging between 100μm – 2mm. Channel and void walls are undulating. Estimated porosity is 20 – 25%.

Basic mineral components

c/f limit at 30μm; the ratio of 10:90.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral, fractured feldspar (50%), quartz (45%) and heavy minerals (~5%). The diameter of feldspar and quartz grains ranging between 50 – 550 μm. Pellicular, cross linear and irregular linear alteration of feldspars are observed.

(b) Fine fraction

It consists of quartz, feldspar and heavy minerals.

Basic organic components

Few broken rootlets are present. Portions of rootlets are oxidized. The width of rootlets is about 300 μm and length ranging between 1-2 mm.

Groundmass

The c/f related distribution is single spaced to open porphyric. The micromass is reddish brown coloured. Mosaic-speckled b-fabric is observed.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings are present along channels and voids. Movement of ferriargillans is noticed through out the section. The thickness of hypo-coatings ranging between 30 - 150μm. The thickness of hypo-coatings is underestimated due to diffuse ferriargillans through out the section. Subrounded Fe-oxide mottles of 100 – 350μm diameter are present with a few having upto 2 mm diameter.

Sample No. J9/3

Location: Chunati, Lohagora Depth: 40 – 70 cm Horizon: B2
Physiography: Upper slope of steep low hill.

Microstructures

Weakly to moderately subangular blocky structures. Channels separate ped faces and ped faces are partially accommodating each other. Ped diameter ranging between 1 – 2 mm with a few larger peds of up to 3 mm diameter. Channel voids are dominant along with subrounded voids. Channels and voids are randomly distributed. The width of channels ranging between 50 - 700μm and the diameter of subrounded voids ranging between 100 - 700μm. Channel and void walls are undulating. Estimated porosity is 20 – 25%.

Basic mineral components

c/f limit at 30μm; the ratio of 15:85.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral, fractured feldspar (45%), fractured quartz (40%) and heavy minerals, muscovite and biotite (15%). About 90% of feldspar and quartz grains ranging between 50 - 750μm. Pellicular and irregular linear alteration of feldspars is observed.

(b) Fine fraction

It consists of quartz, feldspar, heavy minerals and micaceous particles.

Groundmass

The c/f related distribution is single to open spaced porphyric. The micromass is reddish brown coloured. Mosaic-speckled b-fabric is observed.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings are present along channels and voids. The thickness of hypo-coatings ranging between 50 – 200μm and at places the thickness is underestimated due to diffuse ferriargillans flow or coating throughout the section. Few moderately impregnated Fe-Mn oxide nodule of 350μm - 2mm diameter are present.

Sample No. J9/4

Location: Chunati, Lohagora Depth: 70 – 90 cm Horizon: B3
Physiography: Upper slope of steep low hill.

Microstructures

Moderately developed subangular blocky structures. Channels separate ped faces and ped faces are partially to completely accommodating each other. Ped diameter ranging between 2 – 3mm. Channel voids are dominant along with subrounded voids. Channels and subrounded voids are randomly distributed. The width of channels and the diameter of subrounded voids ranging between 50 - 700μm. Channel and void walls are undulating to smooth. Estimated porosity is 10 – 15%.

Basic mineral components

c/f limit at 30μm; the ratio of 25:75.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral, fractured feldspar (60%), quartz (30%) and heavy minerals and biotites (10%). Majority of the feldspar grains ranging between 100 - 800μm in diameter. Pellicular, parallel linear and irregular linear alteration of feldspars and biotites are observed.

(b) Fine fraction

It consists of quartz, feldspar and heavy minerals.

Groundmass

The c/f related distribution is single spaced to open porphyric. The micromass is reddish brown to yellowish brown. Mosaic-speckled b-fabric is observed.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings are present along channels and voids. The thickness of hypo-coatings ranging between 50 - 150μm and the thickness is underestimated due to diffuse ferruginous materials/coatings throughout the section. Few moderately to strongly impregnated Fe-Mn oxide nodule of 700μm - 2mm diameter are present.

Sample No. J9/5
Location: Chunati, Lohagora Depth: 90 – 140 cm Horizon: B4
Physiography: Upper slope of steep low hill.

Microstructures

Weakly developed subangular blocky structures to apedal soil material. Channels incompletely separate ped faces and ped faces are not accommodating each other. Channel voids are dominant along with subrounded voids. Channels and voids are randomly distributed. The width of channels ranging between 150 - 550µm and the diameter of subrounded voids ranging between 100 - 700µm with few irregular shaped voids having a diameter up to 2mm. Channel and void walls are undulating. Estimated porosity is 10 – 15%.

Basic mineral components

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

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral, fractured feldspar (50%), quartz (40%) and heavy minerals and biotite (10%). Majority of the feldspar and quartz grains ranging between 100 - 450µm. Weak pellicular alteration of feldspars is observed.

(b) Fine fraction

It consists of quartz, feldspar and heavy minerals.

Groundmass

The c/f related distribution is chitonic to gefuric. The micromass is reddish brown to yellowish brown coloured. Mosaic-speckled to stipple speckled b-fabrics are observed.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings are present along channels and voids. Movement of ferriargillans is noticed. The thickness of hypo-coatings ranging between 50 - 200µm.

SUB-MEMBER IVa

Island Hillocks

Sample No. M1/2
Location: Pani Chara, Maiskhali Depth: 20 – 55 cm Horizon: B1
Physiography: Upper slope of steep high hill.

Microstructures

Moderately developed subangular blocky structures and ped faces accommodating each other partially, separated by channels. Ped diameter ranging between 1 – 2 mm. Subrounded voids dominant along with channel voids. Voids and channels are randomly distributed. Void diameter ranges from 200 - 550µm and channel width ranges from 100 - 800µm. Void and channel walls are undulating. Estimated porosity is 15 – 20%.

Basic mineral components

c/f limit at 40µm; the ratio of 20:80.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral, fractured quartz and feldspars of about 40% and 50% respectively. The rest 10% comprises muscovite and biotite. Quartz and feldspar grains ranges from 200 - 450μm in diameter. Quartz and feldspars are highly fractured. Muscovite crystals are of 200 - 300μm in length and 30 - 50μm in width.

(b) Fine fraction

It consists of clay aggregates, micaceous particles and quartz. But their optical characters are very poorly defined.

Basic organic components

Impression of one root of ~500μm width is observed, replaced by channel void and filled with clayey materials. A portion of the zone is impregnated with iron oxides.

Groundmass

The c/f related distribution is single to double spaced porphyric. The micromass is yellowish brown to yellowish red coloured. It is assumed from the colour that it might be because of fine dispersed hematite, goethite or Fe-gel. Mosaic-speckled b-fabric observed throughout the section and parallel striated b-fabric is observed in the roots, replaced and filled by clayey materials.

Pedofeatures

Clay (argillans) and ferruginous (ferriargillans) coating and hypo-coating along voids and channels are observed. The thickness of coating and hypo-coating is 100μm or less. Few impregnated concretions / nodules of Fe-Mn oxides are present having a diameter of ~2mm.

Sample No. M1/3

Location: Pani Chara, Maiskhali Depth: 55 – 90 cm Horizon: B2
Physiography: Upper slope of steep high hill.

Microstructures

Moderately developed subangular blocky structures and ped faces accommodating each other separated by channels; ped diameter ranges between 1mm – 1.5mm. Subrounded voids are dominant along with channels and irregular shaped voids. Voids and channels are randomly distributed. Subrounded voids ranges from 200μm - 1.2mm in diameter. Channels have a width of 100 - 500μm. Void and channel walls are smooth to undulating. Estimated porosity is about 15%.

Basic mineral components

c/f limit at 30μm; the ratio of 10:90.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral quartz (50%), feldspar (40%) and muscovite and biotite (10%). Quartz and feldspar grains are highly fractured and the concentration is less from the upper horizon. About 80% of quartz and feldspar grains ranging in diameter from 100 - 350μm.

(b) Fine fraction

It consists of quartz, clay aggregates and micaceous particles. But their optical characters are very poorly defined.

Basic organic components

Rootlets are common in the section with a width ranging from 30 - 200μm. Portions of the roots are impregnated with iron oxides.

Groundmass

The c/f related distribution is single to double spaced porphyric. The micromass is yellowish brown to yellowish gray coloured. Mosaic-speckled b-fabric observed throughout the section. Within the root zone the groundmass is reddish might be because of iron oxides and or fine dispersed hematite. Porostriated b-fabric is also observed along channel voids.

Pedofeatures

Clay (argillans) and ferruginous (ferriargillans) hypo-coating along voids and channels are observed. The thickness of hypo-coating is about 30 - 100µm. Few rounded to subrounded Fe-oxide mottles of 150 - 250µm diameter and moderately impregnated Fe – Mn nodules with silt cappings on the top having a diameter of ~1.5 mm are present. Boundaries of mottles with adjacent groundmass are sharp with prominent contrast.

Sample No. M1/4

Location: Pani Chara, Maiskhali Depth: 90 – 140+ cm Horizon: C1

Physiography: Upper slope of steep high hill.

Microstructures

Weakly developed subangular blocky structure to apedal soil material. Rounded to subrounded voids are dominant with few channel, planner and irregular shaped voids. Voids and channels are randomly distributed. Diameter of rounded to subrounded voids ranging between 150µm -1mm. Width of channel and planner voids ranges from 50 - 450µm. Void and channel walls are undulating to smooth. Estimated porosity is 10 – 15%.

Basic mineral components

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

(a) Coarse fraction

Coarse fraction composed of anhedral to subhedral, fractured quartz (50%) and feldspars (30%) along with muscovite and biotite (20%). Quartz and feldspar grains ranges between 100 - 700µm in diameter. Few sporadic black and reddish grains are observed, might be of heavy minerals having diameter of 100 - 300µm.

(b) Fine fraction

It consists of clay aggregates, micaceous particles and quartz grains.

Basic organic components

Impression of one rootlet is observed having a width of ~300µm. Portion of root is impregnated with iron oxides.

Groundmass

The c/f related distribution is single to double spaced porphyric. The micromass is yellowish brown to yellowish red and gray coloured. The yellowish brown and yellowish red colour may be because of fine dispersed goethite and hematite or Fe-gel. Cross striated, parallel striated and discontinuous stipple-speckled b-fabrics are observed.

Pedofeatures

Clay (argillans) and ferruginous (ferriargillans) hypo-coating along voids and channels are observed. The thickness of hypo-coating is 30 - 100µm. Few moderately impregnated Fe-Mn nodules / concretions are present with a diameter of ~1.5mm and marked with silt cappings on the top.

MEMBER III

Proximal Piedmont Plains

Sample No. J1/2

Location: Dakhin Kanchana, Satkania   Depth: 12 – 24 cm   Horizon: Ap2
Physiography: Nearly level Piedmont plain   Flooding: Occasionally flooded.

Microstructures

Weakly developed subangular blocky structures to apedal soil material. Channel voids are dominant along with few subrounded and irregular shaped voids. Channel and voids are randomly distributed. The channel width ranging between 400µm - 2mm and the subrounded voids ranging between 150 - 700µm in diameter. Few irregular shaped voids having diameter greater than 2mm. Void walls are rough to undulating. Estimated porosity is 15 – 20%.

Basic mineral components

c/f limit at 30µm; the ratio 20:80.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured feldspar (50%), quartz (30%); and biotite and muscovite composes the rest (20%). Feldspar and quartz grains ranging in diameter between 100 - 500µm. Pellicular alteration of feldspars and biotites are observed.

(b) Fine fraction

It is composed of quartz, feldspar, micaceous particle and clay aggregates.

Basic organic components

Few broken channel shaped root like impressions are observed. The width of rootlets ranging between 150 - 500µm and having lengths between 500µm - 1mm.

Groundmass

The c/f related distribution is single to double spaced porphyric. The micromass is yellowish brown to gray coloured and at places reddish brown to red. The reddish brown colour concentrated around the Fe-Mn oxide nodules and might be because of fine dispersed hematite and or Fe-gel. Mosaic-speckled, parallel to random striated b-fabric and porostriated b-fabrics are observed.

Pedofeatures

Clay (argillans) coatings and hypo-coatings along channel and void walls are observed. The thickness of coatings and hypo-coatings ranging between 50 - 200µm. Few subrounded strongly impregnated Fe-Mn oxide nodule are present having diameter ~ 2mm.

Sample No. J1/3

Location: Dakhin Kanchana, Satkania   Depth: 24 – 42 cm   Horizon: B1
Physiography: Nearly level Piedmont plain   Flooding:Occasionally flooded.

Microstructures

Weakly developed subangular blocky structures. Ped faces are partially or not accommodating each other. Subrounded voids dominant along with few channel voids. Void and channels are randomly distributed. The diameter of subrounded voids ranging between 300μm – 1mm. Few subrounded voids having diameter up to 1.5 mm. The channel width ranging between 200 - 700μm. Void and channel walls are rough to undulating. Estimated porosity is 15 – 20%.

Basic mineral components

c/f limit at 40μm; the ratio of 25:75.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured feldspar (50%) and quartz (40%) and the rest 10% is composed of biotite and muscovite. Majority of feldspar and quartz grains ranging between 100 - 550μm in diameter. Pellicular alteration of feldspar and biotites and parallel alteration of biotites are observed.

(b) Fine fraction

It consists of quartz, feldspar and micaceous particles.

Groundmass

The c/f related distribution is single spaced porphyric. The micromass is yellowish brown to gray coloured and at some places yellowish red or reddish brown coloured. The yellowish red or reddish brown colour might be because of fine dispersed goethite, hematite and or Fe-gel. Mosaic-speckled and random striated b-fabrics along with porostriated b-fabrics are observed.

Pedofeatures

Clay (argillans) and ferruginous (ferriargillans) hypo-coating along voids and channels are observed. Ferruginous hypo-coating is dominant. The thickness of hypo-coatings ranging between 50 - 150μm. Few rounded to subrounded Fe-oxide mottles of 300 - 450μm diameter are present.

Sample No. J1/4

Location: Dakhin Kanchana, Satkania Depth: 42 – 70 cm Horizon: B2
Physiography: Nearly level Piedmont plain Flooding:Occasionally flooded.

Microstructures

Weakly developed subangular blocky structures. Ped faces are partially or not accommodating each other. Ped diameter is 1 – 2 mm. Channel voids are dominant along with few rounded to subrounded voids. Few vertically parallel channels are present and rest voids are randomly distributed. The width of channels and diameter of subrounded voids ranging between 300 - 700μm. Channel and void walls are undulating. Estimated porosity is about 20%.

Basic mineral components

c/f limit at 30μm; the ratio of 30:70

(a) Coarse fraction

Coarse fraction comprises annedral to subhedral and fractured feldspar (50%), quartz (30%) and biotite, muscovite and heavy minerals (20%). About 90% of feldspar and quartz grains ranging in diameter between 100 - 550μm.

Pellicular alteration of feldspar and biotite along with parallel alteration of biotites are observed.

(b) Fine fraction

It consists of quartz, feldspar, micaceous particles and heavy minerals.

Basic organic components

Impression of one rootlet is observed having a width of ~350µm. The root is impregnated on the walls with iron oxides.

Groundmass

The c/f related distribution is single to double spaced porphyric. The micromass is yellowish brown to gray coloured and at places yellowish red or reddish brown coloured. The micromass might be containing fine dispersed goethite, hematite and or Fe-gel. Mosaic-speckled and random striated b-fabrics are observed.

Pedofeatures

Ferruginous (ferriargillans) hypo-coating along channels and voids are observed. The thickness of hypo-coating ranging between 30 - 200µm. Few moderately impregnated Fe-Mn oxide nodules are present having a diameter of 150 - 600µm.

Sample No. J1/5

Location: Dakhin Kanchana, Satkania Depth: 70 – 142 cm Horizon: B3
Physiography: Nearly level Piedmont plain Flooding: Occasionally flooded.

Microstructures

Weakly developed subangular blocky structures to apedal soil material. Channel voids are dominant along with subrounded to irregular shaped voids. Channels and subrounded voids are randomly distributed. The channel width ranging between 150 - 500µm and the diameter of subrounded voids ranging between 150 - 700µm. Few irregular shaped voids having a diameter ~2mm. Channel and void walls are undulating to rough. Estimated porosity is 10 – 15%.

Basic mineral components

c/f limit at 30µm; the ratio of 15:85.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured feldspars about 50%. The rest is composed of fractured quartz (40%), biotite and muscovite. Fractured feldspar and quartz grains ranging in diameter between 150 - 600µm. Pellicular alteration of feldspars and parallel linear alteration of biotites are observed.

(b) Fine fraction

It consists of quartz, feldspar and micaceous particles.

Groundmass

The c/f related distribution is single to double spaced porphyric. The micromass is yellowish brown to yellowish red at the upper part and yellowish gray to gray in the lower portion. It seems that the oxidation process is reduced in the lower part. Mosaic-speckled, random striated and cross striated b-fabrics are observed.

Pedofeatures

Clay (argillans) and ferruginous (ferriargillans) coatings and hypo-coatings are observed along channels and voids. The thickness of coatings and hypo-coatings ranging between 50 - 200µm. Flow of ferriargillans are noticed at the upper portion. Few subrounded to irregular Fe-oxide mottles are observed of 1 – 2 mm diameter. Few moderately impregnated Fe-Mn oxide nodules of 2mm diameter is also observed.

Sample No. J1/6

Location: Dakhin Kanchana, Satkania Depth: 142 – 170 cm Horizon: B1
Physiography: Nearly level Piedmont plain Flooding: Occasionally flooded.

Microstructures

Apedal soil material. Subrounded voids are dominant along with irregular shaped voids. Voids are randomly distributed. The diameter of subrounded voids ranging between 100 - 700µm and few irregular shaped voids having a diameter >1mm. Void walls are undulating to rough. Estimated porosity is 10 – 15%.

Basic mineral components

c/f limit at 30µm; the ratio of 25:75.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured feldspar (40%) and fractured quartz (40%) and biotite and muscovite (20%). Fractured feldspar and quartz grains ranging in diameter between 70 - 350µm. Alteration of feldspar and mica is very less.

(b) Fine fraction

It consists of quartz, feldspar and micaceous particles.

Groundmass

The c/f related distribution is single spaced porphyric. The micromass is yellowish gray to gray coloured. Parallel striated b-fabric and at places undifferentiated b-fabrics are observed.

Pedofeatures

Clay (argillans) hypo-coatings are observed along voids. The thickness of hypo-coatings ranging between 30 - 150µm.

Sample No. J2/3

Location: Dakhin Kanchana, Satkania Depth: 30 – 50 cm Horizon: B2
Physiography: Nearly level Piedmont plain Flooding: Occasionally flooded.

Microstructures

Weakly developed subangular blocky structures to apedal soil material. Channels and voids separate ped faces. Ped faces are not accommodating each other. Subrounded voids are dominant along with channels. Voids and channels are randomly distributed. The diameter of subrounded voids ranging between 200 - 850µm with few subrounded voids having diameter up to 1.5 mm. The width of channels ranging between 100 - 700µm. Void and channel walls are rough to undulating. Estimated porosity is 15 – 20%.

Basic mineral components

c/f limit at 30µm; the ratio of 15:85.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral, fractured feldspar (50%), quartz (30%) and muscovite, biotite and heavy minerals (20%). About 90% of feldspar and quartz grains ranging between 100 - 350μm in diameter. Pellicular alteration of feldspars is observed.

(b) Fine fraction

It consists of quartz, few feldspar and micaceous particles.

Groundmass

The c/f related distribution is single spaced porphyric. The micromass is yellowish brown to yellowish gray coloured. Random striated and mosaic-speckled b-fabrics are observed.

Pedofeatures

Clay (argillans) hypo-coatings along void and channels are observed. Few irregular (discontinuous) quasi-coatings are also observed. The thickness of hypo-coatings ranging between 100 - 200μm. Strongly impregnated subrounded Fe-Mn oxide nodules of 550μm - 2mm diameter is present. The nodules have silt cappings on the top.

Sample No. J2/4

Location: Dakhin Kanchana, Satkania Depth: 50 – 80 cm Horizon: B3
Physiography: Nearly level Piedmont plain Flooding: Occasionally flooded.

Microstructures

Weakly developed subangular blocky structures. Voids and channels separate peds and ped faces are not accommodating each other. Rounded to subrounded voids are dominant along with channels. Voids and channels are randomly distributed. The diameter of subrounded voids ranging between 150μm – 1mm with few larger voids. The width of channels ranging between 100 - 700μm. Void and channel walls are undulating to smooth. Estimated porosity is 20 – 25%.

Basic mineral components

c/f limit at 30μm; the ratio of 10:90.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured feldspar (50%), quartz (35%) and muscovite and biotite (15%). Majority of feldspar and quartz grains ranging in diameter between 100 - 550μm. Pellicular alteration of feldspars and biotites are observed.

(b) Fine fraction

It consists of quartz, feldspar, micaceous particles and heavy minerals.

Groundmass

The c/f related distribution is single to double spaced porphyric. The micromass is yellowish gray to gray and around the Fe-Mn oxide nodules, the micromass is reddish may be because of fine dispersed hematite and or Fe-gel. Cross striated and mosaic-speckled b-fabrics are observed.

Pedofeatures

Very thin clay (argillans) and ferruginous (ferriargillans) hypo-coatings along voids and channels are present. Flow of argillans and ferriargillans are noticed. The thickness of hypo-coatings is about 30 - 100μm. Few moderately impregnated Fe-Mn oxide nodules of 1 - 2mm diameter are present.

Sample No. J2/5
Location: Dakhin Kanchana, Satkania Depth: 80 – 100 cm Horizon: B4
Physiography: Nearly level Piedmont plain Flooding: Occasionally flooded.
Microstructures

Weakly developed subangular blocky structures. Channels and voids separate ped faces. Ped faces are partially or not accommodating each other. Smallest ped diameter is about 1mm. Rounded to subrounded voids dominant along with channel voids. Subrounded voids and channels are randomly distributed. The diameter of subrounded voids and the width of channels ranging between 100 - 700µm. Few irregular shaped void having a diameter of >1mm are also present. Void and channel walls are undulating to rough. Estimated porosity is 20%.

Basic mineral components
c/f limit at 30µm; the ratio of 10:90.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured feldspar (40%), quartz (30%) and muscovite, biotite and heavy minerals (30%). Majority of feldspar and quartz grains ranging between 50 - 300µm in diameter. Pellicular alteration of feldspars and biotites are observed.

(b) Fine fraction

It consists of quartz, feldspar, micaceous particles and heavy minerals.

Basic organic components

Few rootlets are present. Portions of which are impregnated with iron oxides. The width of the rootlets are ~1mm.

Groundmass

The c/f related distribution is double spaced to open porphyric. The micromass is yellowish gray to gray and around the Fe-Mn oxide nodules the micromass is reddish (under crossed polarized light), may be due to fine dispersed hematite and or Fe-gel. Parallel striated, cross striated and mosaic-speckled b-fabrics are found.

Pedofeatures

Clay (argillans) and ferrugineous (ferriargillans) hypo-coatings are present along voids and channels. Irregular flow of ferriargillans is also noticed. The thickness of hypo-coatings ranging between 50 - 150µm. Few weakly to moderately impregnated, orthic, Fe-Mn oxide nodules of ~ 2mm diameter is present. Few of the nodules contain silt cappings on the top.

Sample No. J2/6
Location: Dakhin Kanchana, Satkania Depth: 100-140+ cm Horizon: C
Physiography: Nearly level Piedmont plain Flooding: Occasionally flooded.
Microstructures

Weakly developed subangular blocky structures. Smallest ped diameter is greater than 1mm. Ped faces are not accommodating each other. Channel voids are dominant along with subrounded voids. Channels and voids are randomly distributed. The width of channels ranging between 100 - 550µm and the diameter of subrounded voids ranging between 150 - 300µm. Channel and void walls are undulating. Estimated porosity is about 15%.

Basic mineral components
c/f limit at 30µm; the ratio of 10:90.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured feldspar (60%), quartz (35%) and muscovite and biotite (10%). Feldspar and quartz grains ranging between 30 - 200µm in diameter.

(b) Fine fraction

It consists of quartz, micaceous particles and clay aggregates.

Basic organic components

Two long roots are present and portions of which are impregnated with iron oxides. The width of roots is about 1mm.

Groundmass

The c/f related distribution is double spaced to open porphyric. The micromass is yellowish gray to gray coloured and around the root zones it is yellowish brown coloured. Parallel striated, cross striated, mosaic-speckled and porostriated b-fabrics are observed.

Pedofeatures

Clay (argillans) and ferruginous (ferriargillans) hypo-coatings are present along channels and voids. The hypo-coatings are ~ 100 µm thick. Flow of ferriargillans is noticed.

Sample No. M3/2

Location: Kalalliakhata, Maiskhali Depth: 10 – 30 cm Horizon: Ap2g
Physiography: Nearly level Piedmont plain Flooding: Occasionally flooded.

Microstructures

Weakly developed subangular blocky structures to apedal soil material. Subrounded to vughy voids present. The diameter of subrounded voids ranging between 300 - 700µm and vughy voids is up to 3 mm in diameter. Voids are randomly distributed. Void walls are undulating. Estimated porosity is 20 – 25%.

Basic mineral components
c/f limit at 30µm; the ratio of 20:80.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured quartz and feldspars of about 50% and 35% respectively. The rest 15% is composed of biotite and muscovite. Majority of quartz and feldspar grains ranging between 100 - 550µm in diameter. Pellicular alteration of feldspars and biotites are observed.

(b) Fine fraction

It consists of quartz and micaceous particles.

Basic organic components

Rootlets are present in the section. Portion of the roots are impregnated with iron oxides and with carbonaceous materials. The width of rootlets ranging between 50 - 200µm.

Groundmass

The c/f related distribution is single spaced porphyric. The micromass is yellowish brown, yellowish red and gray coloured. Mosaic-speckled, random striated and porostriated b-fabrics are observed.

Pedofeatures

Clay (argillans) and ferruginous (ferriargillans) hypo-coatings along voids are observed. The thickness of hypo-coatings varies between 50 - 200µm. Few moderately impregnated Fe-Mn oxide nodules are present having a diameter of 200 - 550µm.

Sample No. M3/3

Location: Kalalliakhata, Maiskhali Depth: 30 – 55 cm Horizon: B1g
Physiography: Nearly level Piedmont plain Flooding: Occasionally flooded.

Microstructures

Moderately to weakly developed subangular blocky structures. Ped faces partially accommodating each other separated by channel voids. Ped diameter ranging between 1.5 – 2mm. Channel voids are dominant along with few subrounded to elliptical voids. Channel width ranging between 100µm – 1mm and subrounded voids ranging between 150 - 550µm in diameter. Void walls are undulating to smooth. Estimated porosity is 15 – 20%.

Basic mineral components

c/f limit at 30µm; the ratio of 15:85.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured quartz (50%), feldspar (30%) and biotite and muscovite (20%). The size and concentration of fractured feldspar and quartz grains reduces from the upper horizon. About 90% of quartz and feldspar grains ranging between 100 - 350µm. Weak pellicular alteration of feldspars and biotites are observed.

(b) Fine fraction

It consists of quartz, feldspar, micaceous particles and clay aggregates.

Basic organic components

Rootlets are present in the section. Rootlets are impregnated with ferruginous and carbonaceous materials. The width of rootlets ranging between 50 - 200µm and the length is about 1 – 2 mm.

Groundmass

The c/f related distribution is single spaced porphyric. The micromass is yellowish brown to gray coloured. Mosaic-speckled, cross- and random striated and porostriated b-fabrics are observed.

Pedofeatures

Clay (argillans) and ferruginous (ferriargillans) hypo-coating along channels are present. The thickness of hypo-coatings varying between 100 - 200µm. Few Fe-oxide mottles of 200µm – 1mm diameter are observed.

Sample No. M3/4

Location: Kalalliakhata, Maiskhali Depth: 55 – 90 cm Horizon: B2g
Physiography: Nearly level Piedmont plain Flooding: Occasionally flooded.

Microstructures

Moderately to weakly developed subangular blocky structures. Ped faces partially accommodating each other. Ped diameter ranges between 1 – 2mm. Subrounded to irregular shaped voids dominant. Few channels are also present. The diameter of subrounded voids ranging between 150 - 700µm.

Few irregular shaped voids having a diameter greater than 2mm. The channel widths ranging between 300 - 700μm. Void walls are smooth to undulating. Estimated porosity is 10 – 15%.

Basic mineral components

c/f limit at 40μm; the ratio of 15:85.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral quartz and fractured feldspar grains about 80%. The rest (20%) is composed of biotite, muscovite and heavy minerals. Majority of quartz and feldspar grains ranging between 100 - 450μm in diameter. Pellicular alteration of feldspar and biotites are observed.

(b) Fine fraction

It consists of quartz, micaceous particles and few heavy minerals identified by their black to deep reddish colour only.

Groundmass

The c/f related distribution is single spaced porphyric. The micromass is yellowish gray to gray coloured. Mosaic-speckled b-fabric is observed.

Pedofeatures

Clay (argillans) and ferruginous (ferriargillans) hypo-coating along voids and channels are observed. The hypo-coatings are ~150μm thick.

Sample No. M3/5

Location: Kalalliakhata, Maiskhali Depth: 90 – 120+cm Horizon: C1
Physiography: Nearly level Piedmont plain Flooding: Occasionally flooded.

Microstructures

Weakly developed subangular blocky structure to apedal soil material. Subrounded voids are dominant along with channels. Void and channels are randomly distributed. Subrounded voids ranging in diameter between 250μm - 1mm and channel width ranging between 250 - 600μm. Void walls are smooth to undulating. Estimated porosity is 15%.

Basic mineral components

c/f limit at 30μm; the ratio of 10:90.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral quartz (50%) and fractured feldspar (30%). The rest (20%) is composed of biotite, muscovite and few grains of heavy minerals. Feldspar and quartz grains ranging between 100 - 350μm.

(b) Fine fraction

It consists of quartz, micaceous particles, few feldspar grains and few heavy minerals identified by their black to deep reddish colour only.

Groundmass

The c/f related distribution is single to double spaced porphyric. The micromass is yellowish gray to gray coloured. Mosaic-speckled b-fabric is observed.

Pedofeatures

Clay (argillans) and ferruginous (ferriargillans) hypo-coatings along voids and channels are observed. The hypo-coating thickness ranging between 75 - 150µm. Few moderately to strongly impregnated Fe-Mn oxide nodule are present having a diameter of 200µm - 2mm.

Sample No. M4/2

Location: Adinath, Maiskhali Depth: 10 -- 30 cm Horizon: Ap2g
Physiography: Nearly level Piedmont plain Flooding: Occasionally flooded.

Microstructures

Apedal soil material. Subrounded voids are dominant along with few irregular shaped voids. Voids are randomly distributed. The diameter of subrounded voids ranging between 150 - 700µm. Void walls are undulating to smooth. Estimated porosity is 15%.

Basic mineral components

c/f limit at 40µm; the ratio of 15:85.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral quartz and feldspar about 50% and 30% respectively. The rest (20%) comprises muscovite and biotite. Quartz and feldspar grains ranging in diameter between 100 - 450µm. Complex and pellicular alteration of feldspar and pellicular alteration of biotites are observed.

(b) Fine fraction

It consists of quartz, few feldspar and micaceous particles and clay aggregates. But the optical properties are very poorly defined

Groundmass

The c/f related distribution is single to double spaced porphyric. The micromass is yellowish brown to gray coloured. The micromass shows random striated and mosaic-speckled b-fabric.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings along voids are observed. The thickness of hypo-coatings ranging between 75 - 150µm. Few rounded to subrounded Fe-oxide mottles of 300 - 600µm diameter is present.

Sample No. M4/3

Location: Adinath, Maiskhali Depth: 30 – 60 cm Horizon: B1
Physiography: Nearly level Piedmont plain Flooding: Occasionally flooded.

Microstructures

Weakly to moderately developed subangular blocky structures. Channels separate peds. Ped faces are partially or not accommodating each other. Ped diameter ranging between 1 – 2mm. Channels and voids are randomly distributed. The channel width ranging between 200 - 550µm. Subrounded voids ranging between 100 - 450µm in diameter. Channel and void walls are smooth to undulating. Estimated porosity is 15 – 20%.

Basic mineral components

c/f limit at 30µm; the ratio of 15:85.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral quartz (~45%), feldspar (50%) and muscovite and biotite (5%). Quartz and feldspars are less fractured. About 90% of quartz and feldspar grains ranging between 100 - 350µm in diameter. Pellicular alteration of feldspars is observed.

(b) Fine fraction

It consists of quartz, few feldspar, micaceous particles and clay aggregates.

Groundmass

The c/f related distribution is single to double spaced porphyric. The micromass is yellowish brown to gray coloured and at places, because of ferruginous materials it appears to be yellowish red coloured. Mosaic-speckled b-fabric and parallel striated b-fabrics are observed.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings and quasi-coatings are present along the channels. Irregular flow of ferruginous coatings is also observed. The thickness of hypo-coatings ranging between 50 - 120μm and the thickness of quasi-coatings ranging between 100 - 200μm. Few weakly impregnated Fe-Mn oxide nodules of 300 - 450μm diameter are present.

Sample No. M4/4

Location: Adinath, Maiskhali Depth: 60 – 100+ cm Horizon: B2
Physiography: Nearly level Piedmont plain Flooding: Occasionally flooded.

Microstructures

Apedal soil material. Subrounded voids are dominant along with few channel voids. Voids and channels are randomly distributed. The diameter of subrounded voids ranging between 150 - 650μm and few subrounded voids having diameter in the range of 1-2 mm. The channel width ranging between 150 - 350μm. Void and channel walls are undulating. Estimated porosity is 15 – 20%.

Basic mineral components

c/f limit at 30μm; the ratio of 20:80.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral feldspar (50 - 60%), quartz (25%) and the rest (15 - 25%) is composed of muscovite, biotite and heavy minerals. About 90% of feldspar and quartz grains ranging in diameter between 100 - 350μm. Pellicular alteration of feldspars are observed.

(b) Fine fraction

It is composed of quartz, few feldspar, micaceous particles and heavy mineral grains.

Groundmass

The c/f related distribution is single to double spaced porphyric. The micromass is yellowish brown to yellowish gray coloured. Random striated and mosaic-speckled b-fabrics are observed.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings along the voids are observed. The thickness of hypo-coatings is about 50 - 60μm. Discontinuous flow of ferruginous materials is noticed. Weakly impregnated, orthic, Fe-Mn oxide nodules of 450μm - >2mm diameter is found.

MEMBER II

Distal Piedmont Plains

Sample No. J4/2

Location: Dakhin Kanchana, Satkania Depth: 20 – 65 cm Horizon: B1
Physiography: Level Piedmont plain Flooding: Flooded for 2-3 months.

Microstructures

Moderately developed subangular blocky structures. Ped faces are separated by channels and accommodating each other. Smallest ped diameter is 500µm – 2 mm. Channels are dominant along with subrounded voids. Channels and voids are randomly distributed. The width of channels ranging between 30 – 200 µm and the diameter of subrounded voids ranging between 100 – 200 µm. Walls of channels and voids are smooth. Estimated porosity is 10 –15%.

Basic mineral components

c/f limit at 15 µm; the ratio of 2:98.

Coarse fraction

Coarse fraction comprises anhedral to subhedral feldspar and quartz about 90% and the rest is composed of heavy (opaque) minerals.

Basic organic components

Few broken rootlets and root like impressions are present. Few rootlets are oxidized, decomposed and blackish. The width of rootlets ranging between 30 - 50µm and length ranging between 300µm – 2 mm.

Groundmass

The c/f related distribution is open porphyric. The micromass is yellowish brown to gray coloured. Yellowish brown colour concentrates around the channels. Parallel striated and cross striated b-fabrics are found.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings are present along channels. The thickness of hypo-coatings ranging between 100 – 150 µm. Few moderately impregnated Fe-Mn oxide nodule and Fe-oxide mottles of ~ 1 mm diameter are present.

Sample No. J4/3

Location: Dakhin Kanchana, Satkania Depth: 65 – 100+ cm Horizon: C
Physiography: Level Piedmont plain Flooding: Flooded for 2-3 months.

Microstructures

Apedal to weakly developed subangular blocky structures. Channels indistinctly separate ped faces. Channels are dominant along with subrounded voids. Channels and voids are randomly distributed. The width of channels ranging between 30 – 200 µm and the diameter of subrounded voids ranging between 100 – 200 µm. Walls of channels and voids are smooth. Estimated porosity is 10 –15%.

Basic mineral components

c/f limit at 15 µm; the ratio of 2:98.

Coarse fraction

Coarse fraction comprises anhedral to subhedral feldspar and quartz about 90% and the rest is composed of heavy (opaque) minerals.

Basic organic components

Few broken rootlets and root like impressions are present. Few rootlets are oxidized, decomposed and blackish. The width of rootlets ranging between 30 - 50μm and length ranging between 300μm – 1.5 mm.

Groundmass

The c/f related distribution is open porphyric. The micromass is yellowish brown to gray coloured. Yellowish brown colour concentrates around the channels and where the concentration of plant remains increased. Parallel striated and cross striated b-fabrics are found.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings are present along channels. The thickness of hypo-coatings ranging between 50 – 100 μm. Few moderately impregnated Fe-Mn oxide nodule and Fe-oxide mottles of ~ 1 mm diameter are present.

Sample No. J10/2

Location: Adhunagar, Lohagara Depth: 15 – 40 cm Horizon: B1
Physiography: Level Piedmont plain Flooding: Flooded for 2-3 months.

Microstructures

Apedal soil material. Subrounded voids are dominant along with channel voids. Voids and channels are randomly distributed. The diameter of subrounded voids ranging between 100 - 500μm and the width of channels ranging between 30 - 400μm. Void and channel walls are smooth to undulating. Estimated porosity is 10 – 15%.

Basic mineral components

c/f limit at 30μm; the ratio of 10:90.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral feldspar (40%), quartz (30%) and muscovite, biotite and heavy minerals (30%). About 90% of feldspar and quartz grains ranging in diameter between 30 - 350μm. Few feldspar grains are fractured and weak pellicular alteration of feldspars is observed.

(b) Fine fraction

It consists of quartz, feldspar, micaceous particles and heavy minerals.

Groundmass

The c/f related distribution is single spaced to open porphyric. The micromass is yellowish brown to gray coloured. The micromass possess weakly developed cross striated and porostriated b-fabrics.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings are present along channels and voids. The thickness of hypo-coatings ranging between 100 - 300μm. Fe-oxide mottles of 150 - 850μm diameters are present.

Sample No. J10/3

Location: Adhunagar, Lohagara Depth: 40 – 75 cm Horizon: B2
Physiography: Level Piedmont plain Flooding: Flooded for 2-3 months.

Microstructures

Weakly developed subangular blocky structures to apedal soil material. Peds are not separated completely. Subrounded voids dominant along with channel voids. Subrounded voids and channels are randomly distributed. The diameter of subrounded voids ranging between 100 - 850μm and the width of channels ranging between 50 - 550μm. Void and channel walls are smooth to undulating. Estimated porosity is 15 – 20%.

Basic mineral components

c/f limit at 30μm; the ratio of 15:85.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured feldspar (50%), quartz (30%) and biotite, muscovite and heavy minerals (20%). About 95% of feldspar and quartz grains ranging in diameter between 100 - 350μm. Weak pellicular, parallel linear alteration of feldspar and pellicular alteration of few biotite grains are observed.

(b) Fine fraction

It consists of quartz, feldspar, micaceous particles and heavy minerals.

Groundmass

The c/f related distribution is single spaced to open porphyric. The micromass is yellowish gray coloured in the upper part and reddish brown coloured in the lower part. Random striated, parallel striated and porostriated b-fabrics are observed.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings are present along channels and voids. The thickness of hypo-coatings ranging between 100 - 300μm. Few diffused Fe-oxide mottles of ~550μm diameters are present.

Sample No. J10/4

Location: Adhunagar, Lohagara   Depth: 75 – 90 cm   Horizon: B3

Physiography: Level Piedmont plain   Flooding: Flooded for 2-3 months.

Microstructures

Weakly developed subangular blocky structures to apedal soil material. Ped are not separated completely. Subrounded voids are dominant along with channel voids. Subrounded voids and channels are randomly distributed. The diameter of subrounded voids ranging between 100 - 450μm and the width of channels ranging between 50 - 550μm. Walls of voids and channels are smooth to undulating. Estimated porosity is 20%.

Basic mineral components

c/f limit at 30μm; the ratio of 15:85.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured feldspar (50%), quartz (40%), and biotite, muscovite and heavy minerals (10%). About 90% of feldspar and quartz grains ranging between 50 - 450μm in diameter.

(b) Fine fraction

It consists of quartz, feldspar, micaceous particles and heavy minerals.

Groundmass

The c/f related distribution is single spaced to open porphyric. The micromass is yellowish brown to reddish brown coloured. Random striated and mosaic-speckled b-fabrics are observed.

Pedofeatures

Clay (argillans) and ferruginous (ferriargillans) hypo-coatings are present along channels and voids. The thickness of hypo-coatings ranging between 50 - 200μm. Movement of ferriargillans is observed. Few strongly impregnated Fe-Mn oxide nodules of 850μm - 2mm diameter are present.

Sample No. J10/5

Location: Adhunagar, Lohagara Depth: 90 – 110 cm Horizon: B4 / BC
Physiography: Level Piedmont plain Flooding: Flooded for 2-3 months.

Microstructures

Weakly developed subangular structures to apedal soil material. Subrounded voids are dominant along with channels and planar voids. Subrounded voids, channels and planar voids are randomly distributed. The diameter of subrounded voids ranging between150 - 850μm and the width of channels and planar voids ranging between 50 - 850μm. Walls of subrounded voids, channels and planar voids are undulating. Estimated porosity is 20%.

Basic mineral components

c/f limit at 30μm; the ratio of 20:80.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured feldspar (50%), quartz (30%) and muscovite, biotite and heavy minerals (20%). About 90% of feldspar and quartz grains ranging between 50 - 350μm in diameter.

(b) Fine fraction

It consists of quartz, feldspar, micaceous particles and heavy minerals.

Groundmass

The c/f related distribution is single spaced to open porphyric. The micromass is yellowish brown to gray coloured. Parallel striated and random striated b-fabrics.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings along voids and channels are present. The thickness of hypo-coatings ranging between 100 - 300μm. Few moderately impregnated Fe-Mn oxide nodules of 2mm diameters are present.

Sample No. J10/6

Location: Adhunagar, Lohagara Depth: 110 – 140+ cm Horizon: C
Physiography: Level Piedmont plain Flooding: Flooded for 2-3 months.

Microstructures

Apedal soil material. Subrounded voids are dominant along with few vughy voids. Voids are randomly distributed. The diameter of subrounded voids ranging between 100 - 850μm and few vughy voids having a diameter of >2mm. Void walls are undulating to rough. Estimated porosity is 10 – 15%.

Basic mineral components

c/f limit at 30μm; the ratio of 25:75.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral, fractured feldspar (60%), quartz (20%) and muscovite, biotite and heavy minerals (20%). About 90% of the feldspar and quartz grains ranging in diameter between 100 - 350μm.

(b) Fine fraction

It consists of quartz, feldspar, micaceous particles and heavy minerals.

Groundmass

The c/f related distribution is single spaced porphyric. The micromass is yellowish brown to reddish brown coloured. Discontinuous stipple speckled and mosaic-speckled b-fabrics are observed.

Pedofeatures

Ferruginous (ferriargillans) hypo-coatings are present along voids. The thickness of hypo-coatings ranging between 100 – 200μm. Movement of ferruginous materials is noticed.

MEMBER II

Old Tidal Flats

Sample No. J6/2

Location: Dongra, Banshkhali Depth: 20 – 80 cm Horizon: B1

Physiography: Old tidal flats Flooding: Flooded for 3-4 months.

Microstructures

Moderately to strongly developed subangular blocky structures. Channels separate ped faces. Ped faces are accommodating each other. Ped diameter ranging between 850μm – 2mm. Channel voids are dominant with few subrounded voids. Channels and voids are randomly distributed. The channel width ranging between 30 - 450μm and the diameter of subrounded voids ranging between 100 - 700μm with a few voids having 2mm diameter. Walls of channels and voids are undulating. Estimated porosity is 15 – 20%.

Basic mineral components

c/f limit at 25μm; the ratio of 2:98.

Coarse fraction

Coarse fraction comprises anhedral to subhedral feldspar (60%) and quartz(20%) and heavy minerals (20%). About 95% of feldspar and quartz grains ranging between 30 - 350μm.

Basic organic components

Few broken rootlets are present. Portions of rootlets are oxidized, decomposed and blackish. The width of rootlets ranging between 30 - 100μm and length ranging between 500μm - 1mm.

Groundmass

The c/f related distribution is open porphyric. The micromass is reddish brown, yellowish brown and gray coloured. Reddish brown colour dominated around channels and in portions where concentration of rootlets and Fe-oxide mottles increased. Cross striated, parallel striated and mosaic-speckled b-fabrics are observed.

Pedofeatures

Clay (argillans) and ferruginous (ferriargillans) hypo-coatings and quasi-coatings, gleyans are observed. The thickness of hypo-coatings, quasi-coatings and gleyans ranging between 100 - 300μm. Few Fe-oxide mottle of 200 - 300μm diameter and moderately impregnated Fe-Mn oxide nodule of ~800μm diameter are present.

Sample No. J6/3

Location: Dongra, Banshkhali Depth: 80 – 120+ cm Horizon: BC
Physiography: Old tidal flats Flooding: Flooded for 3-4 months.

Microstructures

Weakly developed subangular blocky structures. Ped faces are separated by channels and are partially accommodating each other. Ped diameter is >1mm. Channel voids are dominant along with subrounded voids. Channel and voids are randomly distributed. The width of channels ranging between 50 - 700μm and the diameter of subrounded voids ranging between 100 - 700μm. Walls of channels and voids are undulating. Estimated porosity is 15%.

Basic mineral components

c/f limit at 15μm; the ratio of 2:98.

Coarse fraction

Coarse fraction comprises anhedral to subhedral feldspar (50%) and quartz (30%) and heavy minerals (20%). Majority of feldspar and quartz grains ranging between 15 - 200μm.

Basic organic components

Few broken rootlets are present. Portions of rootlets are oxidized and impregnated with iron oxides. The width of rootlets ranging between 30 - 100μm and length ranging between 300μm – 1.5 mm.

Groundmass

The c/f related distribution is open porphyric. The micromass is reddish brown, yellowish brown to gray coloured. Reddish brown colour dominates around channels and in portions where concentration of rootlets and mottles increased. Cross striated and parallel striated b-fabrics are observed.

Pedofeatures

Clay (argillans) hypo-coatings are present along channels and voids. Few patches of ferruginous (ferriargillans) hypo-coatings and irregular movements of ferriargillans are observed. The thickness of hypo-coatings ranging between 100 - 200μm. Few subrounded Fe-oxide mottles of 200 - 450μm diameter are present.

Sample No. M2/2

Location: Dakhin Hoanok, Maiskhali Depth: 20 – 40 cm Horizon: B1g
Physiography: Old tidal flats Flooding: Flooded for 2-3 months.

Microstructures

Apedal soil material. Channel voids dominant along with subrounded to irregular shaped voids. Voids are randomly distributed. Channel width ranges from 450 - 700μm. Diameter of subrounded voids ranges from 150 - 700μm and few have a diameter of 2mm. Void walls are smooth to undulating. Estimated porosity is 15 – 20%.

Basic mineral components

c/f limit at 30µm; the ratio of 10:90.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral, fractured quartz and feldspar grains of about 40% and 50% respectively. Muscovite and biotite composes rest 10%. Quartz and feldspar grains ranging from 100 - 400µm in diameter.

(b) Fine fraction

It consists of quartz, micaceous particles, clay aggregates and heavy minerals.

Basic organic components

Rootlets are common in the section. Portion of roots are impregnated with iron oxides. Width of rootlets ranges between 200 - 500µm and length is of 1 – 2 mm.

Groundmass

The c/f related distribution is single to double spaced porphyric. The micromass is yellowish brown to yellowish gray coloured. Mosaic-speckled, cross striated and porostriated b-fabrics are observed.

Pedofeatures

Clay (argillans) coating and hypo-coatings and gleyans along channels and subrounded voids are observed. The thickness of coating, hypo-coatings and gleyans varies between 50 - 250µm and the thickness are greater along the subrounded voids. Few weakly impregnated orthic nodule of Fe-Mn oxides are present having a diameter ranging between 300 - 450µm.

Sample No. M2/3

Location: Dakhin Hoanok, Maiskhali Depth: 40 – 70 cm Horizon: B2g
Physiography: Old tidal flats Flooding: Flooded for 2-3 months.

Microstructures

Moderately developed subangular blocky structures; peds are separated by channels and planner voids. Ped faces are generally accommodating each other. Ped diameter ranges from 700µm to greater than 2mm. Channels and planner voids dominant along with few subrounded voids. The width of channel and planner voids ranging between 30 - 200µm. Subrounded void diameter ranging between 150 - 600µm. Void walls are smooth to undulating. Estimated porosity is about 20%.

Basic mineral components

c/f limit at 30µm; the ratio of 5:95.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral quartz (30%), fractured feldspars (60%) and muscovite and biotite (10%). About 90% of quartz and feldspar grains ranging between 30 - 600µm in diameter.

(b) Fine fraction

It consists of quartz, micaceous particles and few clay aggregates. Few fine black and reddish particles are also noticed may be heavy minerals but beyond identification under simple polarizing microscope.

Basic organic components

Few small remains of roots are noticed with a length of 150 - 350µm and are impregnated with iron oxides.

Groundmass

The c/f related distribution is open porphyric. The micromass is yellowish gray to gray coloured and around the root zone the micromass is reddish to yellowish red in colour. Cross striated to mosaic-speckled b-fabric and porostriated b-fabrics are observed.

Pedofeatures

Clay (argillans) and ferruginous (ferriargillans) hypo-coatings and gleyans are observed. The thickness of hypo-coating ranges from 150 - 300µm. Few rounded to subrounded Fe-oxide mottles of 300 - 600µm diameter are present.

Sample No. M2/4

Location: Dakhin Hoanok, Maiskhali Depth: 70 – 110+cm Horizon: Cg
Physiography: Old tidal flats Flooding: Flooded for 2-3 months.

Microstructures

Apedal soil material. Subrounded to rounded voids dominant along with few channel voids. Voids are randomly distributed. Subrounded to rounded void diameter ranging between 100 - 450µm and the width of channel voids ranging between 30 - 200µm. Void walls are undulating. Estimated porosity is 15 – 20%.

Basic mineral components

c/f limit at 30µm; the ratio of 2:98.

(a) Coarse fraction

Coarse fraction comprises anhedral to subhedral and fractured feldspars (~80%) and the rest 20% is composed of quartz, muscovite and biotite. Fractured feldspar and quartz grains are very few and very small in size in comparison to the upper horizons. Feldspar and quartz grains ranging between 30 - 300µm in diameter.

(b) Fine fraction

It consists of quartz and micaceous particles.

Groundmass

The c/f related distribution is open porphyric. The micromass is yellowish gray to gray coloured. Parallel striated to cross striated b-fabric and mosaic-speckled b-fabrics are observed.

Pedofeatures

Clay (argillans) coating and hypo-coating along subrounded and channel voids. The thickness of coatings and hypo-coatings ranging between 50 - 200µm.

Remarks : Feldspar is found to be dominant in mineral fractions of the soils of the area. This is also confirmed through Thermoluminescence studies of the mineral fraction.

APPENDIX - III
Age Calculation by Grun Software
(Subroutine for Feldspar Grains)

Mainland Higher Hillocks
Sample No. J5

Location		Jaldi			
Dose	[Gy]	153.10± 11.29	U-Sediment	[ppm]	4.10± 1.25
U-Content	[ppm]	0.00± 0.00	Th-Sediment	[ppm]	10.37± 4.86
Th-Content	[ppm]	0.00± 0.00	K-Sediment	[%]	1.64± 0.08
K-Content	[%]	0.00± 0.00	Water Sed.	[WGT%]	10.00± 5.00
Alpha Efficiency		0.07± 0.00	For α/β Irr. Only	?	N
Beta Attenuation?		Y	Ext. Alpha	[μGy/a]	0.00± 0.00
Diameter	[μm]	7.50± 3.50	Av. α-Attenuation	?	N
Layer Removed	[μm]	0.00± 0.00	Ext. Beta	[μGy/a]	0.00± 0.00
Density	[g/cm^3]	2.60± 0.00	Av. β-Attenuation	?	N
Int. Alpha	[μGy/a]	0.00± 0.00	Ext. Gamma	[μGy/a]	0.00± 0.00
Av. α-Selfirr.	?	N	Water att. For ext	?	N
Int. Beta	[μGy/a]	0.00± 0.00	Cosmic	[μGy/a]	150.00± 30.00
Av. β-Selfirr.	?	N			

RESULTS		
Age [a]		34779 ± 6718
Σ Dose Rate [μGy/a]		4402 ± 786
	Internal	External
α	0 ± 0	1060 ± 293
β	0 ± 0	1947 ± 245
τ + cos		1396 ± 271

External Attenuation Factors	Alpha	Beta
U	0.921 ± 0.039	0.984 ± 0.007
Th	0.933 ± 0.033	0.972 ± 0.010
K		0.998 ± 0.001

Remarks: External Attenuation Factors are constant for Feldspar grains.

Mainland Higher Hillocks
Sample No. J7

Location		Jaldi			
Dose	[Gy]	101.18± 9.63	U-Sediment	[ppm]	3.71± 1.16
U-Content	[ppm]	0.00± 0.00	Th-Sediment	[ppm]	8.25± 3.93
Th-Content	[ppm]	0.00± 0.00	K-Sediment	[%]	0.93± 0.05
K-Content	[%]	0.00± 0.00	Water Sed.	[WGT%]	10.00± 5.00
Alpha Efficiency		0.07± 0.00	For α/β Irr. Only	?	N
Beta Attenuation?		Y	Ext. Alpha	[μGy/a]	0.00± 0.00
Diameter	[μm]	7.50± 3.50	Av. α-Attenuation	?	N
Layer Removed	[μm]	0.00± 0.00	Ext. Beta	[μGy/a]	0.00± 0.00
Density	[g/cm^3]	2.60± 0.00	Av. β-Attenuation	?	N
Int. Alpha	[μGy/a]	0.00± 0.00	Ext. Gamma	[μGy/a]	0.00± 0.00
Av. α-Selfirr.	?	N	Water att. For ext	?	N
Int. Beta	[μGy/a]	0.00± 0.00	Cosmic	[μGy/a]	150.00± 30.00
Av. β-Selfirr.	?	N			

RESULTS		
Age [a]		30145 ± 6633
Σ Dose Rate [μGy/a]		3356 ± 666
	Internal	External
α	0 ± 0	912 ± 254
β	0 ± 0	1339 ± 201
τ + cos		1106 ± 226

Mainland Lower Hillocks

Sample No. J3

Location		Jaldi			
Dose	[Gy]	103.32± 19.43	U-Sediment	[ppm]	2.81± 1.32
U-Content	[ppm]	0.00± 0.00	Th-Sediment	[ppm]	14.44± 5.01
Th-Content	[ppm]	0.00± 0.00	K-Sediment	[%]	1.37± 0.07
K-Content	[%]	0.00± 0.00	Water Sed.	[WGT%]	10.00± 5.00
Alpha Efficiency		0.07± 0.00	For α/β Irr. Only	?	N
Beta Attenuation?		Y	Ext. Alpha	[μGy/a]	0.00± 0.00
Diameter	[μm]	7.50± 3.50	Av. α-Attenuation	?	N
Layer Removed	[μm]	0.00± 0.00	Ext. Beta	[μGy/a]	0.00± 0.00
Density	[g/cm^3]	2.60± 0.00	Av. β-Attenuation	?	N
Int. Alpha	[μGy/a]	0.00± 0.00	Ext. Gamma	[μGy/a]	0.00± 0.00
Av. α-Selfirr.	?	N	Water att. For ext	?	N
Int. Beta	[μGy/a]	0.00± 0.00	Cosmic	[μGy/a]	150.00± 30.00
Av. β-Selfirr.	?	N			

RESULTS		
Age [a]		25104 ± 6821
Σ Dose Rate [μGy/a]		4115 ± 807
	Internal	External
α	0 ± 0	1029 ± 303
β	0 ± 0	1691 ± 243
τ + cos		1395 ± 280

Mainland Lower Hillocks

Sample No. J8

Location		Jaldi			
Dose	[Gy]	111.10± 14.94	U-Sediment	[ppm]	2.88± 1.35
U-Content	[ppm]	0.00± 0.00	Th-Sediment	[ppm]	15.15± 4.61
Th-Content	[ppm]	0.00± 0.00	K-Sediment	[%]	1.97± 0.10
K-Content	[%]	0.00± 0.00	Water Sed.	[WGT%]	10.00± 5.00
Alpha Efficiency		0.07± 0.00	For α/β Irr. Only	?	N
Beta Attenuation?		Y	Ext. Alpha	[μGy/a]	0.00± 0.00
Diameter	[μm]	7.50± 3.50	Av. α-Attenuation	?	N
Layer Removed	[μm]	0.00± 0.00	Ext. Beta	[μGy/a]	0.00± 0.00
Density	[g/cm^3]	2.60± 0.00	Av. β-Attenuation	?	N
Int. Alpha	[μGy/a]	0.00± 0.00	Ext. Gamma	[μGy/a]	0.00± 0.00
Av. α-Selfirr.	?	N	Water att. For ext	?	N
Int. Beta	[μGy/a]	0.00± 0.00	Cosmic	[μGy/a]	150.00± 30.00
Av. β-Selfirr.	?	N			

RESULTS		
Age [a]		23250 ± 5003
Σ Dose Rate [μGy/a]		4779 ± 803
	Internal	External
α	0 ± 0	1069 ± 296
β	0 ± 0	2145 ± 261
τ + cos		1564 ± 270

Island Hillocks

Sample No. **M1**

Location		Maiskhali			
Dose	[Gy]	68.48±16.03	U-Sediment	[ppm]	4.55± 1.00
U-Content	[ppm]	0.00± 0.00	Th-Sediment	[ppm]	12.80± 5.51
Th-Content	[ppm]	0.00± 0.00	K-Sediment	[%]	1.27± 0.06
K-Content	[%]	0.00± 0.00	Water Sed.	[WGT%]	10.00± 5.00
Alpha Efficiency		0.07± 0.00	For α/β Irr. Only	?	N
Beta Attenuation?		Y	Ext. Alpha	[μGy/a]	0.00± 0.00
Diameter	[μm]	7.50± 3.50	Av. α-Attenuation	?	N
Layer Removed	[μm]	0.00± 0.00	Ext. Beta	[μGy/a]	0.00± 0.00
Density	[g/cm^3]	2.60± 0.00	Av. β-Attenuation	?	N
Int. Alpha	[μGy/a]	0.00± 0.00	Ext. Gamma	[μGy/a]	0.00± 0.00
Av. α-Selfirr.	?	N	Water att. For ext	?	N
Int. Beta	[μGy/a]	0.00± 0.00	Cosmic	[μGy/a]	150.00± 30.00
Av. β-Selfirr.	?	N			

RESULTS		
Age [a]		15207 ± 4447
Σ Dose Rate [μGy/a]		4504 ± 790
	Internal	External
α	0 ± 0	1229 ± 295
β	0 ± 0	1800 ± 226
τ + cos		1474 ± 288

Island Hillocks

Sample No. **A1**

Location		Maiskhali			
Dose	[Gy]	91.10± 8.90	U-Sediment	[ppm]	2.04± 1.25
U-Content	[ppm]	0.00± 0.00	Th-Sediment	[ppm]	19.73± 5.23
Th-Content	[ppm]	0.00± 0.00	K-Sediment	[%]	2.14± 0.11
K-Content	[%]	0.00± 0.00	Water Sed.	[WGT%]	10.00± 5.00
Alpha Efficiency		0.07± 0.00	For α/β Irr. Only	?	N
Beta Attenuation?		Y	Ext. Alpha	[μGy/a]	0.00± 0.00
Diameter	[μm]	7.50± 3.50	Av. α-Attenuation	?	N
Layer Removed	[μm]	0.00± 0.00	Ext. Beta	[μGy/a]	0.00± 0.00
Density	[g/cm^3]	2.60± 0.00	Av. β-Attenuation	?	N
Int. Alpha	[μGy/a]	0.00± 0.00	Ext. Gamma	[μGy/a]	0.00± 0.00
Av. α-Selfirr.	?	N	Water att. For ext	?	N
Int. Beta	[μGy/a]	0.00± 0.00	Cosmic	[μGy/a]	150.00± 30.00
Av. β-Selfirr.	?	N			

RESULTS		
Age [a]		17760 ± 3377
Σ Dose Rate [μGy/a]		5129 ± 837
	Internal	External
α	0 ± 0	1129 ± 305
β	0 ± 0	2273 ± 267
τ + cos		1727 ± 292

Proximal Piedmont Plains

Sample No. J1

Location		Jaldi			
Dose	[Gy]	39.15± 3.33	U-Sediment	[ppm]	4.74± 0.92
U-Content	[ppm]	0.00± 0.00	Th-Sediment	[ppm]	27.71± 8.65
Th-Content	[ppm]	0.00± 0.00	K-Sediment	[%]	1.44± 0.07
K-Content	[%]	0.00± 0.00	Water Sed.	[WGT%]	10.00± 5.00
Alpha Efficiency		0.07± 0.00	For α/β Irr. Only	?	N
Beta Attenuation?		Y	Ext. Alpha	[μGy/a]	0.00± 0.00
Diameter	[μm]	7.50± 3.50	Av. α-Attenuation	?	N
Layer Removed	[μm]	0.00± 0.00	Ext. Beta	[μGy/a]	0.00± 0.00
Density	[g/cm^3]	2.60± 0.00	Av. β-Attenuation	?	N
Int. Alpha	[μGy/a]	0.00± 0.00	Ext. Gamma	[μGy/a]	0.00± 0.00
Av. α-Selfirr.	?	N	Water att. For ext	?	N
Int. Beta	[μGy/a]	0.00± 0.00	Cosmic	[μGy/a]	150.00± 30.00
Av. β-Selfirr.	?	N			

RESULTS		
Age [a]		6111 ± 1190
Σ Dose Rate [μGy/a]		6407 ± 1123
	Internal	External
α	0 ± 0	1875 ± 417
β	0 ± 0	2315 ± 293
τ + cos		2218 ± 431

Proximal Piedmont Plains

Sample No. J2

Location		Jaldi			
Dose	[Gy]	35.12± 3.39	U-Sediment	[ppm]	4.68± 1.29
U-Content	[ppm]	0.00± 0.00	Th-Sediment	[ppm]	7.77± 4.41
Th-Content	[ppm]	0.00± 0.00	K-Sediment	[%]	1.78± 0.09
K-Content	[%]	0.00± 0.00	Water Sed.	[WGT%]	10.00± 5.00
Alpha Efficiency		0.07± 0.00	For α/β Irr. Only	?	N
Beta Attenuation?		Y	Ext. Alpha	[μGy/a]	0.00± 0.00
Diameter	[μm]	7.50± 3.50	Av. α-Attenuation	?	N
Layer Removed	[μm]	0.00± 0.00	Ext. Beta	[μGy/a]	0.00± 0.00
Density	[g/cm^3]	2.60± 0.00	Av. β-Attenuation	?	N
Int. Alpha	[μGy/a]	0.00± 0.00	Ext. Gamma	[μGy/a]	0.00± 0.00
Av. α-Selfirr.	?	N	Water att. For ext	?	N
Int. Beta	[μGy/a]	0.00± 0.00	Cosmic	[μGy/a]	150.00± 30.00
Av. β-Selfirr.	?	N			

RESULTS		
Age [a]		7871 ± 1546
Σ Dose Rate [μGy/a]		4462 ± 764
	Internal	External
α	0 ± 0	1041 ± 284
β	0 ± 0	2056 ± 249
τ + cos		1368 ± 256

Proximal Piedmont Plains

Sample No. M3

Location		Maiskhali				
Dose	[Gy]	28.51± 2.81	U-Sediment	[ppm]	4.41±	1.04
U-Content	[ppm]	0.00± 0.00	Th-Sediment	[ppm]	5.99±	3.52
Th-Content	[ppm]	0.00± 0.00	K-Sediment	[%]	1.48±	0.07
K-Content	[%]	0.00± 0.00	Water Sed.	[WGT%]	10.00±	5.00
Alpha Efficiency		0.07± 0.00	For α/β Irr. Only	?	N	
Beta Attenuation?		Y	Ext. Alpha	[μGy/a]	0.00±	0.00
Diameter	[μm]	7.50± 3.50	Av. α-Attenuation	?	N	
Layer Removed	[μm]	0.00± 0.00	Ext. Beta	[μGy/a]	0.00±	0.00
Density	[g/cm^3]	2.60± 0.00	Av. β-Attenuation	?	N	
Int. Alpha	[μGy/a]	0.00± 0.00	Ext. Gamma	[μGy/a]	0.00±	0.00
Av. α-Selfirr.	?	N	Water att. For ext	?	N	
Int. Beta	[μGy/a]	0.00± 0.00	Cosmic	[μGy/a]	150.00±	30.00
Av. β-Selfirr.	?	N				

RESULTS		
Age [a]		7348 ± 1381
Σ Dose Rate [μGy/a]		3881 ± 621
	Internal	External
α	0 ± 0	926 ± 231
β	0 ± 0	1764 ± 204
τ + cos		1191 ± 207

Proximal Piedmont Plains

Sample No. M4

Location		Maiskhali				
Dose	[Gy]	43.02± 3.22	U-Sediment	[ppm]	3.61±	1.39
U-Content	[ppm]	0.00± 0.00	Th-Sediment	[ppm]	13.69±	4.76
Th-Content	[ppm]	0.00± 0.00	K-Sediment	[%]	1.35±	0.07
K-Content	[%]	0.00± 0.00	Water Sed.	[WGT%]	10.00±	5.00
Alpha Efficiency		0.07± 0.00	For α/β Irr. Only	?	N	
Beta Attenuation?		Y	Ext. Alpha	[μGy/a]	0.00±	0.00
Diameter	[μm]	7.50± 3.50	Av. α-Attenuation	?	N	
Layer Removed	[μm]	0.00± 0.00	Ext. Beta	[μGy/a]	0.00±	0.00
Density	[g/cm^3]	2.60± 0.00	Av. β-Attenuation	?	N	
Int. Alpha	[μGy/a]	0.00± 0.00	Ext. Gamma	[μGy/a]	0.00±	0.00
Av. α-Selfirr.	?	N	Water att. For ext	?	N	
Int. Beta	[μGy/a]	0.00± 0.00	Cosmic	[μGy/a]	150.00±	30.00
Av. β-Selfirr.	?	N				

RESULTS		
Age [a]		9961 ± 2011
Σ Dose Rate [μGy/a]		4318 ± 810
	Internal	External
α	0 ± 0	1121 ± 306
β	0 ± 0	1760 ± 248
τ + cos		1437 ± 275

Proximal Piedmont Plains

Sample No. **A2**

Location		Maiskhali				
Dose	[Gy]	31.85± 1.54		U-Sediment	[ppm]	2.69± 1.28
U-Content	[ppm]	0.00± 0.00		Th-Sediment	[ppm]	13.68± 4.37
Th-Content	[ppm]	0.00± 0.00		K-Sediment	[%]	1.75± 0.09
K-Content	[%]	0.00± 0.00		Water Sed.	[WGT%]	10.00± 5.00
Alpha Efficiency		0.07± 0.00		For α/β Irr. Only	?	N
Beta Attenuation?		Y		Ext. Alpha	[μGy/a]	0.00± 0.00
Diameter	[μm]	7.50± 3.50		Av. α-Attenuation	?	N
Layer Removed	[μm]	0.00± 0.00		Ext. Beta	[μGy/a]	0.00± 0.00
Density	[g/cm^3]	2.60± 0.00		Av. β-Attenuation	?	N
Int. Alpha	[μGy/a]	0.00± 0.00		Ext. Gamma	[μGy/a]	0.00± 0.00
Av. α-Selfirr.	?	N		Water att. For ext	?	N
Int. Beta	[μGy/a]	0.00± 0.00		Cosmic	[μGy/a]	150.00± 30.00
Av. β-Selfirr.	?	N				

RESULTS		
Age [a]		7344 ± 1326
Σ Dose Rate [μGy/a]		4337 ± 755
	Internal	External
α	0 ± 0	979 ± 280
β	0 ± 0	1928 ± 243
τ + cos		1429 ± 255

Distal Piedmont Plains

Sample No. **J4**

Location		Jaldi				
Dose	[Gy]	6.19± 0.78		U-Sediment	[ppm]	5.03± 0.19
U-Content	[ppm]	0.00± 0.00		Th-Sediment	[ppm]	15.63± 6.52
Th-Content	[ppm]	0.00± 0.00		K-Sediment	[%]	1.34± 0.07
K-Content	[%]	0.00± 0.00		Water Sed.	[WGT%]	10.00± 5.00
Alpha Efficiency		0.07± 0.00		For α/β Irr. Only	?	N
Beta Attenuation?		Y		Ext. Alpha	[μGy/a]	0.00± 0.00
Diameter	[μm]	7.50± 3.50		Av. α-Attenuation	?	N
Layer Removed	[μm]	0.00± 0.00		Ext. Beta	[μGy/a]	0.00± 0.00
Density	[g/cm^3]	2.60± 0.00		Av. β-Attenuation	?	N
Int. Alpha	[μGy/a]	0.00± 0.00		Ext. Gamma	[μGy/a]	0.00± 0.00
Av. α-Selfirr.	?	N		Water att. For ext	?	N
Int. Beta	[μGy/a]	0.00± 0.00		Cosmic	[μGy/a]	150.00± 30.00
Av. β-Selfirr.	?	N				

RESULTS		
Age [a]		1221 ± 249
Σ Dose Rate [μGy/a]		5069 ± 814
	Internal	External
α	0 ± 0	1420 ± 298
β	0 ± 0	1981 ± 216
τ + cos		1668 ± 318

Distal Piedmont Plains

Sample No. J10

Location		Jaldi			
Dose	[Gy]	6.55± 0.50	U-Sediment	[ppm]	2.02± 0.69
U-Content	[ppm]	0.00± 0.00	Th-Sediment	[ppm]	9.74± 2.39
Th-Content	[ppm]	0.00± 0.00	K-Sediment	[%]	1.34± 0.07
K-Content	[%]	0.00± 0.00	Water Sed.	[WGT%]	10.00± 5.00
Alpha Efficiency		0.07± 0.00	For α/β Irr. Only	?	N
Beta Attenuation?		Y	Ext. Alpha	[μGy/a]	0.00± 0.00
Diameter	[μm]	7.50± 3.50	Av. α-Attenuation	?	N
Layer Removed	[μm]	0.00± 0.00	Ext. Beta	[μGy/a]	0.00± 0.00
Density	[g/cm^3]	2.60± 0.00	Av. β-Attenuation	?	N
Int. Alpha	[μGy/a]	0.00± 0.00	Ext. Gamma	[μGy/a]	0.00± 0.00
Av. α-Selfirr.	?	N	Water att. For ext	?	N
Int. Beta	[μGy/a]	0.00± 0.00	Cosmic	[μGy/a]	150.00± 30.00
Av. β-Selfirr.	?	N			

RESULTS		
Age [a]		2010 ± 311
Σ Dose Rate [μGy/a]		3258 ± 438
	Internal	External
α	0 ± 0	713 ± 157
β	0 ± 0	1453 ± 152
τ + cos		1092 ± 147

Distal Piedmont Plains

Sample No. J11

Location		Jaldi			
Dose	[Gy]	5.11± 1.09	U-Sediment	[ppm]	5.47± 1.04
U-Content	[ppm]	0.00± 0.00	Th-Sediment	[ppm]	10.19± 5.42
Th-Content	[ppm]	0.00± 0.00	K-Sediment	[%]	1.44± 0.07
K-Content	[%]	0.00± 0.00	Water Sed.	[WGT%]	15.00± 5.00
Alpha Efficiency		0.07± 0.00	For α/β Irr. Only	?	N
Beta Attenuation?		Y	Ext. Alpha	[μGy/a]	0.00± 0.00
Diameter	[μm]	7.50± 3.50	Av. α-Attenuation	?	N
Layer Removed	[μm]	0.00± 0.00	Ext. Beta	[μGy/a]	0.00± 0.00
Density	[g/cm^3]	2.60± 0.00	Av. β-Attenuation	?	N
Int. Alpha	[μGy/a]	0.00± 0.00	Ext. Gamma	[μGy/a]	0.00± 0.00
Av. α-Selfirr.	?	N	Water att. For ext	?	N
Int. Beta	[μGy/a]	0.00± 0.00	Cosmic	[μGy/a]	150.00± 30.00
Av. β-Selfirr.	?	N			

RESULTS		
Age [a]		1160 ± 315
Σ Dose Rate [μGy/a]		4408 ± 747
	Internal	External
α	0 ± 0	1166 ± 275
β	0 ± 0	1842 ± 223
τ + cos		1400 ± 269

Old Tidal Flats

Sample No.		**J6**				
Location		Jaldi				
Dose	[Gy]	2.64± 0.44	U-Sediment	[ppm]	2.67±	1.11
U-Content	[ppm]	0.00± 0.00	Th-Sediment	[ppm]	20.20±	5.25
Th-Content	[ppm]	0.00± 0.00	K-Sediment	[%]	2.60±	0.13
K-Content	[%]	0.00± 0.00	Water Sed.	[WGT%]	15.00±	5.00
Alpha Efficiency		0.07± 0.00	For α/β Irr. Only	?	N	
Beta Attenuation?		Y	Ext. Alpha	[μGy/a]	0.00±	0.00
Diameter	[μm]	7.50± 3.50	Av. α-Attenuation	?	N	
Layer Removed	[μm]	0.00± 0.00	Ext. Beta	[μGy/a]	0.00±	0.00
Density	[g/cm^3]	2.60± 0.00	Av. β-Attenuation	?	N	
Int. Alpha	[μGy/a]	0.00± 0.00	Ext. Gamma	[μGy/a]	0.00±	0.00
Av. α-Selfirr.	?	N	Water att. For ext	?	N	
Int. Beta	[μGy/a]	0.00± 0.00	Cosmic	[μGy/a]	150.00±	30.00
Av. β-Selfirr.	?	N				

RESULTS

	Internal	External
Age [a]		483 ± 105
Σ Dose Rate [μGy/a]		5464 ± 784
α	0 ± 0	1150 ± 274
β	0 ± 0	2513 ± 266
τ + cos		1802 ± 276

Old Tidal Flats

Sample No.		**M2**				
Location		Maiskhali				
Dose	[Gy]	8.74± 1.16	U-Sediment	[ppm]	5.51±	1.20
U-Content	[ppm]	0.00± 0.00	Th-Sediment	[ppm]	10.83±	5.02
Th-Content	[ppm]	0.00± 0.00	K-Sediment	[%]	2.40±	0.12
K-Content	[%]	0.00± 0.00	Water Sed.	[WGT%]	15.00±	5.00
Alpha Efficiency		0.07± 0.00	For α/β Irr. Only	?	N	
Beta Attenuation?		Y	Ext. Alpha	[μGy/a]	0.00±	0.00
Diameter	[μm]	7.50± 3.50	Av. α-Attenuation	?	N	
Layer Removed	[μm]	0.00± 0.00	Ext. Beta	[μGy/a]	0.00±	0.00
Density	[g/cm^3]	2.60± 0.00	Av. β-Attenuation	?	N	
Int. Alpha	[μGy/a]	0.00± 0.00	Ext. Gamma	[μGy/a]	0.00±	0.00
Av. α-Selfirr.	?	N	Water att. For ext	?	N	
Int. Beta	[μGy/a]	0.00± 0.00	Cosmic	[μGy/a]	150.00±	30.00
Av. β-Selfirr.	?	N				

RESULTS

	Internal	External
Age [a]		1642 ± 324
Σ Dose Rate [μGy/a]		5321 ± 779
α	0 ± 0	1196 ± 278
β	0 ± 0	2500 ± 266
τ + cos		1625 ± 266