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Palaeoclimatic impact on the flood basin accretion and palaeosol development in northwestern Bangladesh

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ABSTRACT

During the Quaternary period, a number of climatic fluctuations occurred as evidenced in the deep-sea core samples, palaeolake deposits, continuous loess profiles in China and glacial deposits in various parts of the world. The fluctuations in palaeoclimatic conditions have influenced eustatic sea-level changes as well resulting in the formation of different sediment facies and landscape evolution worldwide. In the northwestern part of Bangladesh, a thick Pleistocene alluvial sequence has left signatures of these climatic changes. Based on different field criteria such as destratification, horizon formation, colour, biogenic-pedogenic features (i.e. rootlets or root traces, burrows, $CaCO_3$ nodules, Fe concretions) and soil structures, 10 buried palaeosols have been recognised in the Pleistocene deposits. The odd numbered palaeosols (i.e., GS1, GS3, GS5, GS7 and GS9) are designated as moderately developed palaeosols as inferred from their relatively finer textures, higher concentration of pedogenic soil carbonate nodules and lower abundance of iron oxides. The even numbered palaeosols (i.e., GS2, GS4, GS6, GS8 and GS10) are strongly developed palaeosols, containing very few or no pedogenic carbonate. They also contain Fe oxide concretions, burrows and root channels. Both moderately developed and strongly developed palaeosols occur in cyclic succession. Strongly developed palaeosols occur in thick sediment sequences, which indicate that the flood basin accretion rate was quite high as a result of stronger hydrodynamic conditions. They are the direct consequence of bigger flood events. The relatively thinner sediment sequences, in which the palaeosols are moderately developed, are a consequence of consecutive smaller flood events under drier conditions. Hence, the 10 buried palaeosols suggest that at least 10 alternating dry and wet climatic phases prevailed during the successive phases of both palaeosol development and sedimentation cycles. These alternating dry and wet climatic cycles most probably influenced the strengthening and/or weakening of the palaeo-summer moonson. Moreover, studies based on isotopic compositions of stable carbon and oxygen as derived from the analysis on pedogenic carbonate nodules, as well as from the measured bulk magnetic susceptibility in the palaeosol sequences, are found to be in good agreement with the above statement on the dry and wet phases.

INTRODUCTION

The study area lies at the northwestern part of Bangladesh between latitudes 24°20'-25°00' N and longitudes 88°10'-88°35'E covering by the Quaternary deposits. A large part of this belongs to the Pleistocene. Locally, this area is called the "Barind Tract", which means a slightly elevated landmass (about 20 to 40 m amsl).The Barind Tract is an uplifted faulted block as described by many authors (Fergusson, 1863; Morgan and McIntire, 1959; Khandokar, 1987). This elevated area of Pleistocene sediments is outlined by well defined faults: the Karatoya-Banar Fault on the northeast, the Padma (Ganges) Fault on the southwest, the Malda-Kishanganj Fault on the northwest and the Dhubri-Jamuna Fault on the east (Khandokar, 1987). The Barind Tract represents one of the major geomorphological units of the Bengal basin.

The study of palaeosols, defined as soils that formed on landscape of the past (Ruhe, 1965; Yaalon, 1971; Valentine and Dalrymple, 1976), represent an excellent record of past environmental conditions, usually integrated over a certain period of time (Yaalon, 1990). Paepe and Van Overloop

(1990) and Paepe (1963, 1971) described the palaeosol or fossil soil as stratigraphic marker horizons. Retallack (1990) also noted the palaeosols as distinctive horizons that can be traced in order to establish the relationship in time and space between different sedimentary units. Examination of fossil soils has long been an integral part of Quaternary stratigraphy (Ruhe, 1956, 1969; Birkland, 1974, 1984; Kraus and Bown, 1986; Catt, 1986). Soils generally respond to climatic change (Yallon, 1990) and the fossil soil or palaeosol can be a powerful tool in reconstructing Quaternary paleoclimate.

Development of soils in all alluvial regimes is a normal phenomenon and most alluvial deposits contain numerous superposed ancient soil profiles. Alluvial palaeosols are potentially useful in understanding the episodic nature of fluvial sedimentation and consequently, the manner in which alluvial succession developed (Kraus and Bown, 1986). The sediment sequences of the northwestern part of Bangladesh (Fig. 1) are essentially related to the ancient alluvial deposits of the Ganges and Tista rivers and their tributaries and distributaries. The whole succession of these Pleistocene alluvial deposits represents a number of palaeosol horizons.

Oxygen and carbon stable isotopic analyses on the carbonate materials have been widely used for the palaeoenvironmental reconstruction since the past few deacades (Urey et al., 1951; Emiliani, 1955; Savin, 1977; Cerling et al., 1977; Magaritz et al., 1981; Cerling, 1884; Cerling and Hay, 1986; Magaritz, 1986; Cerling et al., 1988). Pedogenic carbonate nodules or concretions are abundant in some of the palaeosol horizons of the Pleistocene deposits of the study area. The stable isotopic analyses of the pedogenic carbonate play a vital role to assess change in Quaternary climate and vegetation.

Low-field susceptibility also called initial susceptibility measurements of the ferromagnetic materials in the sediment sequences may reflect climatic changes. This weak field susceptibility and its climatic significance have been widely used in loess-palaeosol sequences reflecting the climatic changes in the sense that loess layers were deposited in a cold dry climate, and soil units developed in them under wet and mild conditions (Liu et al., 1985; Kukla, 1987; Kukla and An, 1989; Wang et al., 1990; Maher and Thomson, 1991; An et al., 1991; Hus and Han, 1992). The palaeosols show higher susceptibility in comparison to the loess. Unlikely loess-palaeosol sequences, the bulk magnetic susceptibility measurements are rarely used for the alluvial palaeosols studies. Here, an effort has been made to measure the initial susceptibility of the alluvial sediments and palaeosol sequences in the northwestern part of Bangladesh.

In this paper, a study on the reconstruction of climatic change of Pleistocene and its implication to the sedimentation pattern and flood basin accretion in northwestern Bangladesh is carried out. The study was primarily founded on the descriptive aspect of palaeosols of the alluvial sequences as well as on the oxygen and carbon stable isotopic composition of pedogenic carbonate nodules and bulk magnetic susceptibility results.

METHODOLOGY

Field Methods

Field investigations were mainly carried out along a stream gully and deep dug-wells in the Barind Tract of northwestern part of Bangladesh. Detailed lithologic variation, destratification, colour, biogenic features (i.e., root trace, animal burrows, trace fossil), pedogenic carbonate nodules, iron root casts and rhizoconcretions (mineral encrusted roots, Wright, 1989) manganese and soil structural features (prismatic/blocky structure) were studied in each of the sections. Loose samples were collected at 0.10-0.30 m interval from the sections for bulk magnetic susceptibility measurements. Soil carbonate samples were collected at 0.10-0.30 m intervals from the pedogenic carbonate containing horizons for oxygen and carbon stable isotopic analyses.

Laboratory Analyses

The stable isotopic analyses of pedogenic carbonate nodules were carried out in the Geochemistry Laboratory of Earth Technology Institute, Vrije Universiteit Brussels, Belgium. For stable isotopic analyses, several (mostly three) nodules per sample (from particular level) were subjected. Moreover, from each nodule a

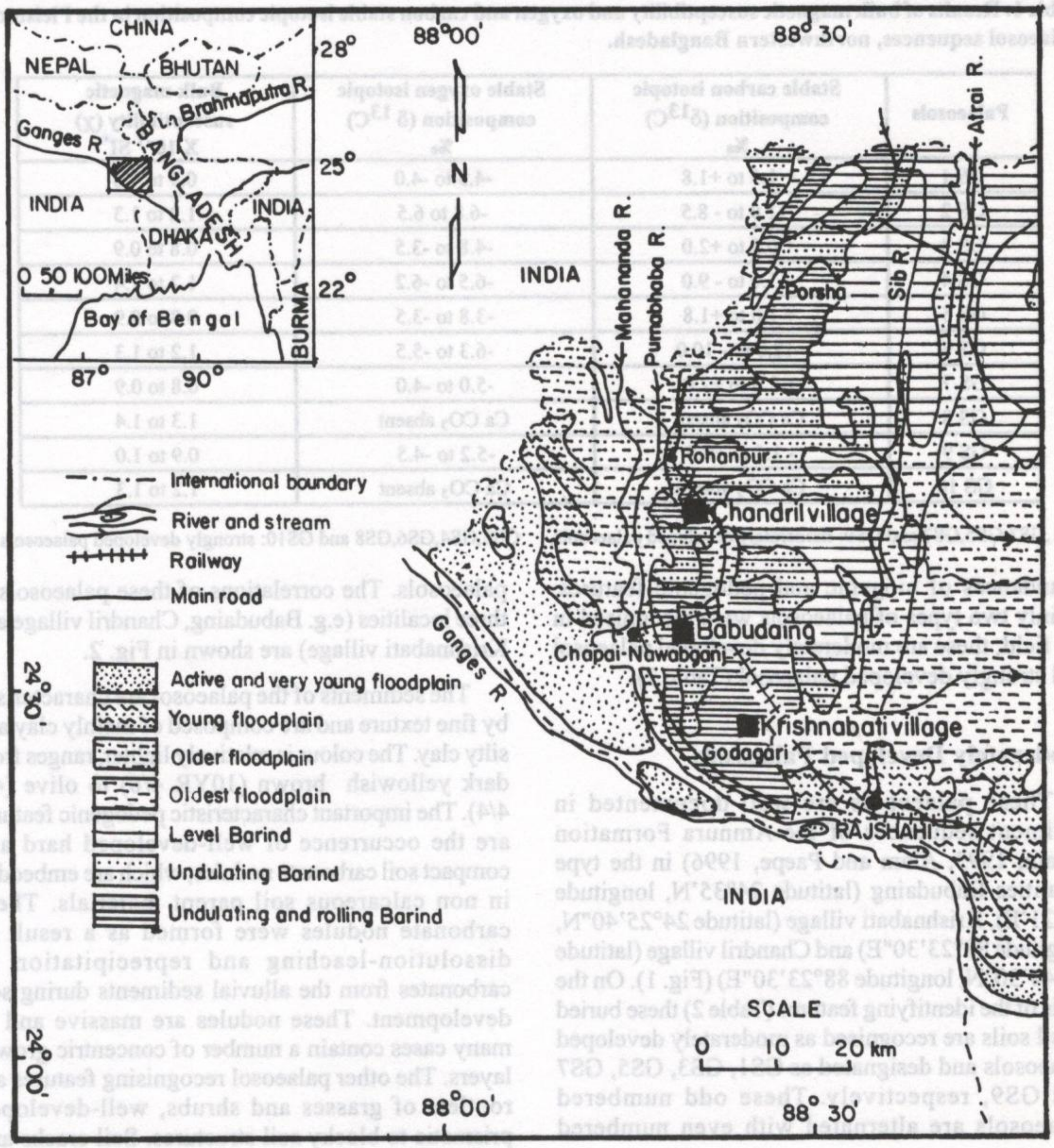

Fig. 1: Location map and physiography of the study area.

total of three measurements were taken to check the reproducibility of the results. The bulk magnetic susceptibility measurements of the loose samples were performed in the Geophysical Centre of Belgium Royal Meterological Institute using KLY-1 magnetic susceptibility bridge. Results of both magnetic susceptibility and oxygen and carbon isotopic composition are given in Table 1.

Recognition and Classification of Palaeosols

Several criteria are used for recognising palaeosols. The palaeosols are mostly formed by the post-depositional process rather than diagenesis. The main post-depositional processes that are responsible for the soil formation are biological activities and geochemical processes within the parent material. These processes are inforced directly by the climate and landscape evolution. Based on the relative

Table 1: Results of bulk magnetic susceptibility and oxygen and carbon stable isotopic composition in the Pleistocene palaeosol sequences, northwestern Bangladesh.

Palaeosols	Stable carbon isotopic composition ($\delta^{13}C$) ‰	Stable oxygen isotopic composition (δ ^{13}C) ‰	Bulk magnetic susceptibility (χ) X 10^{-7} SI
GS 1	+ 1.5 to +1.8	-4.5 to -4.0	0.9 to 1.0
GS 2	-11.0 to - 8.5	-6.8 to 6.5	1.2 to 1.3
GS 3	+ 0.5 to +2.0	-4.8 to -3.5	0.8 to 0.9
GS 4	-11.0 to - 9.0	-6.5 to -6.2	1.2 to 1.4
GS 5	+ 1.0 to +1.8	-3.8 to -3.5	0.8 to 0.9
GS 6	-12.0 to - 10.0	-6.3 to -5.5	1.2 to 1.3
GS 7	+ 1.8 to +2.0	-5.0 to -4.0	0.8 to 0.9
GS 8	Ca CO_3 absent	Ca CO_3 absent	1.3 to 1.4
GS 9	- 1.5 to +0.5	-5.2 to -4.5	0.9 to 1.0
GS 10	Ca CO_3 absent	Ca CO_3 absent	1.2 to 1.3

GS1,GS3,GS5,GS7 and GS9: moderately developed palaeosols. GS2,GS4,GS6,GS8 and GS10: strongly developed palaeosols.

abundances of biogenic and pedogenic features, mainly two types of palaeosols were recognised in the field; these are moderately developed palaeosol and strongly developed palaeosol (Table 2).

Moderately Developed Palaeosols

These palaeosols are well documented in sediment sequences of the Amnura Formation (Alam, 1993; Alam and Paepe, 1996) in the type localities Babudaing (latitude 24°35'N, longitude 88°21'E), Krishnabati village (latitude 24°25'40"N, longitude 88°23'30"E) and Chandril village (latitude 24°44'30"N, longitude 88°23'30"E) (Fig. 1). On the basis of the identifying features (Table 2) these buried fossil soils are recognised as moderately developed palaeosols and designated as GS1, GS3, GS5, GS7 and GS9, respectively. These odd numbered palaeosols are alternated with even numbered palaeosols. The correlations of these palaeosols in three localities (e.g. Babudaing, Chandril village and Krishnabati village) are shown in Fig. 2.

The sediments of the palaeosol are characterised by fine texture and are composed of mainly clay and silty clay. The colour is relatively lighter, ranges from dark yellowish brown (10YR 4/6) to olive (4Y 4/4). The important characteristic pedogenic features are the occurrence of well-developed hard and compact soil carbonate nodules, which are embedded in non calcareous soil parent materials. These carbonate nodules were formed as a result of dissolution-leaching and reprecipitation of carbonates from the alluvial sediments during soil development. These nodules are massive and in many cases contain a number of concentric growth layers. The other palaeosol recognising features are rootlets of grasses and shrubs, well-developed prismatic to blocky soil structures. Soil cracks and

Table 2: Classification of palaeosols on the basis of colour, pedogenic and biogenic features.

Soil type	Colour range	Features
Moderately developed palaeosol	Dark yellowish brown 10YR 4/6 to olive 5Y 4/4	Clayey silty texture, well developed hard and compact, pedogenic carbonate nodules became pro- prominant features, root traces and burrows rela tively less abundant, strongly prismatic to blocky soil structures present, Fe/Mn concretion occasionally found.
Strongly developed palaeosol	Brownish yellow10 YR 6/6 to moderate yellowish brown 10YR 5/4	Clayey to silty texture, full of root traces and burrows, carbonaceous coating along the soil-ped surface and root channel, pseudogleyed, Fe/Mn concretion abundant, prismatic soil structure present, no well developed soil carbonate nodules except some tiny piece of carbonate along the soil-ped, root channel or burrows and drab-haloes features predominant.

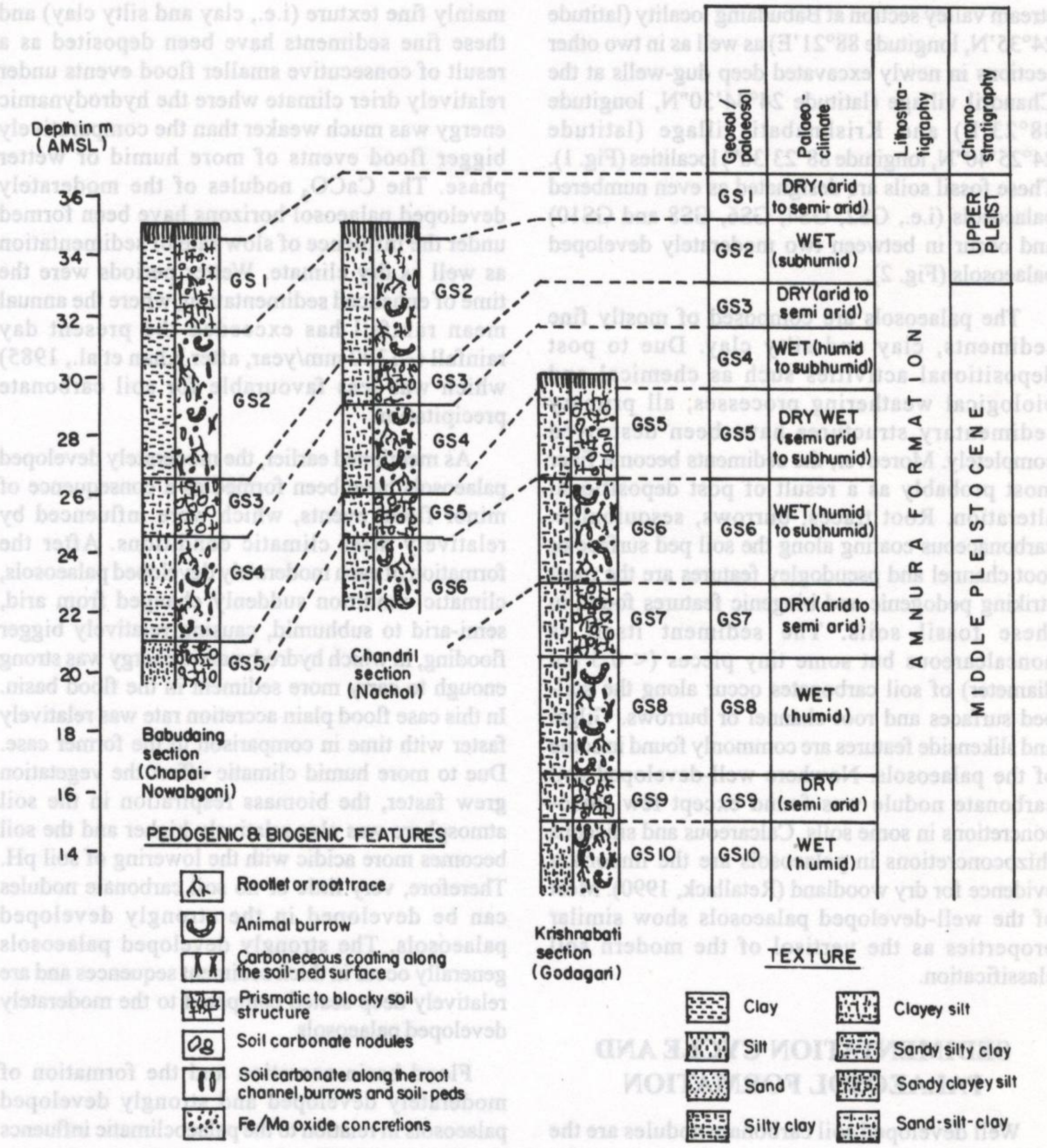

Fig. 2: Correlation of moderately and strongly developed palaeosols between the three localities: Babudaing (Chapai-Nowabgonjdistrict), Chandril village (Nachol Thana) and Krishnabati village (Godagari Thana) in NW Bangladesh.

gilgai features commonly observed in GS1 and GS3. Fe and Mn oxide concretions are also observed in these palaeosols. Apparently, most of the moderately developed palaeosols show close resemblance to the aridisol as seen from their characteristic features.

Strongly Developed Palaeosols

Strongly developed palaeosols are commonly found in the vertical sequences of the Amnura Formation. These soils were clearly observed in the stream valley section at Babudaing locality (latitude 24°35'N, longitude 88°21'E) as well as in two other sections in newly excavated deep dug-wells at the Chandril village (latitude 24°44'30"N, longitude 88°23'E) and Krishnabati village (latitude 24°25'40"N, longitude 88°23'30") localities (Fig. 1). These fossil soils are designated as even numbered palaeosols (i.e., GS2, GS4, GS6, GS8 and GS10) and occur in between two moderately developed palaeosols (Fig. 2).

The palaeosols are composed of mostly fine sediments, clay and silty clay. Due to post depositional activities such as chemical and biological weathering processes, all primary sedimentary structures have been destroyed completely. Moreover, the sediments become finer most probably as a result of post depositional alteration. Root traces, burrows, sesquioxide, carbonaceous coating along the soil ped surface or root channel and pseudogley features are the most striking pedogenic and biogenic features found in these fossil soils. The sediment itself is noncalcareous but some tiny pieces (< 0.5 cm diameter) of soil carbonates occur along the soil-ped surfaces and root channel or burrows. Gilgai and slikenside features are commonly found in some of the palaeosols. Nowhere well-developed soil carbonate nodule was found except few rhizo-concretions in some soils. Calcareous and siliceous rhizoconcretions in palaeosols are the important evidence for dry woodland (Retallack, 1990). Most of the well-developed palaeosols show similar properties as the vertisol of the modern soil classification.

SEDIMENTATION CYCLE AND PALAEOSOL FORMATION

Well developed soil carbonate nodules are the most important characteristic features of the moderately developed palaeosols. Formation of these pedogenic nodules in alluvial sediments is related to the flood plain accretion rate versus time. Slow rate of sedimentation during dry period associated with occasional rainfall could create a favourable situation to form the pedogenic carbonate nodules. As mentioned before the sediments of the palaeosols have mainly fine texture (i.e., clay and silty clay) and these fine sediments have been deposited as a result of consecutive smaller flood events under relatively drier climate where the hydrodynamic energy was much weaker than the comparatively bigger flood events of more humid or wetter phase. The $CaCO_3$ nodules of the moderately developed palaeosol horizons have been formed under the influence of slow rate of sedimentation as well as dry climate. Wetter periods were the time of enhanced sedimentation, where the annual mean rainfall has exceeded the present day rainfall (~1300 mm/year, after Khan et al., 1985) which was less favourable for soil carbonate precipitation.

As mentioned earlier, the moderately developed palaeosols have been formed as a consequence of minor flood events, which were influenced by relatively drier climatic conditions. After the formation of each moderately developed palaeosols, climatic condition suddenly changed from arid, semi-arid to subhumid, causing relatively bigger flooding, in which hydrodynamic energy was strong enough to carry more sediment in the flood basin. In this case flood plain accretion rate was relatively faster with time in comparison to the former case. Due to more humid climatic effect the vegetation grew faster, the biomass respiration in the soil atmosphere was also relatively higher and the soil becomes more acidic with the lowering of soil pH. Therefore, very little or no soil carbonate nodules can be developed in the strongly developed palaeosols. The strongly developed palaeosols generally occur in thick sediment sequences and are relatively deep seated compared to the moderately developed palaeosols

Flood basin accretion and the formation of moderately developed and strongly developed palaeosols in relation to the palaeoclimatic influencs are illustrated in Fig. 3.

Moreover, the strongly developed palaeosols were most probably formed in the coarser (i.e., more silty and sandy) sediment sequences. These relatively coarser sediments have been carried away and deposited during bigger flood events. The primary texture may have disintegrated as a result of intensive weathering influenced by warm and humid climates during soil forming processes.

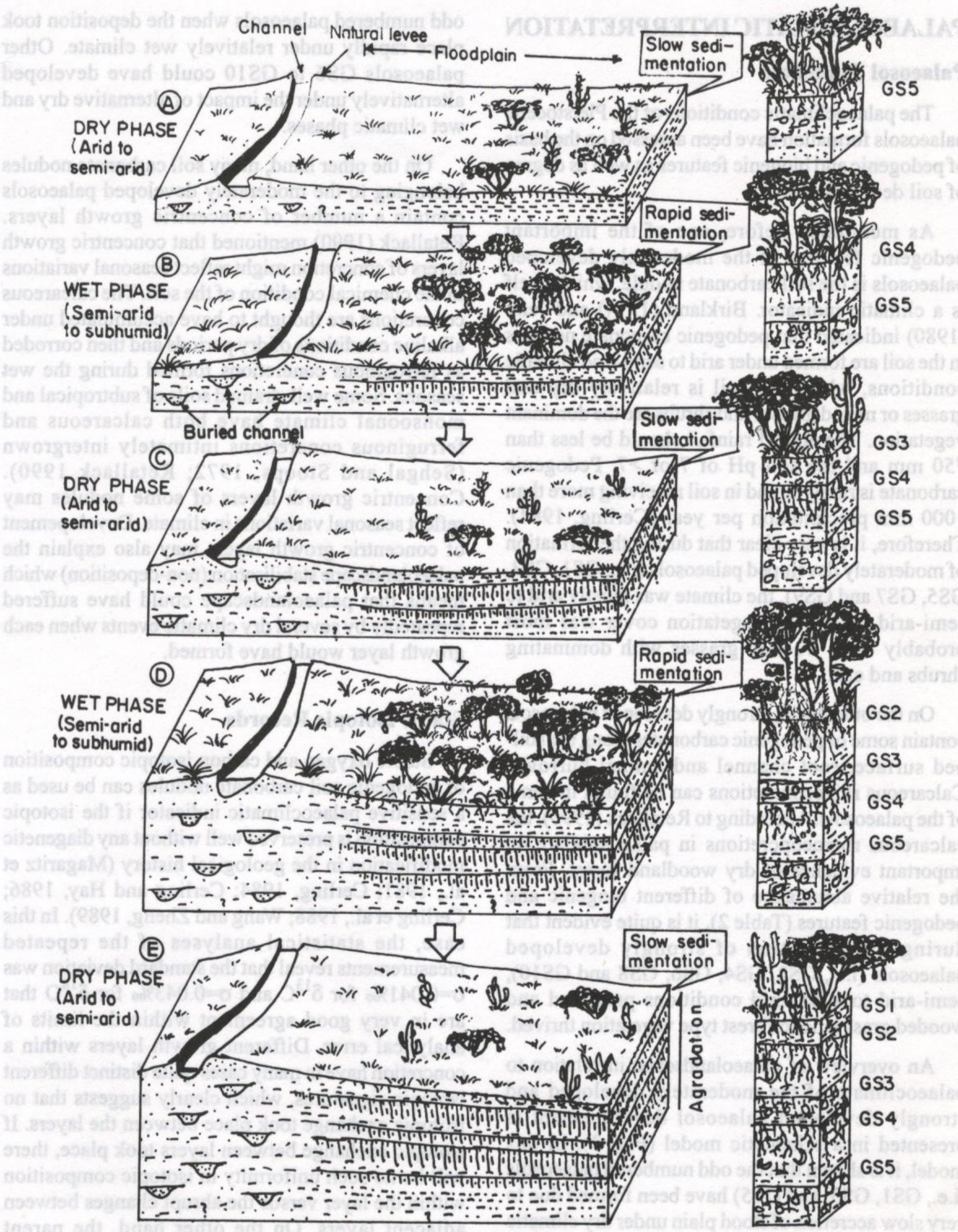

Fig. 3: Schematic model of landscape evolution and palaeosol formation during the late Pleistocene in the Barind area, northwestern Bangladesh.

PALAEOCLIMATIC INTERPRETATION

Palaeosol Sequences

The palaeoclimatic conditions of the Pleistocene palaeosols formation have been assessed on the basis of pedogenic and biogenic features as well as degree of soil development.

As mentioned before, one of the important pedogenic features of the moderately developed palaeosols is the soil carbonate nodule, which itself is a climatic indicator. Birkland (1974) and Jeny (1980) indicated that pedogenic carbonate nodules in the soil are formed under arid to semi-arid climatic conditions, where the soil is relatively dry and grasses or mixed grasses and shrubs are the dominant vegetation. The annual rainfall should be less than 750 mm and the soil pH of 7 or >7. Pedogenic carbonate is rarely found in soil receiving more than 1000 mm precipitation per year (Cerling, 1984). Therefore, it is very clear that during the formation of moderately developed palaeosols (i.e., GS1, GS3, GS5, GS7 and GS9), the climate was mostly arid to semi-arid where the vegetation cover was most probably open wooded grasses with dominating shrubs and cacti.

On the other hand, strongly developed palaeosols contain some of pedogenic carbonates along the soil-ped surface, root channel and animal burrows. Calcareous rhizoconcretions can be found in some of the palaeosols. According to Retallack (1990), the calcareous rhizoconcretions in palaeosols are an important evidence of dry woodland forest. From the relative abundance of different biogenic and pedogenic features (Table 2), it is quite evident that during the formation of strongly developed palaeosols (i.e., GS2, GS4, GS6, GS8 and GS10), semi-arid to subhumid conditions prevailed and wooded grass land to forest type vegetation thrived.

An overview of palaeolandscape in relation to palaeoclimate of the moderately developed and strongly developed palaeosol developement is presented in a schematic model (Fig. 3). In this model, it is shown that the odd numbered palaeosols (i.e., GS1, GS3, and GS5) have been formed due to very slow accretion of flood plain under dry climatic condition, whereas even numbered palaeosols (i.e., GS2 and GS4) have been developed in between the odd numbered palaeosols when the deposition took place rapidly under relatively wet climate. Other palaeosols GS6 to GS10 could have developed alternatively under the impact of alternative dry and wet climatic phases.

On the other hand, many soil carbonate nodules belonging to the moderately developed palaeosols contain a number of concentric growth layers. Retallack (1990) mentioned that concentric growth layers of concretion might reflect seasonal variations in the chemical condition of the soil. The calcareous concretions are thought to have accumulated under alkaline conditions of dry periods and then corroded as ferruginous concretions formed during the wet seasons. Some well-drained soils of subtropical and monsoonal climate have both calcareous and ferruginous concretions intimately intergrown (Sehgal and Stoops, 1972; Retallack 1990). Concentric growth layers of some nodules may reflect seasonal variations in climate. Developement of concentric growth layers may also explain the palaeolandscape stabilisation (non-deposition) which means that palaeolandscape could have suffered repeatedly by several dry climatic events when each growth layer would have formed.

Stable Isotopic Records

Stable oxygen and carbon isotopic composition of pedogenic soil carbonate nodules can be used as a sensitive palaeoclimatic indicator if the isotopic composition is preserved well without any diagenetic modification in the geological history (Magaritz et al., 1981; Cerling, 1984; Cerling and Hay, 1986; Cerling et al., 1988; Wang and Zheng, 1989). In this case, the statistical analyses of the repeated measurements reveal that the standard deviation was σ=0.041‰ for $\delta^{13}C$ and σ=0.043‰ for $\delta^{18}O$ that are in very good agreement within the limits of analytical error. Different growth layers within a concretion have in many cases quite distinct different isotopic signatures, which clearly suggests that no isotopic exchange took place between the layers. If isotopic exchange between layers took place, there will be no such uniformity in isotopic composition within the layer versus the abrupt changes between adjacent layers. On the other hand, the parent materials in which the carbonate nodules occur are completely noncalcareous. These observations point that the isotopic signatures can be used as good recorders of the palaeo-environmental conditions during which the different palaeosols have been formed. The $\delta^{13}C$ and $\delta^{18}O$ records from the palaeosol sequences (i.e., GS1 to GS10) show abrupt variations (Table 1). The carbon and oxygen stable isotopic composition of the soil carbonates from the moderately developed palaeosols represent much heavier values (-1 5 to +2.0‰ for $\delta^{13}C$ and -5.2 to -3.5‰ for $\delta^{18}O$). From the relatively heavier $\delta^{13}C$ and $\delta^{18}O$ values belonging to these moderately developed palaeosols, the climatic conditions can be described as having a higher evaporation rate, lower humidity and lower rainfall. Consequently, the biological productivity was remarkably low and as a result soil atmospheric partial pressure of CO_2 became also low. The low partial pressure in arid and semi-arid soils is a contributary factor leading to carbonate precipitation (Marion et al., 1985; Wright, 1990). On the contrary, the isotopic signatures of the soil carbonates from the strongly developed palaeosol (Table 1) show much lighter values (-12.0 to -8.5‰ for $\delta^{13}C$ and -6.8 to -5.5‰ for $\delta^{18}O$), which may indicate wetter climatic condition. Therefore, two alternating distinct climatic phases can be deduced from the cyclic trend in both $\delta^{13}C$ and $\delta^{18}O$ records from one moderately developed palaeosol to next strongly developed palaeosol and vice versa.

Magnetic Susceptibility Records

Le Borgne (1955, 1960) proposed that the enhanced susceptibility of the soil is due to 'in situ' transformation of the iron oxides from an antiferromagnetic form such as haematite or goethite to the ferrimagnetic form such as maghaemite. The popular enhancement mechanism of Le Borgne is the fermentation processes in which reduction takes place as a result of decay of organic materials in anaerobic conditions under wet periods followed by reoxidation to maghaemite in aerobic conditions during subsequent dry periods. The enhancement mechanism of Le Borgne were followed by many others (Oades and Townsend, 1963; Mullins, 1977; Longworth et al., 1979). 'In situ' formed maghaemite is a common iron oxide in highly weathered oxisols of the tropical and subtropical areas (Taylor and Schwertman, 1974a,b; Fine et al., 1989; Hus and Han, 1992). Moreover, the presence of soil carbonate, a diamagnetic mineral may decrease the bulk magnetic susceptibility of the palaeosols.

The moderately developed palaeosols (i.e., GS1, GS3, GS5, GS7 and GS9) show magnetic susceptibility (χ) peaks of magnitude <1 X 10^{-7} SI units (Table 1) reflecting the lower concentration of magnetic minerals which in turn indicate a lower rate of pedogenesis. The strongly developed palaeosols (i.e., GS2, GS4, GS6, GS8 and GS10) alternate successively with moderately developed palaeosols. They have χ peaks >1.2 X 10^{-7} SI units (Table 1) indicating relatively increased concentrations of magnetic minerals in comparison to the moderately developed palaeosols. The χ variations from the moderately to strongly developed palaeosols can be mainly attributed to concentration changes of the primary magnetic minerals, grain-size changes and authigenesis of magnetic minerals, all induced by climatically controlled pedogenic processes. Therefore, the cyclic variations of bulk magnetic susceptibility with respect to the moderately and strongly developed palaeosols may indicate the alternating dry and wet climatic phases.

Palaeomonsoon

The strengthening of summer solar radiation during the early Holocene and during warm intervals of the late Pleistocene gave rise to an increased atmospheric pressure gradient between the continents and the oceans, thereby producing a strong.summer monsoon that brought more moisture from the ocean on to the land (Kutzbach and Guetter, 1986; An et al., 1991). According to Prell and Kutzbach (1987), under interglacial conditions increased northern hemisphere solar radiation produced a larger land-ocean pressure gradient, stronger winds, and greater precipitation over southern Asia. On the contrary, under glacial conditions, the monsoon was weakened in southern Asia. In the northwestern part of Bangladesh, an alternating phase of strenghtening and weakening of the summer monsoon can be revealed from the magnetic susceptibility results as well as carbon and oxygen isotopic records during the Middle to Upper Pleistocene. The age Midle to Upper Pleistocene have been obtained from the palaeomagnetic measurements of the palaeosol sequences (Alam, 1993; Alam and

Hus, 1997). The strongly developed palaeosols marked by the high susceptibility values and lighter isotopic values represent intervals during which the summer monsoon circulation dominated and precipitation increased. On the contrary, the moderately developed palaeosols with low susceptibility values and heavier isotopic values reflect intervals during which summer monsoon declined and precipitation decreased.

CONCLUSIONS

Based on the relative abundance of pedogenic features (i.e. secondary $CaCO_3$ nodules, Fe/Mn oxide concretions), biogenic features (i.e., root traces or rootlets, animal burrows), colour and different soil structures (i.e., prismatic, blocky etc.), mainly two types of palaeosols are named as (i) moderately developed and (ii) strongly developed. These degrees of palaeosol development are interpreted in a semi-qualitative way in terms of climatic conditions during their development. This, in turn, gives a clue to the sedimentation pattern and flood basin accretion under different climatic conditions in the Pleistocene in the northwestern part of Bangladesh. The cyclic variations of the climatic changes as reflected in the bulk magnetic susceptibility and stable isotopic signatures in the palaeosol sequences are supposedly related to the alternating strengthening and weakening of the summer monsoon during the Pleistocene Epoch in Bangladesh.

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