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Characterization and Evolution of Laterites in West Bengal: Implication on the Geology of Northwest Bengal Basin

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Abstract

It is quite impossible to travel far in India without observing the remarkable ferruginous crust to which F. Buchanan in 1807 gave the name of laterite. In Indian peninsula it is a post-Cretaceous stratigraphic succession with polycyclic nature of evolution which marks the unconformity with Recent Quaternary Alluvium. There are perennial problems and research gaps in the investigation of laterites in India as well as West Bengal – (1) defining, indentifying and classifying lateritic materials, (2) mode of formation of laterite and its other horizons, (3) determining the ages of laterites, (4) reliability of laterites as palaeoclimatic indicators, (5) identifying topographic requirements and pedo-geomorphic processes for laterite formation and (6) reconstructions of former lateritized landscapes. The formation of north – south lateritc cover (i.e. Rarh Bengal) on the Rajmahal Traps, Archaean granite – gneiss, Gondwana sedimentary, Tertiary gravels and Old Deltaic Alluvium is analyzed here to resolve the aforesaid problems and to depict the variable characteristics of laterites with special reference to its tectono – climatic evolution in northwest marginal part of the Bengal Basin. This paper reveals that the low-level secondary laterites (probably Pliocene – Early Pleistocene age) of Rarh Bengal are composed of heterogeneous iron – aluminum rich gravelly materials which were derived from the high-level primary laterites (probably Eocene – Miocene age) of Plateau since Tertiary Period by the peninsular river system, following the underlying structure of the Bengal Basin. Alongside the roles of drifting of Indian Plate, establishment of monsoon climate, neo-tectonic uplifts and re-lateritisation of ferruginous shelf deposits are determined here to unearth the palaeogenesis of primary and secondary laterites in West Bengal.

Key Words: *Laterite, Bengal Basin, Rarh Bengal, Palaeogeography, Monsoon, Tertiary*

1.0 Introduction

The reddish-brown colour as like as brick with concentration of iron-aluminum oxides have fascinated many researchers of earth sciences about its evolution and variable occurrences on different geological formations. The tropical to sub-tropical wet – dry types of climate, mainly 'rubefaction zone' of Pedro (Tardy, 1992), are allied with the ferruginous crusts which are widely recognized as the laterites or ferricretes or plinthites (MacFarlane, 1976; Tardy, 1992; Bourman, 1993; Schaetzl and Anderson, 2005). In spite of numerous publications and researches on laterites, much confusion, contradictions and controversies still proliferate in the available literatures on the genesis, distribution, classification, geological age, sub-surface profiling of laterites and present day lateritisation process. As the term 'laterite' originated in India (Buchanan, 1807) this type of ferruginous deposits in peninsular India retains its special research interest due to its potentiality to expose the palaeogeographic environment of a region since Tertiary Period. We are quite fortunate enough to have the glimpses of laterites in West Bengal. An emblematic north – south lateritic belt of West Bengal (geographically recognized as Rarh Bengal by Bagchi and Mukherjee in 1983) with the ferruginous gravels and kaolinte deposits (from Rajmahal Hills to Subarnarekha Basin) borders this province to make the transitional diagnostic landforms and distinct sedimentation pattern in between Archaean – Gondwana Formation at west and Recent Quaternary Alluvial Formation of Bengal Basin at east (Niyogi et al, 1970; Biswas, 2002; Mahadevan, 2002; Das Gupta and Mukherjee, 2006). The northwest margin of Bengal Basin, in between the western part of Bhagirathi – Hooghly River and eastern part of Chotanagpur Plateau, shows all the variations of lateritic terrain, consisting of western hilly upland, intermediate degradational plain and eastern old deltaic plain (Biswas, 2002). On the intermediate degradational plain (dissected by rills and gullies) a great variety of laterites (i.e. primary and secondary laterites) is observed, showing the sub-surface horizons of hard duricrust, mottled zone and pallid kaolinitic zone. To understand the genesis and development of this geomorphologically important material some imperative considerations and queries are borne in mind. First, there is the question of source of ferrallitic materials which contribute to the make-up of reddish – brown duricrust. Second, whether laterite and its variants are highly related to weathering on the Rajmahal Basalt-Traps or shelf deposits of Bengal Basin. Third point is whether primary (in situ) or secondary (ex situ) origin of laterites is observed in this region. Fourth, whether there is any possibility of lateritisation being an ongoing process in the monsoon region or is an indicator of palaeomonsoon. Fifth question is raised about the geomorphic evolution (with respect to drifting of plate and neo-tectonic movement) of lateritic belt particularly in this zone of West Bengal. So this paper attempts to explain these queries and has provided a pedogeomorphic and palaeogeographic outlook to the laterites of northwest Bengal Basin in relation to its geological evolution and characteristics.

2.0 Previous Important Works

The term laterite has been applied to such a diverse array of geomorphic features that it no longer has value as a precise descriptive term (Paton and Williams, 1972). Nomenclature, classification, morphological and analytical characteristics, global distribution, processes of horizon development, environmental conditions of laterites are precisely analyzed by Alexander and Cady (1962), Maignien (1966), Paton and Williams (1972), Thomas (1974), McFarlane (1976), Young (1976), Tardy (1992), Bourman (1993) and Schaetzl and Anderson (2005) etc. Importantly Row Chowdhury et al (1965), Pascoe (1964), Raychaudhuri (1980), Babu (1981), Devaraju and Khanadali (1993), Wadia (1999) and Ollier and Sheth (2008) have investigated various profiles of lateritic deposits in Peninsular India and tried to solve the problems of origin of Indian laterites. The general belief is that the high-level or primary laterites were formed due to in situ chemical weathering of basalt plateau in the monsoon wet – dry climate and low-level or secondary laterites are formed by denudation and transport of primary laterites and cementation of accumulated detritus. Ollier and Sheth (2008) have mentioned the inversion of relief hypothesis in place of the ferricrete plain hypothesis to explain the origin of high Deccan duricrusts of India. The laterites of West Bengal are investigated by Morgan and McIntire (1959), Hunday and Banerjee (1967), Sengupta (1972), Niyogi et al. (1970), Goswami (1981), Vaidyanadhan and Ghosh (1993), Das and Bandhyopadhay (1995), Singh et al. (1998), Biswas (2002), Ghosh and Ghosh (2003), Chatterjee (2008), Mukhopadhyay and Pal (2008). They have provided significant geological and geomorphological explanations of lateritic landforms which carry distinct palaeogeographic individuality of this northwestern marginal part of the Bengal Basin.

3.0 Materials and Methods

To collect spatial information the topographical sheets (1: 50,000 scale) of Survey of India (72 P/12, 73 M/3, M/4, M/6, M/10, M/11 and 73 N/1), GSI (Geological Survey of India) district resource maps of Birbhum, Barddhaman, Bankura and West Medinipur districts, and district planning maps of National Atlas Thematic Map Organization (NATMO) are used. To identify major physiographic features of southern West Bengal seven Landsat ETM+ (Enhanced Thematic Mapper Plus), post-monsoon images of 2000 – 2001 (path/row: 138/43, 138/44, 138/45, 139/43, 139/44, 139/45 and 140/44) are downloaded from the website of GLCF (Global Land Cover Facility: glcf.umd.edu/data/landsat/). The Landsat ETM+ sensor has six multispectral bands (1,2,3,4,5, and 7) with spectral range of 0.450 – 2.350 μm and spatial resolution of 30 m, including two thermal bands (6.1 and 6.2) with 60 m resolution and one Panchromatic band of 15 m spatial resolution. These georeferenced bands (UTM WGS84) of each scene are integrated in one image using Erdas Imagine 9.1 software. Finally seven images are joined using mosaic tool of Erdas Imagine 9.1 to get total coverage of southern West Bengal. The ASTER (Advanced Space Borne Thermal Emission and Reflection Radiometer) elevation data with 30 m resolution (GCS WGS84) of 2011 is downloaded from the website of the Earth Explorer (http://earthexplorer.usgs.gov/) and it is also processed through Erdas, using AOI and subset tools. All unrectified raster and vector data are projected in UTM (Universal Transverse Mercator) assigning datum of WGS84 (World Geodetic Survey, 1984) using the project raster tool of ArcGIS 9.3 software to overlap these data accurately. The contours of elevation are generated using ASTER data and the spatial analyst tool of ArcGIS with an interval of 50 metre. To identify and plot the region of laterites we have applied NDVI (Normalized Difference Vegetation Index) and Iron Oxide Index using the processed FCC image. Niyogi et al. (1970), Bagchi and Mukherjee (1983), Singh et al. (1998), Biswas (2002) and NBSS - LUP (2005) have investigated the composition of soil series and radiometric dating of laterite which are used to recognize soil-geomorphic units of lateritic Rarh region. The horizons of each lateritic profile are studied on the basis of texture, colour, cementation, degree of mottling and bleaching, weathering front, iron - aluminum oxides assemblages and other pedogenic, petrograhic and geochemical characteristics.

4.0 Study Area

The zone of laterites is the main spatial unit of study, bounded by the latitude 22° 00´ to 24° 30´ N and longitude 86° 45´ to 87° 50´ E (figure 1). In between 115 m and 45 m contours the Rarh, i.e. 'land of red soil' (Sarkar, 2004), lateritic patches hold the remnants of thick forest cover which includes tropical deciduous plant species like *Shorea Robusta, Madhuca Indica, Terminalia Chebula, Eucalyptus Globulus, Tectona Grandis and Acacia Auriculaeformis* (Ghosh, 2008). The distribution of laterites and lateritic soils is limited to parts of western plateau fringe of West Bengal, comprising the eastern part of Bankura, west – central part of Birbhum, middle Barddhaman, part of Murshidabad, West Medinipur and eastern parts of Purulia districts, altogether covering an area of approximately 7,700 km2 (Hunday and Banerjee, 1967). An overall parallel drainage system (i.e. Brahmani, Dwarka, Mayurakshi, Kopai, Ajay, Damodar, Dwarakeswar, Silai, Kangsabati and Subarnarekha etc.) dissect the lateritic Rarh region into the patches of forests and degraded badlands. It has been found that in the aforementioned districts approximately 387. 91 km2 of lateritic land has suffered from intensive soil erosion which exceeds the tolerance limit of 11.2 t ha-1 year-1 (Sarkar et al., 2005). The climate is observed in this part of India which experiences a hot and sub-humid monsoonal climate, controlled mainly by proximity to the Bay of Bengal in the south and the alignment of the Himalayas in the north (Singh et al., 1998). This part of Bengal Basin is identified as Tropical Wet – Dry Morphogenetic Region (AW climate) with dominance of basal chemical weathering, surface crusting of Al and Fe minerals, highly seasonal sheetfloods and badlands (Chorley et al, 1984).

The Bengal Basin, in the eastern part of Indian subcontinent (about 25° N latitude to about 7° S) between the Indian Shield to the west and north, and the Indo – Burman Ranges to the east, covers Bangladesh, parts of West Bengal, Tripura and the Bay of Bengal and it is well known for the development of a thick (~ 22 km) Early Cretaceous – Holocene sedimentary succession (Alam et al, 2003; Das Gupta and Mukherjee, 2006). Its Stable Shelf Province (Alam et al, 2003) covers the western lateritic part of West Bengal, renowned as Rarh Bengal (Sengupta, 1970; Bagchi and Mukherjee, 1983). Fringing Jurassic Rajamahal Basalt-Traps, Gondwana Formation and Archaean Formation at west and Quaternary Older Alluvium (Panskura and Sijua Formations) at east, the lateritic zone of Tertiary to Pleistocene Formation is found at middle part of south Bengal or northwestern part of the Bengal Basin. Zonal latosols (Bagchi and Mukherjee, 1983) or upland red soils (Singh et al., 1998) formed primarily of sedentary materials cover the plateau proper and plateau fringe regions, while azonal alluvium with iron nodules and caliches (older and newer) formed of drift materials cover the eastern plains.

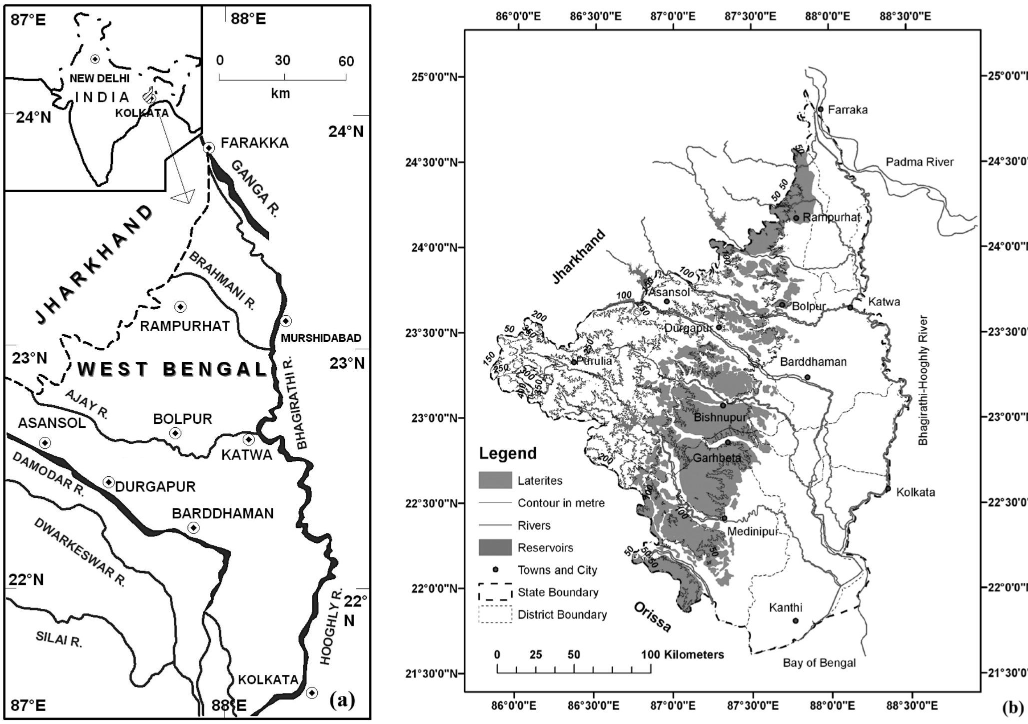

Fig. 1 (a) Location map of study area, showing part of southern West Bengal; and (b) the demarcated lateritic interfluves (i.e. central Rarh region) of West Bengal.

5.0 Laterite and Its Composition

In a broadest sense the term laterite includes ferricretes, iron or aluminum duricrusts, mottled horizons, carapaces, cuirasses, plinthites, pisolite or nodule bearing materials and also kaolinitic lithomarges (MacFarlane, 1976; Tardy, 1992). Laterite is the reddish – brown coloured product of intense tropical weathering made up of mineral assemblages that may include iron or aluminum oxides, oxyhydroxides or hydroxides, kaolinite and quartz, characterized by a ratio SiO2 : R^2O^3 (where R2O3 = Al2O3 + Fe2O3) and subjected to hardening up on exposure to alternate wetting and drying (Alexander and Cady, 1962; Maignien, 1966; McFarlane, 1976; Tardy, 1992; Bland and Rolls, 1998). It is suggested that materials having Fe^2O^3 : Al^2O^3 ratio more than 1 and SiO^2 : Fe^2O^3 ratio less than 1.33 be termed as 'ferruginous laterite'; while those with Fe^2O^3 : Al^2O^3 ratio less than1 and SiO^2 : Fe^2O^3 less than 1.33 as 'aluminous laterite' (Karunakaran and Roy, 1981). According to Ollier and Sheth (2008) the lateritic crust is categorized as massive, pisolitic (isolated concretions), vesicular and vermicular or vermiform (having worm like holes). Minerologically laterite is essentially mixture of varying proportions of goethite [FeO(OH)], hematite (Fe2O3), gibbsite (Al2O3, 3H2O), boehmite [AlO(OH], limonite [γ–FeO(OH)] and kaolinite [Al2Si2O5(OH)4] (Row Chowdhury et al, 1965; Bland and Rolls, 1998; Schaetzl and Anderson, 2005).

Table 1 Proportion of chemical components (%) in the samples of laterite, kaolinte clay and bed rock at Adda bore hole (23° 52´ N, 87° 32´ E) near Suri, Birbhum district (Mukherjee et al, 1969)

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	TiO_2
Laterite at 2 m depth	10.23	39.86	32.05	0.46	0.28	0.32	2.13
Kaolin at 11 m depth	46.67	35.82	1.43	0.22	0.53	0.26	1.18
Bedrock – Gneiss at 31 m depth	61.92	20.10	3.83	1.62	0.78	3.25	0.65

Note: Major minerals in laterite – gibbsite, hematite and goethite

The compound red soil is developed over weakly formed plinthite and the parent material is mostly composed of mottles, alternating red gravelly sand and mudstone consisting of detrital red soils particles bound by iron oxide (Singh et al, 1998). Vermicular laterites have important ferruginous minerals, e.g. gibbsite, hematite, goethite and limonite, having high percentage of Al2O3 and Fe2O3 (table 1). It has been observed that the molar ratio (SiO2/ R2O3) of lateritc soils are decreasing with depth with high percentage of kaolinite at base (Singh et al, 1998). At the top diffuse nodules (< 1 mm) of Fe – Mn concretions are considered to be formed by current pedogenic processes and sub-surface nodules with sharp boundaries are formed due to past lateritisation process. The maximum thickness of massive laterite varies from 1.07 m in Archeans, 8.0 m in Rajmahals, 5.15 m in Tertiary sediments and 6.12 m in Older Alluvium (Chatterjee, 2008). It is only in the eastern fringe of Rajmahal Traps that nodular horizons (33 – 75 percent of ferricrete layer) supersede massive layer of laterite.

Rather than using the term laterite or ferricrete it is very applicable here to use the term lateritic profile (Bourman, 1993) which generally comprises deep weathering profile having distinct horizons of dismantled concretions, duricrust (i.e. ferricrete), mottle zone, pallid zone and weathered parent materials (i.e. saprolite) (figure 2). Laterites of India are variously classified by Vaidyanadhan (1962), Roy Chowdury et al (1965), Raychaudhuri (1980), Wadia (1999), as well as Ollier and Sheth (2008) as in situ and ex situ laterites, high-level and low-level laterites, plateau and valley laterites etc. Reviewing the earlier works, the laterites of West Bengal are categorized as primary laterites (in situ weathering of parent rocks) and secondary laterites (ex situ weathering of redeposited materials) to compare these with ideal weathered profile of tropical climate (figure 2).

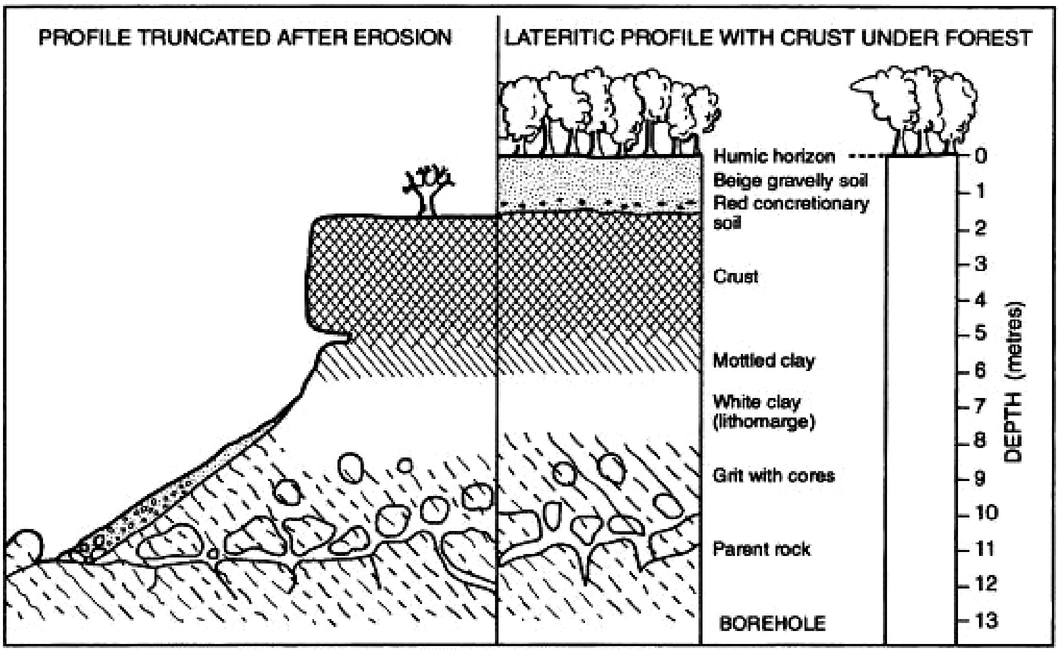

Fig. 2 Ideal profile of laterite in tropical wet – dry climate. (after Thomas, 1974; Ollier and Sheth, 2008)

6.0 Nomenclature and Individuality of Laterites in West Bengal

According to soil taxonomy of laterite, in the Rarh Plain of West Bengal alfisols, oxisols and entisols (Sarkar et al, 2005) dominate the Rajmahal Basalt-Traps, Archaean – Gondwana Formation and Tertiary gravelly interfluves of Brahmani, Dwarka, Mayurakshi, Kopai, Ajay, Damodar, Dwarakeswar, Silai, Kasai and Subarnarekha rivers respectively (Niyogi et al., 1970; Chatterjee, 2008). On the basis of occurrence, topographic position and formation of distinct mature profiles, two types of laterites are found in West Bengal – (1) relatively older Tertiary primary laterite (high-level) and (2) relatively younger Pleistocene secondary laterite (low-level). Basically three domains are common in all lateritic profiles at northwest margin of the Bengal Basin – (1) zone of alteration at the base (coarse saprolite and fine saprolite or lithomarge), (2) glaebular zone located at the middle part (mottle zone, ferricrete or cementation of iron and gritty layer with nodular concretion), and (3) a soft non-indurated zone at top (dismantled nodules of hematite with cortex of secondary goethite).

6.1 Primary Laterite

Merely the laterites on Rajmahal Basal-traps have massive appearance (in situ weathering) reflecting vermicular lateritic crust (probably Eocene – Miocene age), mottled zone with lithomarge clay and deeply weathered basalts. According to Alexander and Cady (1962) and Young (1976) the features which distinguish primary in situ laterite and account for its hardness, are a greater degree of crystallinity of minerals and a greater continuity of the crystalline phase. At Rajmahal Basalt-trap and its outliers, the consolidated nodular, vermicular and gravelly amalgam of lateritic materials directly overlie on the basaltic bed rock. The average thickness of lateritic duricrust is recorded in this area up to 9.15 metre (Chatterjee, 2008). At Rampurhat, Nalhati and Pakur, the laterite directly overlies basalt showing box structure defined by thin hematite bands. In pure basalt ferric oxide is 2.40 percent whereas in laterite after weathering of basalt it can be 70 percent (Chatterjee, 2008). In the foothill region of Rajmahal the lateritic hardcaps are covered with loosened ferruginous gravels, having stoneline at the base of duricrust. It reflects the derived materials by the gullies or streams. The laterite cap is thicker over the higher relief parts (greater depth of bedrock), where the greater depth of weathering has allowed the zone of water table fluctuation to be more extensive. But where the basaltic bed rock has convex appearance (upland with stony waste), the zone of weathering is so small to develop well consolidated laterite and mottled zone. At a basalt-quarry of Nalhati the profile shows a true laterite or ferricrete layer at least 4 m in depth, extremely hard, ox-blood in colour, containing cellular as well as vesicular cavities; but not having cemented nodules (Biswas, 2002). A 3 m thick horizon of mottles (red, yellow and purple colour) and next predominantly 4 m thick clayey containing whitish kaolinised materials show high degree of weathering and intensive leaching of silica (Biswas, 2002).

6.1.1. Identified Profile of Primary Laterite

In a moorum quarry of Baramasia, near Rampurhat (24° 12´ N, 87° 40´ E) three distinct domains (i.e. lithomarge, mottle zone and duricrust) of laterite profile (fig.3a see page 117) are clearly observed, corresponding to the ideal profile of Thomas (1974), Tardy (1992) and Ollier and Sheth (2008).

A. Saprolite Domain or lithomarge (> 6.5 metre depth from land surface) – The saprolite-alteration domain (i.e. strongly weathered basalt) are normally located below the ground water table (i.e. saturated zone), that is in permanently wet condition, having a depth of more than 11.5 metre. In this profile fine saprolite or lithomarge is observed in between 6.5 and 8.3 metre depth and the structures of the parent rock and the original volumes are almost preserved. The dominant minerals are secondary kaolinite [Al2Si2O5(OH)4)] and ferruginous hydroxides in amorphous phase. An excessively leached lithomarge (Tardy et al, 1991) corresponds to pallid zone is found here, underlining the mottled zone and separating by red bands of laminated lithomarge and ferruginous grit.

B. Glaebular Domain – According to Ollier (1991), Tardy et al. (1991) and Trady (1992) under contrasted tropical climates fine saprolite, lithomarge and iron is naturally redistributed and concentrated in distinct positions to characterize a glaebular zone, in which duricrust or ferricrete may develop (figure 3a).

B.1. Mottle Zone (6.5 – 3.9 metre depth from land surface) – Fe-mottles, mostly of a brown red colour, are diffuse glaebules and result in a concentration of iron which precipitates mainly as goethite and as hematite together with kaolinte matrix. Due to intensive leaching of kaolinte, macrovoids (tubules and alveoles) are formed. Importantly lithorelictual Fe-mottles (Tardy, 1992) are accumulated, reflecting the palaeostructure of weathered Rajmahal basalt (fig. 3b See page 117).

B.2. Ferricrete Zone (3.9 – 1.2 metre depth from land surface) – It corresponds to a progressive accumulation of iron and as a consequence, to a progressive development of hematitic iron nodules. The bleached zone is reduced in size, so that the yellow – white coloured domain decrease in size while the purple – red Indurated domain enlarges and develops. A goethite cortex (concentric yellow brown) develops at the periphery of purple – red hematitic nodules. The colours, ranging from yellow to brown, orange – brown and brownish black, signifies the presence of limonite which consist of poorly crystalline goethite or lepidocrocite (γ-FeO(OH)) and adsorbed water, i.e. FeO.OH.nH2O (Bland and Rolls, 1998).

C. Dismantled Gritty Layer (1.2 – 0.52 metre depth from land surface) – A gritty horizon is developed at the top laterite profile with development of latosol. This horizon is made of the products of the dismantling of the pseudoconglomeratic (Gmg facies) of the pisolitic-underlined ferricrete. A surfacial sandy layer, made of corroded quartz, is liberated by the dissolution of the ferricrete and a pebbly layer develops at the expense of the pisolitic iron crust, came from the early hematitic nodules.

6.2 Secondary Laterite

The low-level laterites separate the lithological formations of Archaean, Gondwana and Tertiary gravels from the Sijua and Chuchura Formations (Quaternary Alluvium) deposited over the shelf of Bengal Basin between Pliocene and Pleistocene (Das, 1972). The secondary laterites (fig.4a See page 119) are specifically found as the interfluves in Rampurhat, Illambazar, Bolpur, Kanksa, Ausgram, Bishnupur, Garhbeta and Kharagpur though the variations of horizons are still observed. The presence of a sub-surface layer of kaolinitic clay reddened from above by ferro-colloids (Biswas, 2002) and of rounded pebbles of different rocks, gravelly appearance of crust and the general absence of conventional horizons of laterite signify a detrital origin (ex situ) in Rarh Bengal.

The badland topography (i.e. Khoai landscape) of Bolpur (Kopai – Ajay interfluve) has developed over moorum (i.e. friable ferruginous concretions) composed of loosely bounded iron concretions, gravels with a rather thin and hardened surface layer and a brunt blackish red colour. In the badlands of Santiniketan (near Bolpur) the Graulometric anbalyis of laterite hard crust reflects 9.02 percent of gravels, 54.72

percent sand, 20.88 percent silt and 14.1 percent clay (Mukhopadhyay and Pal, 2008). The soft, brown to grey coloured and iron stained mottle zone (thickness of 1 – 4 m) is merged with less mottled clayey material (thickness of 4 – 7 m) with no iron concretions in this region (Niyogi et al, 1970).

In the forest tract of Durgapur, Kanksa, Galsi, Augram I and II blocks of Barddhaman district (Ajay – Damodar interfluve) the hardcrust of gravelly laterite is partly eroded by rills and gullies (fig. 4b See page 118). Here two distinct layers of pisolitic nodules are identified – (1) loose and less compacted gravelly iron concreted zone (70 – 80 cm thick) and (2) compacted and hard layer composed of regularly spaced nodules cemented by red clayey matrix being ox-blood in colour (Singh et al, 1998; Biswas, 2002). The lateritic exposure in the Silabati – Dwarkeswar interfluve (at Bishnupur) is appeared as 'laterite mesa' (Biswas, 2002) with 10 m relative relief. The remnants of crust have thickness of 3 m and it is overlain on mottle zone and whitish or light yellow kaolinitic pallid zone.

Spectacular gully development at Gangani near Garhbeta, West Medinipur district, has given rise to a micro-level badland development over the multi-level laterite profile near the right bank of Siliai River (Das and Bandyopadhyay, 1995). Resembling with Australian 'breakways' (Biswas, 2002) this scarp-like duricrust is extended up to Kharagpur, appeared as interfluve. The major indurated layer (thickness 2 – 4 m) consists of red – brown or brick red, hard, vesicular and slag-like porous laterite in which cavities (tubular) are filled with red brown or white earthy material (Niyogi et al., 1970; Das and Bandyopadhyay, 1995). This layer is overlain on purple mottled sandy loam (3 – 5 m thick) and underlain by a pallid zone (10 m thick) with abundance of gravels and coarse sands.

6.2.1. Identified Profile of Secondary Laterite

Laterite on Tertiary gravelly sediments (figure 4 b) covers a large area from Durgapur and Bishnupur up to the Silai – Kagsabati – Subarnarekha Basin, creating spectacular badland topography. Based on the observations in Rampurhat, Bolpur, Durgapur, Ausgram, Bishnupur and Garhbeta, the following three domains of secondary laterites are identified.

A. Lithomarge or Pallid Zone

Greyish white to pale coloured soft and porous kaolintic layer is observed in 10 – 15 metre depth. It is overlain on the Upper Tertiary gravel deposits which are appeared as conglomerate of clasts, inversely to normally graded fluvial facies in the medium of bleached kaolin matrix.

B. Glaebular Domain

B.1. Mottled Zone – Brown – Greyish brown coloured clayey materials with original quartz are observed in between 3.5 and 10 metre depth from the ground surface. Fe – Mn and Fe – Al mottles are created in the tubules with kaolinite matrix.

B.2. Duricrust – Crumbly and slag-like, vesicular and porous ferruginous crust is observed up to depth of 1 – 3.5 metre. Red – brown coloured nodules signifies the dominance of hematite and burned black coloured cortex reflects goethite.

The most noticeable form of duricrust is centripetal accumulation of iron materials and coarse sands in pores of small size.

C. Dismantled Gritty Layer

Loose and rounded lateritic nodules or concretions or plinthites (0.3 metre thick) are dominated the surface of duricrust, signifying the recent weathering and pedogenic processes. The presence of iron-stained sub-angular to irregular gravels reflects fluvial deposits. Under vegetation cover and adequate moisture, latosol is developed but on exposure it is harden.

7.0 Processes of Ferruginous Accumulation

The laterite described by Buchanan is only one member of laterite families whose members have different properties but are similar genesis (Schellmann, 1981). In Rarh Bengal the processes of primary and secondary laterite formation are slightly different in the basis of magnitude of involving factors (i.e. type of weathered materials, source of ferrallitic materials, wet – dry type of climate, fluctuation of groundwater table, topographic positions, stability of favourable environment etc.). In the tropical geo-climatic settings, the processes of lateritisation (transfers of Fe), latosolization (residual accumulation of Fe), desilication (loss of silica from the profile) and rubification (reddening the regolith and soil horizons with iron oxides) are simultaneously operated to develop distinct horizons of laterite (Schaetzl and Anderson, 2005).

Singer (1975) considers that there are three accepted modes of iron enrichment: vertical leaching, capillary rise and fluctuating water table. Bourman (1993) proposed that lateral migration of iron and aluminium involves the accumulation at preferred sites. The influence of water table fluctuation has great impact on the lateritisation processes. There is no doubt that the change to oxidizing conditions above water table would led to the oxidation and precipitation of ferrous iron (Bourman, 1993). Primary silicates are kaolinised in the early weathering stages and most of the alkalis and alkaline materials removed though leaching. Incongruent dissolution of kaolinte with formation of gibbsite is occurred over the regolith of basic rocks (e.g. basalt) (Schellmann, 1981). Water does not enter between the successive layers (1:1 layer) of kaolinte crystals, so the kaolinite is non-swelling (Tardy, 1992). The occurrence of lithomarge kaolinte clay between laterite and bed rock is acted as perched aquifer, influencing the loss of water and free silica through upper slope of kaolinte zone (Biswas, 1981; Ravindran and Kittu, 1981).

Alternating wetting and drying with the fluctuation of groundwater table, perhaps accompanied by local reduction and reoxidation, is believed to be the main cause of the movement and recrystallization of the iron. In the area covered by secondary laterites (Bankura and West Menidipur) the groundwater level measurements on 433 observation open wells are ranging from 5 to 25 m below land surface (Biswas, 1981). The seasonal fluctuation of groundwater table varies significantly from 1.00 – 10.00 m below land surface of secondary laterites (Biswas, 1981). The range of groundwater fluctuation is associated with wet – dry season (seasonal extremity) of monsoon climate and porous nature of ferruginous deposits. According to continual weathering model of laterite formation (Bourman, 1993), within the zone of water table fluctuation, primary iron minerals within the weathered basement rocks are degraded by weathering under reducing conditions, forming ferrous iron that is redistributed and segregated within the lithomarge zone to from ferric iron rich mottles under oxidizing conditions.

Pascoe (1964) and Roy Chowdhury et al (1965) have emphasized the role of sols and gels in the formation of laterite suggesting that the alumina rich layer (leached zone) acted as a semi-permeable membrane preventing the movement of iron oxide downward and colloidal silica upward. The more soluble constituents, both crystalloids and colloids, have been carried away in solution or suspension. Negative and positive sols have each year been precipitating hydrogels of alumina, ferric – ferrous and titanium oxide with silicic acid (Pascoe, 1964). These are dehydrated later due to alternate dry and wet seasons along with fluctuation of groundwater. Suspended matter (gels) has been deposited at the outer base of the laterite profile by spring discharge water and basal sapping, as complicated red bands of laminated lithomarge and ferruginous grit (Pascoe, 1964). Large quantities of ferric hydroxides have been forced to that surface from the mottle zone, possibly as result of surface tension, ionic diffusion and capillary pressure as the level of groundwater slow falls (Pascoe, 1964; Das and Bandhyopadhyay, 1995).

Concretion of iron nodules designates the mechanism of cementation and induartion, by centripetal accumulation of material, in pores of small size. In a sequence of ferricrete development from mottles (diffuse accumulation) to subnodules (nodules with diffuse edges), nodules (with distinct edges) and to metanodules (anastomosed), iron content increase, quartz content decreases drastically (Tardy et al, 1991). Nahon (1986) and Tardy (1992) describe the metabolism of ferricrete – an iron crust is generally built at the top of laterite profile by a combination of successive small-scale migration of iron, leaching or dissolution of kaolinite and quartz grains, formation voids, secondary accumulation of kaolinite together with small quartz crystals and ferruginization of these accumulations. In first case goethite, a hydrated mineral, prevails during wet season, while in the second case, hematite, a dehydrated mineral, dominates during the dry season. The hematite – kaolinite nodules are rehydrated and corroded at their edges. Kaolinite is dissolved and Al-hematite is transformed into Al-goethite (Tardy, 1992).

8.0 Tectono – Climatic Evolution of Laterites in West Bengal

The source of major disagreements as to the origin of these ferruginous formations is to be found in the presence of evidence of residual or in situ alteration and weathering as well as undoubted detrital or sedimentary features (Roy et al., 1965). It is accepted that laterization process signifies a particular set of geo-climatic environment, analogous with wet – dry type of Tropical climate and it is a common pedogeomorphic process in this climate. Based on the previous literatures and geological framework of the Bengal Basin it is hypothesized that the north-south lateritic belt (i.e. Rarh Bengal) was developed due to (i) drifting of Indian Plate from Gondwanaland, (ii) onset of monsoon wet – dry climate in Indian subcontinent, (iii) sedimentation of Bengal Basin with peninsular ferruginous sediments and (iv) neo-tectonic movements (Tertiary – Pleistocene) of Bengal Basin.

8.1 Drifting of Indian Plate and Establishment of Monsoon Climate –

The geomorphic aspect of duricrust formation is the speed at which they form and the rapidity with which they may harden on exposure (Goudie, 2004). It is suggested that the geographical distribution of African, Brazilian, Indian and Australian laterites are very much correlated with the drifting of continents and influence of tropical seasonal climate during the past 150 – 100 million years (McFarlane, 1976; Tardy et al, 1991; Widdowson, 2004). Following the continental

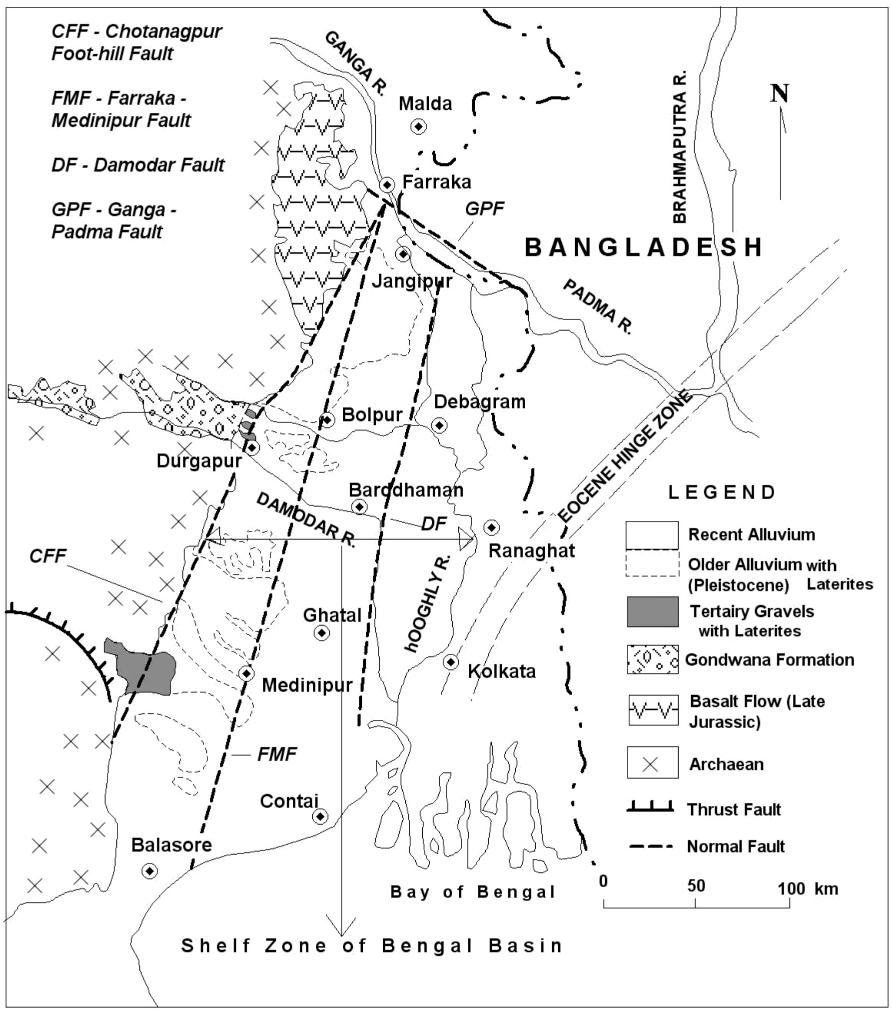

Fig. 5 Geological setup of northwestern part of Bengal Basin (shelf zone) linking Tertiary and lateritic deposits with fault controlled structure (modified from Sengupta, 1972; Singh et al., 1998).

drift hypothesis of Alfred Wegener it is already established that the climatic zones are stable only the plates are moved apart from the giant Gondwanaland. The favourable climatic condition of laterite genesis is characterized by contrasted seasons, high temperature, ranging between 28° C and 35° C, annual rainfall lower than 1700 mm and long dry seasons during which atmospheric relative humidity decreases, sometimes below 80 percent. (McFarlane, 1976; Tardy et al, 1991; Tardy, 1992; Ghosh and Ghosh, 2003). This type of climatic conditions is very much analogous with the monsoon climatic system of India which was gradually established due to equator-ward drift of Indian Plate since 150 Ma (Jurassic Period) and was certainly strengthen by the evolution of Himalayas, colliding with Asian Plate at ~ 55 Ma (Tardy et al, 1991; Adlakha et al, 2013).

The date of complete separation of the Indian segment of the Gondwanaland from the Antarctic – Australia segment may be placed in Early Cretaceous (120 – 127 Ma) (Vaidyanadhan and Ghosh, 1993; Kent and Muttoni, 2008; Meert et al, 2010). As rifting widen a new sea floor was created on which the Indian Ocean entered as Bay of Bengal (Vaidyanadhan and Ghosh, 1993). The Rajmahal Volcanics (Late Jurassic) were the earliest manifestation of volcanic activity (followed by Late Cretaceous lava flow in Deccan region, India) which bordered the sea from the peninsular landmass. According to Sychanthavong and Patel (1987) based on the discovery of angiosperm plant fossils, the lower age limit of plateau laterites cannot be older than Late Cretaceous; most likely Paleocene. To assign a Cretaceous age this formation is not plausible because at this

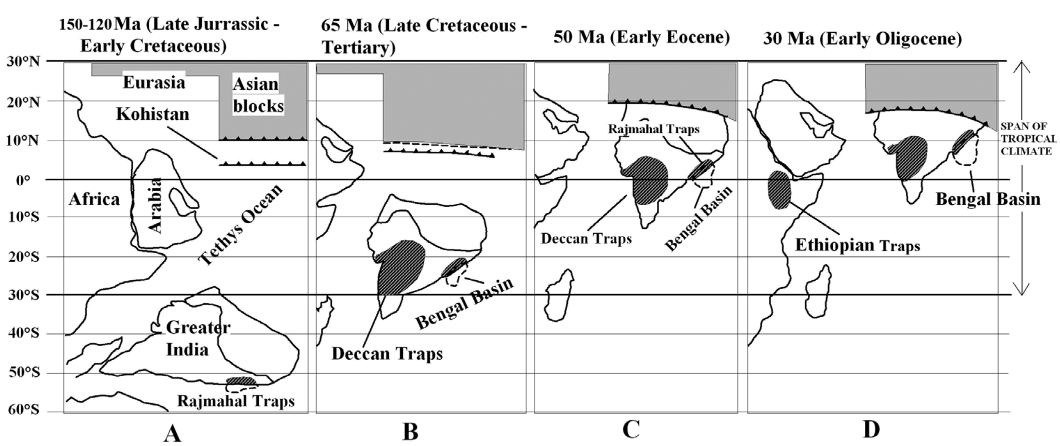

Fig. 6 Palaeogeographic reconstruction of Indian subcontinent, Rajamahal Traps and Bengal Basin and their entry to the region of tropics – (A) separation of Indian segment from Gondwanaland and emplacement of Rajamahal Basalt-Traps in Early Jurassic – Early Cretaceous, (B) reconstruction just after the Cretaceous – Tertiary boundary and emplacement of Deccan Traps, (C) collision between Eurasian Plate and Indian Plate and (D) reconstruction for Early Oligocene and emplacement of Ethiopian Traps (modified from Tardy et al, 1991; Alam et al, 2003; Kent and Muttoni, 2008).

juncture the Indian Plate had just started drifting apart from its original position between latitudes 40° S and 60° S (more conducive for temperate climate) in the Gondwanaland (Sychanthavong and Patel, 1987). The Indian Plate was rotated by 40° in an anticlockwise direction in the northern hemisphere and the lateritic belt had crossed the intense tropical zone during this rotation (Sychanthavong and Patel, 1987). If we consider the palaeopostion of the Indian Plate and the study area, it is expected that the lateritic region was trending more northwest – southeast (presently north – south) with the alignment of the latitudinal positions (in between Equator and Tropic and Cancer).

During Jurassic times, present day South Africa, greater part of present day Brazilian Shield and Peninsular Shield of India were subjected to arid – semi-arid type of climate (Tardy et al, 1991). Due to movement of plates the continents of Gondwanaland were progressively reached toward the zone of tropics but former humid climates progressively become more arid (Tardy et al, 1991). From the end of Triassic to the Cretaceous the Indian continent's climate evolved from hot and dry to hot and humid (figure 6). Climatic conditions were favourable for intense laterization process from Cretaceous to Palaeocene times for during that period, the Indian Plate crossed the zone between 30° S and 0° (Kumar, 1986; Tardy et al, 1991; Devaraju and Khandali, 1993). After strong collision of India against Eurasia at the end of Miocene, the climate became more tropical less temperate but remained humid with no important arid episode (Tardy et al, 1991). The development of plateau laterites (i.e. primary high-level laterite) began at the end of Cretaceous and continued during the Tertiary on the surface of Deccan Plateau and Rajamahal Basalt-Traps (Sychanthavong and Patel, 1987). Fox observed that possibly no laterization began in Indian peninsula until a monsoon climate was established at the close of Mesozoic (Devaraju and Khandali, 1993). In the Paduvari Plateau of coastal Karnataka the occurrences of aluminous laterite or bauxite (5.0 – 7.0 m thick) underlain by ferruginous laterite (0.5 – 1.5m thick) signify that climate was evolved from humid tropical to tropical wet – dry condition in the Tertiary Period (Tardy, 1992; Devaraju and Khandali, 1993). The deep profiles of primary laterite with ferricrete, observed in the Rajmahal Hills, Ranchi Plateau, Raniganj Coal-field and Singhbhum Shear Zone, were probably developed during Eocene – Miocene Epoch. The prevalence of a tropical to sub-tropical climate during Late Palaeocene is borne out by the presence of prolific tropical and sub-tropical flora in the lateritic formation of this region (Devaraju and Khandali, 1993). The dicotyledonous and angiospermous fossil woods are found in the moorrum quarries and deep gullies of eastern plateau fringe of Rajamahal Basalt-Traps.

The major part of the Indian peninsula falls within Koppen's 'AW' climatic zone to which formation of laterite in the present day is confined (Subramanian and Mani, 1981). Considering this reality the question arises whether all the laterites traced on varied rock types of different ages in Indian peninsula are to be related to the evolution of monsoon wet – dry type of climate which is still active. According to Subramanian and Mani

(1981) if stable conditions prevail, then under favourable climatic conditions, the intensity of lateritisation processes will be high. So there was a critical balance between tropical climate and tectonic stability in Tertiary times. The present occurrences of low-level laterites are the erosional remnants of fossil laterite, indicating the palaeoclimate of laterite (Bourman, 1993). Clearly there must be a geological time framework (prior to Pleistocene) of India within which the climatically induced processes had been operated to form deep profiles of laterites and bauxites on variable parent materials. Frakes and Kemp (1972) complete the continent reconstructions using ocean – current evaluations, oxygen isotope measurement and palaeobotanic data and suggested that the climate of Eocene and Middle Oligocene was more favourable for laterite formation in peninsular India. In Eocene the equator was running across central Gujarat to southern West Bengal (Bardossy, 1981).

The Indian summer monsoon evolved during the Miocene at about ~ 23 Ma and certainly exited by ~ 12 – 20 Ma because increased sediment fluxes are reported during Middle Miocene (Adlakha et al, 2013). The monsoon rainfall was again intensified at ~ 8 Ma ago (Adlakha et al, 2013). Then the primary and secondary laterites were subjected to severe erosion and the eroded ferruginous materials with gravels and pebbles were deposited by parallel river system toward eastward depression of the Bengal Basin as the shelf deposits. Then the lateritic uplands and ferruginous soils were gradually developed at eastern fringe of the Chotanagpur – Rajmahal Plateau at the highest elevation of 35 to 120 m msl in West Bengal, separating the Quaternary deposits of Bengal Basin (Singh et al, 1998).

Table 2 Occurrences of ferruginous nodules in the deep alluvium of Bengal Basin (Roy and Banerjee, 1990)

Site of Boreholes (Galsi I and II blocks)	**Litho-Unit**	**Depth (m) from Ground Surface**
Sukdal, Budbud	Yellow – yellowish white sand medium to coarse grain, feldspar with iron nodules	18.29 – 48.8 m, 48.8 – 54.9 m and 207.4 – 213.19 m
Galsi	Light yellowish grey medium to coarse grain sand, gravels and feldspar with sub-angular iron nodules	22.88 – 27.45 m
Ghsohkamalpur	Whitish yellow medium to coarse grain sand, quartz and feldspar with iron nodules	41.4 – 56.4 m and 90.2 – 94.5 m
Mankar	Reddish yellow clay with iron nodules	33.52 – 40.25 m

Development of Tertiary laterites and its episodic erosion are confirmed due to existence of ferruginous nodules in different great depths of basin sediments. Due to reactivation of basement faults and erosion in palaeomonsoon climate the ferruginous sediments with medium to coarse grain sands and gravels were expected to deposit cyclically in the depression of Bengal Basin as the monsoon rainfall intensified periodically (table 2). The base of the Jalangi Formation 6 (Oligocene to Miocene) consists of poorly sorted medium grained ochreous, hematitic, lithomargic sandstone with thickness of 119.5 m (Hundy and Banerjee, 1967; Babu, 1981). Again a number of thin bands of laterite have been encountered in Jalangi Formation 7 (Pliocene to Pleistocene) along with gravel, claystone and kankar with thickness of 275 m (Hundy and Banerjee, 1967; Babu, 1981).

8.2 Role of Tectonics and Ferrugination of Shelf deposits –

During Early Tertiary Period (Palaeogene) the Bay of Bengal was reached northwards up to the Garo – Rajmahal Saddle (Vaidyanadhan and Ghosh, 1993). The whole of the present day Bengal Basin (including Ganga – Brahmaputra Delta) was under water until the Mio – Pliocene Epoch and the strandline grazed the eastern margin of the Peninsular Shield, i.e. much inland (towards west) from the present day Orissa – Bengal Coastline (Vaidyanadhan and Ghosh, 1993; Das Gupta and Mukherjee, 2006). The western Tectonic Shelf and Barind Tract Horst of the Bengal Basin are separated by the Ganga – Padma Fault (GPF) and the Damodar Fault (DF) separates the Tectonic Shelf and Ganga Fluvio – deltaic Plain Graben (Singh et al, 1998). The Medinipur – Farraka Fault (MFF) within the Tectonic Shelf separates the low-level laterites of Rarh Bengal (i.e. Upland Red Soils) in the west from the soils of Bhagirathi – Ajay – Damodar Deltaic Plain in the east (figure 5 and 7). Three successive major faults (north – south trend) extend for variable distances into the overlying Cretaceous – Tertiary sequence and the Lower Gangetic landforms of Bengal Basin had been formed due to reactivation of these faults (Sengupta, 1966; Singh et al, 1998).

The zone of secondary laterites between the Raniganj Coalfield (west) and the Bhagirathi – Hooghly River (east) is recognized as the north-western delta shelf zone of Bengal Basin which is stretched from Farakka in the north to Digha – Haldia coastline in the south (figure 1 and 7) (Vaidyanadhan and Ghosh, 1993). Faults of western margin of Bengal Basin are arranged in an en echelon pattern (Sengupta, 1972) and it is possible that this structural zone along the Basin margin behaved as a tectonic hinge (Eocene Hinge Zone) and controlled the depositional conditions throughout the Tertiary Period (Sengupta 1972). Due to intensification of heavy monsoon rainfall (around Late Tertiary) the western plateau laterites were severely eroded and transported towards the break of slope of peninsular landmass, i.e. Chotanagpur Foot-hill Fault (CFF). An overall parallel drainage system (fig. 7a See page 119) flowing west to east is a significant geomorphic feature of the plateau fringe of West Bengal, reflecting structural control on drainage pattern and fluvial sedimentation since Miocene (Niyogi et al, 1970). Up to end of Tertiary the ferruginous materials were deposited by the rivers of Damodar, Ajay, Mayurakshi, Kopai, Brahmani, Dwarkeswar, Silai and Subarnarekha as para-deltaic formation (under shallow marine condition up to Durgapur) in between CFF and MFF (figure 7b). At 7 – 6 ka only the eastern Tectonic Shelf (figure 5 and 7b) subunit subsided along the Damodar Fault (directed the southerly course of Damodar River near Palla, Barddhaman district) and was subject to marine transgression (Singh et al, 1998). It favoured subsequent erosion of lateritic upland and re-deposited the materials toward the downthrown block with development of Damodar Fan-Deltaic Plain (Achryya and Saha, 2007). For that reason the few isolated patches of lateritic exposures (compound lateritic profiles) are found at a distance from MFF at Rampurhat, Mallarpur, Labhpur, Bolpur, Guskara, Khandaghosh and Kharagpur, following the fault-line scarp (Biswas, 2002).

During the Early Pleistocene the entire eastern unit of Tectonic Shelf (in between MFF – DF) of the Bengal Basin subsided to become the site deposition and the western unit (in between CFF – MFF) uplifted following the transgression of sea (figure 7b) (Singh et al, 1998). The Dwarkeswar, Silai and Kasai Rivers have an annular drainage pattern, suggesting relatively active domal uplift around Bishnupur, Garhbeta and Kharagpur (Singh et al, 1998). Sea level gradually decreased and reached their lowest level of ~ 135 m during the Early Pleistocene around 18,000 years BP, when the Pleistocene and Late Tertiary sediments located in the shelf areas were exposed as relief inversion (Acharyya and Saha, 2010). These deposited ferruginous materials were exposed at the surface, influenced by erosion and prolong lateritic pedogenesis under persistent wet – dry monsoon climate. Due to well drainage condition, intensive leaching and chemical weathering (in acidic medium) the top facies of laterites were very much influenced by ferrugination. The tropical wet – dry climate was prevailed in this region up to Early Tertiary because dicotyledonous fossil woods (probably Miocene - Pliocene age) are still found in the lateritic forest tracts of Panagarh and Ausgram, Barddhaman district (Hundy and Banerjee, 1967). The lateritic topographic level (50 – 120 m above msl) represents reworked laterite and contains vertebrate fossils of Middle – Early Pleistocene age along with the palaeolithic tools (Vaidyanadhan and Ghosh, 1993). The nodular ferruginous soils or Upland Red Soils (after Singh et al, 1998) observed under the forest covers of West Bengal could appear to be relics of ancient ferricretes which developed when these areas were subject to a contrasted tropical climate but which are now being destroyed under very humid tropical condition that prevails today. Increased precipitation during the ~15 – 5 ka period of monsoon recovery probably increased discharge and promoted incision and widespread badland formation (i.e. Khoai landscape in West Bengal) (Sinha and Sarkar, 2009). Observing the western parallel drainage pattern of West Bengal and extent of Rarh Bengal it is clearly observed that the lateritic uplands are now appeared as the dissected interfluves which were once as the valleys of ferruginous deposition (i.e. earliest fan deposits of the Bengal Basin), now appeared as inversion of relief (Bourman, 1993; Biswas, 2002; Ollier and Sheth, 2008) due to tectonic uplifts, re-lateritisation and incision of rivers. The dominance of kaolinite (with presence of

Hystrichospherids in the spores of clay beds in Birbhum district) indicates lacustrine to fluvio – lacustrine condition of deposition in Late Tertiary (Mukherjee et al, 1969).

The age of the whole Indian laterites decreases from north to south in concordance with the drift tectonic history of the Indian Plate across the equator (Sychanthavong and Patel, 1987). So the primary laterite over Rajmahal Hills must be older than the laterite of Western Ghats. According to Niyogi (1975) the eastern lateritic soils of Rarh Bengal (i.e. Lower Lalgarh Formation), old deltaic plain (i.e. Sijua Formation) and young deltaic plain (i.e. Chuchura Formation) has been assigned ages of 350 – 1000 ka, 175 – 275 ka and 60 – 82 ka respectively. Singh et al (1998) suggest that the red soil groups of Rarh Bengal are the oldest soils from the Indian part of these Gangetic Plains. In the Durgapur Depression (Kumar, 2006) the ferruginous concretions (Pliocene) were formed over deposited gravels which is probably Oligocene to Miocene age (Das, 1972). The presence of Younger Toba-Ash Bed Marker (~ 75,000 yrs BP) has been recored from basal parts of the Quaternary profile from the Brahmani and Barakar river sections, located west of the Bengal Basin margin (Acharyya and Saha, 2010). These bed are tentatively correlated with the lateritic unit which may be assigned Pleistocene age (Acharyya and Saha, 2010). According to Morgan and McIntire (1959) the Late Pleistocene ferruginous sediments are found principally in four areas of the Bengal Basin – (i) east of the Rajmahal hill system (i.e. Rarh Bengal), (ii) Barind tract, (iii) Madhupur jungle and (iv) west of the folded Tripura system.

Near surface occurrence of lateritic conglomerate (Gmg facies – matrix-supported massive gravels, inverse to normal grading) is the product of ex situ lateritisation of debris flow – fluvial deposits during Pliocene to Early Pleistocene (Mahapatra and Dana, 2009). It is comparable to Early Pleistocene Lalgarh Formation (West Medinipur district), Saltora Formation (Bankura district), Illambazar Formation (Birbhum district), Kharagpur Formation (East Medinipur district) and Worgram Formation (Barddhaman district) (Vaidyanadhan and Ghosh, 1993). These formations can be considered as the palaeoclimate proxy of strong Tropical wet – dry climate which is prerequisite for the development of ferruginous concretions. In this region the lateritisation process was favoured by the following factors (Niyogi et al, 1970; Singh et al, 1998; Biswas, 2002) –

Onset of monsoonal rainfall with prolonged dry months (Late Eocene – Early Pleistocene) accelerated sub-aerial chemical weathering in the derived ferruginous matrix;

Uplifted block (in between CFF and MFF) and its influences on seasonal groundwater regime, sub-aerial exposure, strong leaching, irreversible dehydration, well sub-surface drainage and prolong erosion;

Adequate permeability and drainage condition to permit deep percolation of silica and deposition of iron oxides as coating over gravels;

Warm and strong seasonal climate to hasten the chemical breakdown, hydration and dehydration of ferruginous and aluminous oxides; and

Prolonged quiescent phase of geological time with permanent regression of sea level (Late Miocene – Early Pleistocene) from this area.

A feedback loop is inherent in the development of residual and detrital laterite cover, because lateritisation and erosion are continuous cyclic processes since Eocene (Karunakaran and Roy, 1981). The loop involves lowering of primary laterite profile for accentuation of weathering and consequent accretion and subsequent uplift for facilitating erosion, re-lateritisation, stripping and etchplain formation (fig. 8).

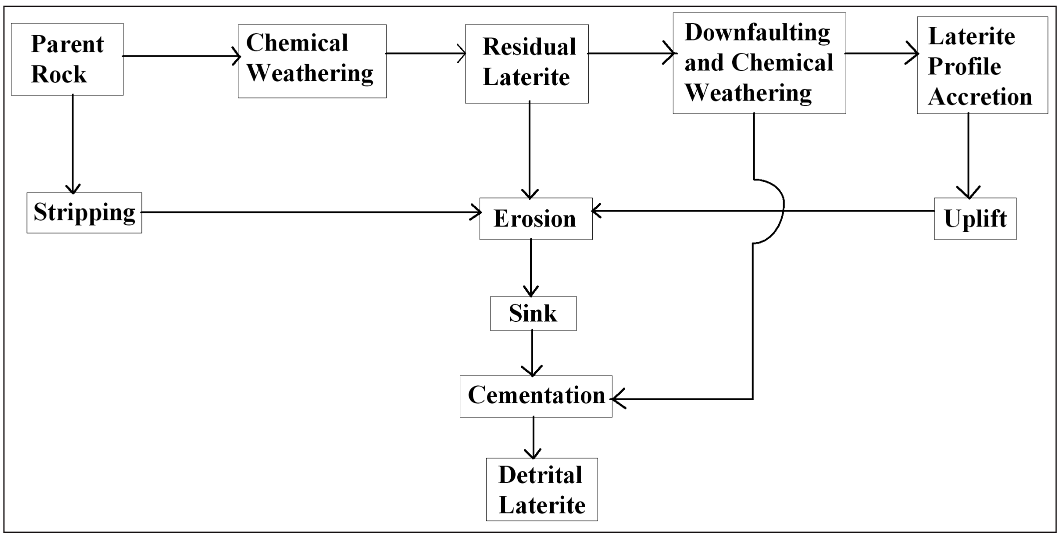

Fig. 8 Possible feedback loop to depict sequential development of primary and secondary laterite in this monsoon climatic setting

9.0 Conclusion

It is finally understood that three basic conditions must be met before enough iron oxide accumulates or segregates to form crust – (1) adequate supply of iron, (2) alternating wet and dry seasons, and (3) iron segregation and accumulation for appreciable periods. It is suggested that the development of both pallid zone and mottled zone is one integrated process and the formation of ferricrete or crust is the final result of that integrated process. If we accept the residuum theory of laterite formation the original iron precipitates are believed to have formed in the narrow fluctuating range of a groundwater table, which declines as the land surface is lowered. With the cessation of downwasting and stabilization of the groundwater table, the ferruginous residuum is thought to have been hydrated to form massive laterite. The mottled zone is formed with the absolute accumulation of iron in kaolinized matrix involving the epigenetic replacement of kaolinte by hematite. Soft nodular and hard nodular iron crusts are described in the upper part of profile that involves the transformation of soft yellow plasma into pisolites. As surface weathering and erosion proceeded, the iron segregations, largely as hematitic mottles with goethite rinds, are progressively exposed at the surface, where they are harden.

Only the profiles of laterite on Upper Jurassic Rajmahal Basal-Traps have massive appearance (in situ weathering) reflecting vermicular lateritic crust (i.e. primary laterite), mottled zone with lithomarge clay and deeply weathered basalts. It is suggested that these primary laterites were started to develop in between Late Cretaceous and Eocene. But if we go southward and eastward direction a ploy-profile of laterites with an intervening erosional surface and original gravels (with iron staining) are present, gradually merging with mottled clay zone and Sijua Formation (Late Pleistocene to Early Holocene). These laterites are identified as the secondary laterites (products of ex situ weathering) which were derived from the primary laterites of western Chotanagpur Plateau, Raniganj Coal-field and Rajmahal Basalt-Traps towards the Bengal Basin. Due to exposure, well drainage condition and prolong monsoonal wet – dry episode the indurated laterite or consolidated gravely lateritic mass or vesicular or pisolithic laterites were formed at the surface in different parts of northwest Bengal Basin. Geomorphologically these laterites are found here in two settings – (1) as continuous crusts on plateau fringe where they act as hard caps on the table-like landforms and source of ferrallitic materials, and (2) at footslopes and interfluves as deposited ferruginous crust, in seepage areas where reduced iron in soil solutions encounters oxidizing conditions and precipitates. The most noticeable feature of south Rarh Bengal is the presence of a ploy-profile or multi-level lateritic hard crust. It is assumed that bottom profile formed earlier from Upper Tertiary gravelly sediments and after subsequent regional uplift and subsequent erosion developed upper profile of ferruginous alluvium deposits which were lateritized in Late Pleistocene. The age of whole Indian Tertiary laterite decreases from north to south in concordance with the drift tectonic history of the Indian Plate across the equator. So the establishment of strong seasonal monsoon climate (since Eocene), due to equatorward drift and evolution of lofty Himalayas, created the favourable conditions for the development of plateau laterites (Eocene – Miocene) which were subsequently eroded, deposited and re-lateritised in the valleys within the span of that seasonal climate (Pliocene – Early Pleistocene).

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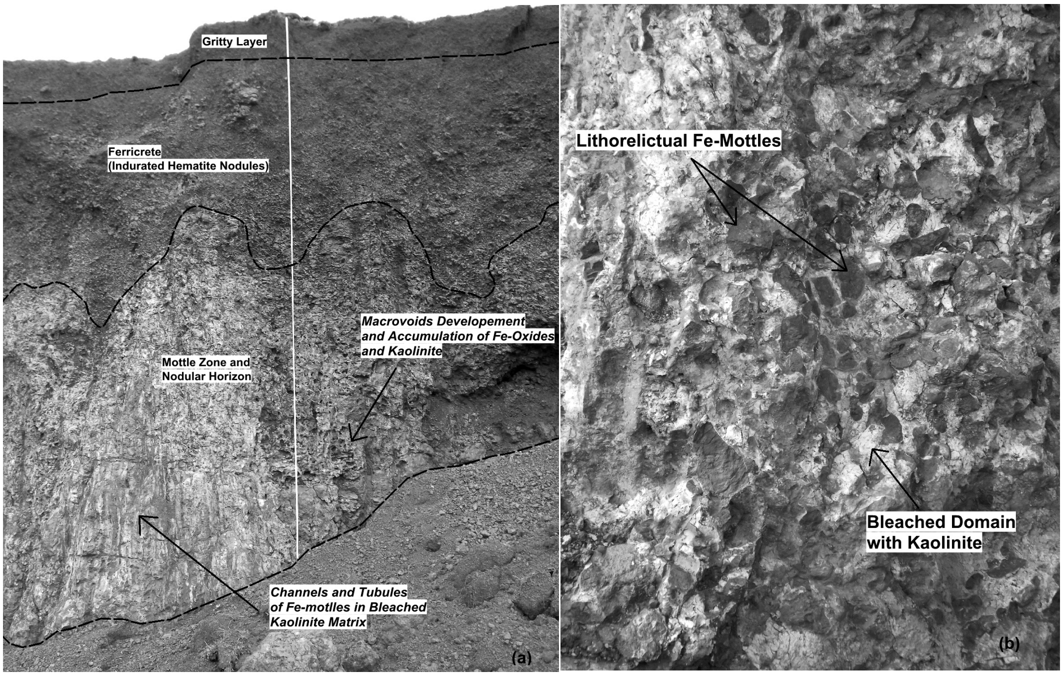

Fig. 3 (a) Gritty dismantled layer at top, massive ferricrete at middle and mottle zone with kaolinite matrix of primary laterite profile (6.77 m depth) at Baramasia, west of Rampurhat and (b) a close view of lithorelictual iron mottles in pale – yellowish kaolinite in that profile, reflecting the palaeostructure of weathered Rajmahal basalt. [See page 100 and 101 for the text]

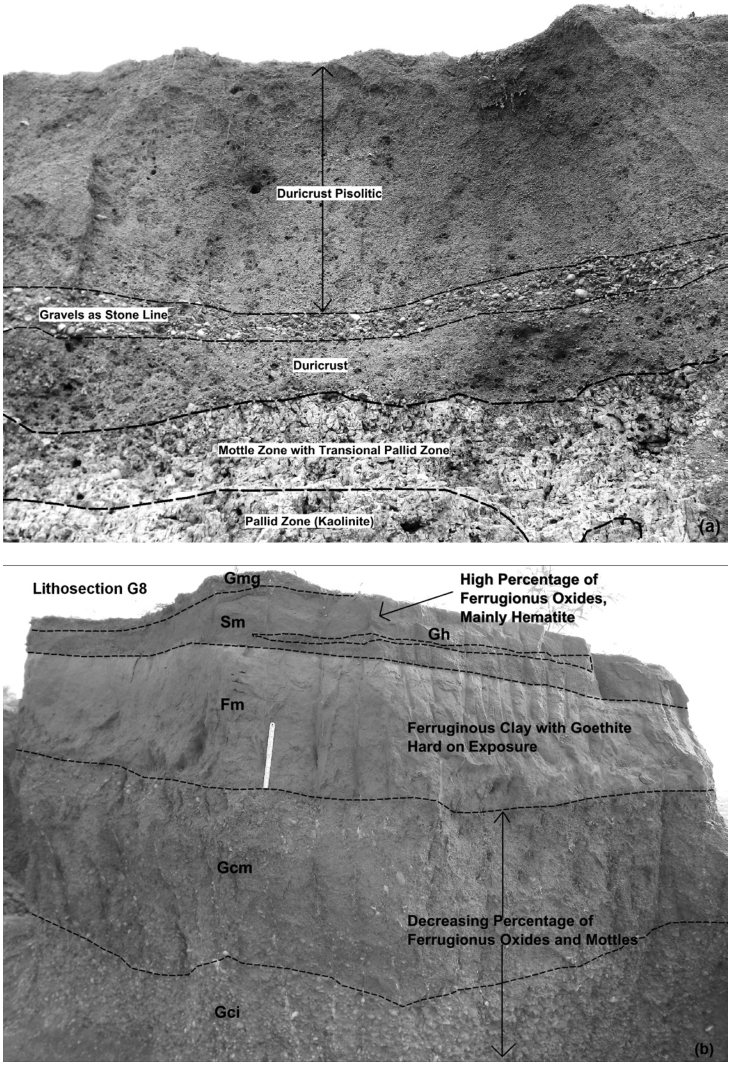

Fig. 4 (a) Pisolitic duricrust with stone line of gravels and transitional mottled to pallid zone (china clay) in the profile (4.5 m depth) secondary laterite at Bhatina, West of Rampurhat, and (b) a laterite profile (2.7 m depth) on the Tertiary gravels at Kamalpur, north of Durgapur, having fluvial to debris flow facies (after Mahapatra and Dana, 2009) – Gci (i.e. inverse grading clast-supported gravels), Gcm (i.e. Clast-supported massive gravel), Fm (i.e. Overbank or waning flow clay deposits), Sm (i.e. sand massive or faint wavy lamination), Gh (i.e. Clast-supported, crudely bedded gravel), and Gmg (i.e. inverse to normal grading matrix-supported massive gravels) (note: length of scale is 30 cm). [See page 101 and 102 for the text]

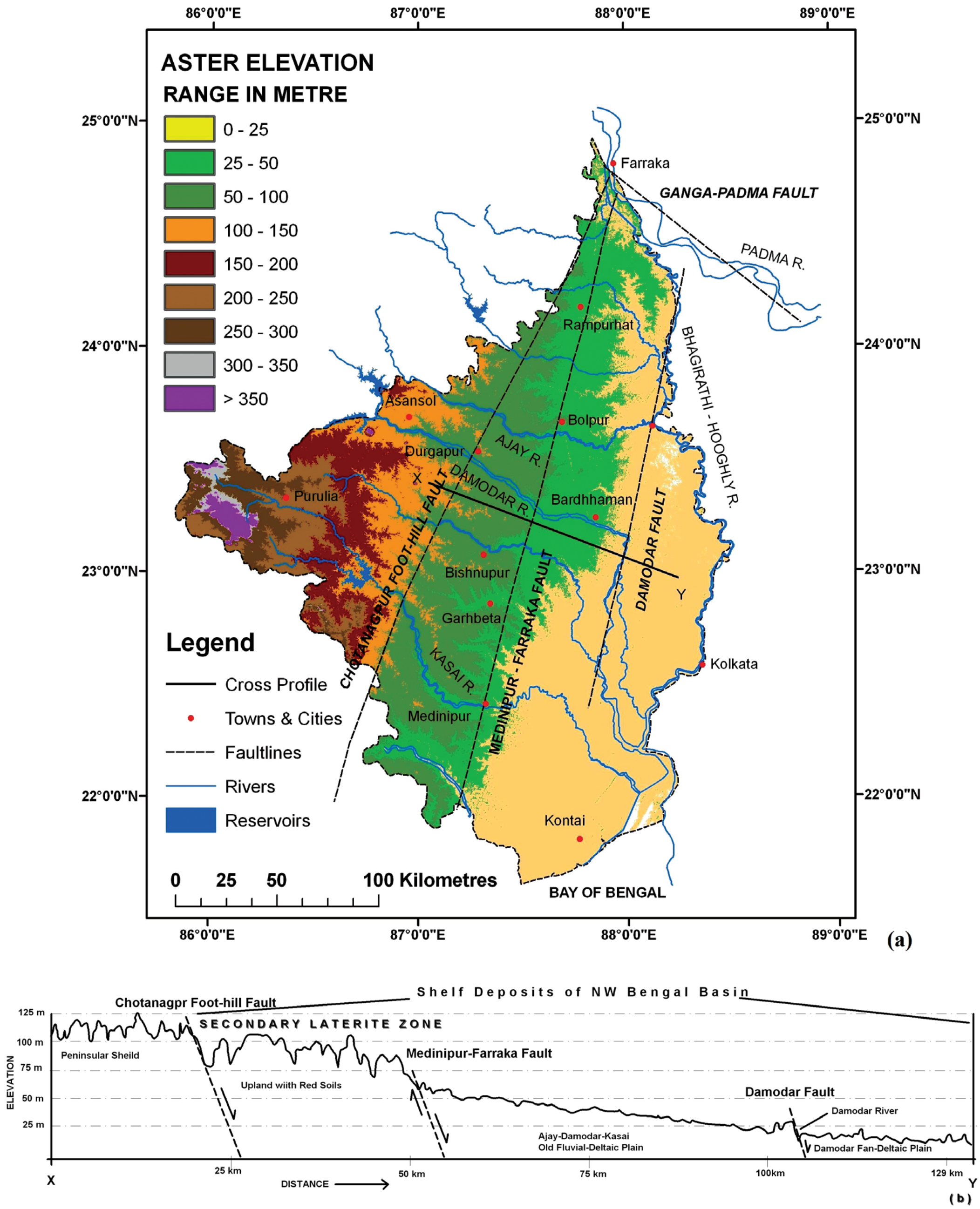

Fig. 7 (a) Elevation map (prepared from ASTER DEM, 2011) and identified major basement faults (modified from Singh et al., 1998) in the western part of Bengal Basin; (b) west – east cross profile (X – Y) with emplacement of faults – the lateritic Rarh region of figure 1 is bounded by Chotanagpur Foot-hill Fault (CFF) at west and Medinipur – Farraka Fault (MFF) at east. [See page 109 for the text]