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Geomorphic evolution and genesis of laterites around the east coast of Madras, Tamil Nadu, India

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Abstract

Laterites and lateritic soils (Red soils) of the east coast especially around Madras, Tamil Nadu have been formed in different geomorphic conditions and on various geological deposits. They occur as caprocks over recent alluvium, Upper Gondwana sandstones and shales, and Precambrian basement rocks. The laterite profiles studied around Madras are generally 2 to 5 m thick and exposed 5 to 45 km inland from the present-day shoreline.

Detailed analysis (micromorphological and chemical) and the bore hole litho-log data reveal that lateritisation was not continuous but occurred in phases. Lateritisation could have taken place in humid to sub-humid conditions with a rich source of iron in the parent rock and sediment and efficient internal drainage.

Geoarchaeological investigations and Quaternary stratigraphical studies date the lateritic crust surface to the early late Neogene. Neotectonics have played a vital role in shaping the present landscape.

1. Introduction

Laterites and lateritic soils of the east coast of Madras (Tamil Nadu, India) have formed on various geomorphic units including Precambrian charnockites, Upper Gondwana sandstones and shales, and the recent alluvium. Laterite deposits have been studied around the sites of Erumaivattipalayam, Alamadi and Manjankarni, all situated within a radius of 30 to 40 km of Madras city. These sites are geoarchaeologically important as the lateritic surfaces bears the evidence of human occupation from the Acheulian to Mesolithic (Foote, 1886; Krishnaswami, 1938). The lateritic surfaces have not been precisely dated until now because of the paucity of palaeontological and radiometrically datable material. The aim of this paper, therefore, is to present the geomorphic evolution of the laterites and the lateritic soils of this landscape and the late Neogene–Quaternary climatic change.

Physiographically, the study area is a low flat, slightly undulating terrain with a general slope of 3° to 5° towards E–ENE direction. The area receives an average annual precipitation of 1200 mm (both southwest monsoon and intense northeast monsoon) and the average monthly temperature varies between 25° and 40°C. Presently, the area is drained by the Korattallaiyar river which meanders with a swooping curve to the west of the study area. It has incised the lateritic landscape to form a bench surface at a height of 30–35 m from the present-day river bed. Further E–ENE, the river also forms the Korattallaiyar flood plain which is formed of uniformed layered and current bedded deltaic sediments. At Kosappur

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(Fig. 1), E–ESE, a peat sample found in the deltaic sediments at the depth of 2.91–3.06 m from the surface was dated by ^{14}C method to 6590 ± 120 yr B.P. (BSIP). This river continues to meander east and debouches its sediments into the Bay of Bengal.

1.1. Profile description

The laterite deposits studied in this area (Fig. 1) exhibit induced ferricrete profiles developed over the Upper Gondwana sandstones and shales. These profiles are generally 3 to 6 m thick with the duricrust missing in all the profiles studied in the above mentioned areas except at Erumaivattipalayam (80°7′30″E: 13°14′15″N).

At this site two phases of ferricritisation (Fig. 2) separated by a ferruginised rubble conglomerate bed (nearly 1 m thick) was observed at an elevation of nearly 30 m above the present-day Koratallaiyar river bed. This unit is capped by a ferruginised lag deposit (50 cm thick). The lag deposit is nodular (1–2 cm in diameter) and rich in MnO_2 pisoliths and nodules. The nodules are coated with a thin film of ferric oxides and the matrix between the nodules and the pisoliths is rich in ferric oxide content. Underlying the rubble conglomerate bed is a 1–1.5 m thick ferricrete exhibiting oolitic and pisolitic textures and relict features of the Upper Gondwana sandstones and shales. The pisoliths exhibit multiple and coupled rinds cemented to form a coherent crust like massive horizon-type hardpan rich in iron oxides. Underlying the ferricrete unit an induced weathering profile (4.5 m thick) of the Upper Gondwana sandstones and shales is observed. This profile is characteristically variegated with many distinct mottles of various sizes. The mottles are dark reddish brown (5YR 3/2), dark brown (7.5YR 4/4) in color and exhibit a structure of high vesicularity cellular zones. Fracture pattern of irregular and polygonal shapes is clearly exhibited probably due to dessication.

1.2. Profile composition

Undisturbed oriented samples were collected covering the entire laterite sections from the sites of Alamadi, Manjankarni, Erumaivattipalayam for micromorphological studies. Micromorphological analyses and XRD results are given in Table 1 for the Erumaivattipalayam site only. Total chemical elemental analysis for the Red Hills and Erumaivattipalayam were completed; composition is given in Table 2.

Mineralogically, the laterites are marked by high clay content, iron oxides, quartz, feldspars, quartzitic

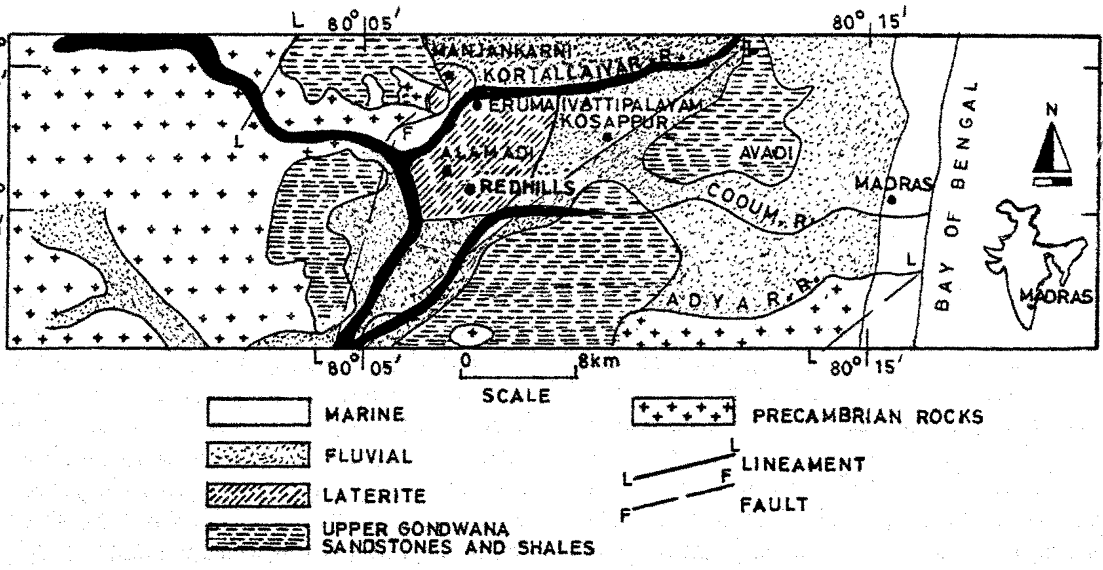

Fig. 1. Geological map of the area.

Table 1
Micromorphological analysis — Erumaivattipalayam site

Litho unit and depth	Lithoglacial components and features	Heavy minerals	Mineralogy + XRD (very fine size)	C/F	G/M + H ratio	Cellular zones	Voids and channels	Mottles	Nodules
Lag deposit 0–0.50 m	Ooliths, pisoliths coated with iron oxide and MnO_2	Zircon 2%, garnet 4%, hematite and magnetite dominant	High % of FeO and MnO_2	3/7	2:8	P	–	Rare	Imp. ferrugeneous
Ferruginised rubble conglomerate bed. FRCB 0.50–1.5 m	Ooliths, pisoliths, ferricritised nodules + pebbles, gravels of quartz, quartzites and sandstones	Zircon 2%, garnet 4%, hematite and magnetite dominant	Quartz, quartzites sandstones, feldspar, iron oxides — hematite, magnetite goethite and kaolinite	5/5	3:7	P	–	P	Imp. ferrugeneous
Lateritic crust 1.5–3.5 m	Ferruginised hardpan type with cavities and vesicles	Zircon 2%, garnet 4%, rutile 4%, hematite and magnetite dominant with geothite and kaolinite	Quartz, quartzites sandstones, iron oxides — hematite, magnetite goethite and kaolinite	2/8	3:7	P	–	P	Imp. ferrugeneous
Weathered horizon 3.5–8.0 m	Vesicular lightly ferruginised, increase of kaolinite down the profile. Variegated mottles of red, ochre, yellow, pisoliths and ooliths decrease toward the bottom		Hematite, goethite, kaolinite, quartz, quart zites, feldspar grains	3/7	1:9	P	P	P but less in lower units	Imp. ferrugeneous
UGS 8 m	bottom								

UGS = Upper Gondwana sandstone; P = Present; IMP = Impregnative nodules.

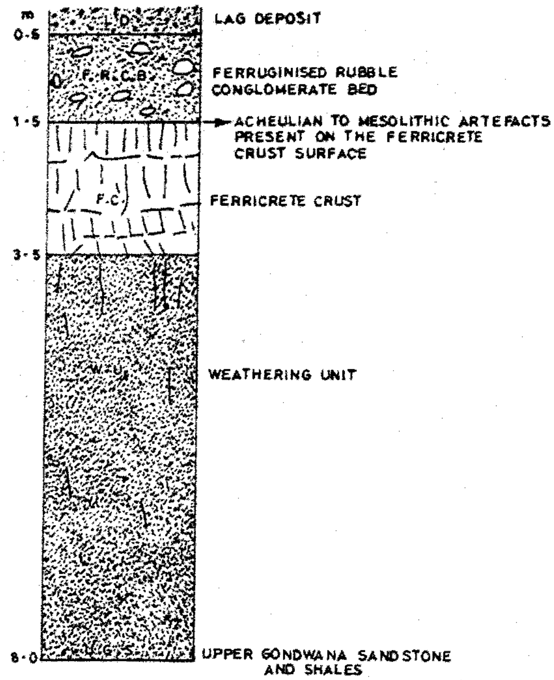

Fig. 2. Litho-section of Erumaivattipalayam profile.

grains and heavy minerals like zircon, rutile and garnet in traces. Quartz, feldspar and quartzitic sediments can be seen randomly distributed throughout. This is with higher incidence of clay towards the bottom of the residual profile. Micromorphological analyses of the laterite samples covering the entire profile (ferricrete crust to the weathered unit (depth 1.5–8.0 m) reveal that it is fairly homogeneous, consists of very fine silt to coarse sand size (30–50 μm to 200 μm), well sorted, sub-angular to sub-rounded quartz, feldspar and quartzitic detrital grains embedded in a matrix of kaolinite, goethite and hematite (Table 1).

Multiple phases of iron oxide mobilisation and precipitation within the individual nodules and pisoliths are revealed by thin sections. Iron seggregation produces a great variability of colors, degree of opacification and of forms both external and internal. Colors range from dark red to black, ochreous and brown. Opacification is directly related to the abundance of Fe oxides and also Mn (Federoff, 1979). This abundance (G/M + H ratio) was roughly estimated by optical microscope. Channels and voids are common. Pipestems, although rare, occur as fossil remnants and are lined with kaolinite and goethite structures. Red clays (2.5YR 3/6) have filled some channels, voids and cracks and have subsequently imparted an overall reddish color to certain parts of the thin section. Many of the voids and channels are also lined with black manganese oxide which represents the final depositional phase that stabilizes them.

In mottles, Fe oxides have stained zones of S matrix. In general, the impregnation is moderate to strong. Fractures (dessication cracks and fractures) are common. Mottles and blotches have amboidal forms with distinct boundaries. Dendritic patterns are discerned at a few places. The degree of bleaching is closely related to opacification by Fe oxides. The more the mottles are opacified by Fe oxides, the

Table 2
Chemical analysis of laterites from Red Hills and Erumaivattipalayam sites

Sl. No.	Depth litho unit	SiO_2	Al_2O_3	Fe_2O_3	FeO	TiO_2	MnO	CaO	MgO	Na_2O	K_2O	Loss on ignition	Total Iron content
1.	Lag	36.74	10.72	38.22	2.11	0.89	0.09	0.28	0.13	0.19	0.54	10.35	28.37
2.	Crust	32.16	11.46	43.72	1.05	0.60	0.09	0.30	0.12	0.24	0.65	10.31	31.40
3.	Weathered unit	37.59	11.85	37.77	1.25	1.00	0.13	0.30	0.11	0.14	0.92	9.82	27.39
4.	Weathered unit	31.76	11.68	43.76	0.86	0.73	0.03	0.78	0.56	0.18	0.66	10.59	31.28
5.	Weathered unit	25.09	13.35	46.31	0.86	0.73	0.10	0.78	0.56	0.12	0.65	12.32	33.06
6.	Lag	28.63	12.24	46.31	0.86	0.48	0.04	0.34	0.68	0.35	0.11	10.68	33.06
7.	F.R.C.B.	35.46	19.01	32.33	1.05	0.68	0.03	0.33	0.97	0.31	0.59	10.91	23.43
8.	Crust	62.96	10.47	10.69	2.59	0.56	0.05	0.52	0.25	2.90	2.32	4.22	9.49
9.	Weathered unit	58.04	11.55	18.37	1.72	0.58	0.18	0.56	0.46	0.60	2.80	5.41	14.30
10.	Weathered unit	64.52	13.05	10.70	1.83	0.52	0.13	0.50	0.77	0.93	1.02	6.53	8.41

Sl. Nos. 1 to 5 — Red Hills. Sl. Nos. 6 to 10 — Erumaivattipalayam.

more the bleaching is expressed. Nodules have a circular to elongated, amboidal form with a smooth abrupt boundary for most of them. The impregnation ranges from medium to high and a few nodules consist of quasi-pure Fe oxides. Nodules observed under the microscope, typically have an undifferentiated internal fabric, consisting of more than one ring of concentric iron rich clays. In the lag unit and the rubble conglomerate bed (0.20–3.5 m) pisoliths and nodules exhibit several generation of ferruginisation features. In some of the horizons Fe oxides are of different colors; red, brown, ochreous, black, yellow corresponding to different mineralogical forms of Fe oxides that can be related to environmental changes. Ferruginisation features exhibit signs of disaggradation followed by new aggradation. This can be interpreted as variations of drainage condition and more generally environmental changes. Hydration processes with alternating cycles of dehydration–hydration involve the mineralogical change of goethite (α-FeOOH) into hematite (α-Fe_2O_3). When they are finally integrated into clay, these iron oxides are responsible for the color of the groundmass. McFarlane (1976) distinguished soil pisoliths from groundwater pisoliths, although in the present study, it may be difficult to determine if the groundwater pisoliths were formed in situ or if they are transported pisoliths undergoing modification by groundwater. Those with irregular shapes and diffuse external borders, however, appear to have formed in situ (Bourman, 1993).

2. Discussion

Warm climates with contrasting wet and dry seasons, for example, those of mediterranean and tropical regions are known to be most favourable for ferruginisation (McFarlane, 1976). Consequently, ferruginisation observed in this in situ profile could indicate an earlier humid hot phase coupled with factors such as intricate drainage pattern, temperature variations and organic matter (vegetational canopy).

Detailed analyses and the borehole litho-log data of the study area reveal that the process of lateritisation has taken place in phases and that it was not a continuous process. The process of lateritisation could have taken place in an humid to subhumid condition with a rich source of iron in the parent rock and sediments and also with good internal drainage system.

The following discussion is an attempt to explain the genesis of this 30–35 m high level palaeo-ferricrete surface with a tentative stratigraphic framework. The ferricrete cover of 5 m have been formed either before or immediately after the Upper Gondwana slope was raised above the sea level (Krishnan, 1968). The ferricrete cap observed around Alamadi, Manjankarni, Erumaivattipalayam is thought to have been formed during the Middle to Late Tertiary continuing into the Early Pleistocene period. This irreversible, self terminating process of ferricritisation has taken place in these deposits under the influence of a fluctuating but high water table. It is postulated that this high water table was associated with the middle to late Tertiary high sea level (Krishnan, 1943).

The occurrence of Acheulian to Mesolithic artefacts on the stable ferricrete surface indicate that the landscape is older than 40,000 to 150,000 yr B.P. or even older as the ferricrete have formed over the Upper Gondwana deposits. The lateritic surface can be dated to the early late Neogene period.

The overlying bed of ferruginised well cemented rubble conglomerate containing a few late Middle Palaeolithic flakes (S. Pappu. pers. commun.), is composed of coarse, well rounded quartz, quartzitic sediments and angular gravels of quartz, quartzites and sandstone grains. This indicates that the rubble bed was deposited on a slope or on river terrace during the initial downcutting of the landscape. River incision must have resulted in the lowering of the water table and changed the drainage conditions. Subsequent deposition of a ferricrete lag over it resulted as an evolution of younger landscape. The lag unit could have also been formed because of surface weathering, erosion and mass wasting processes which progressively exposed the hematitic mottles forming lags over an river terrace. No residual lags were observed on steep slopes. Based on geoarchaeological, mineralogical and geomorphological data, Van Rooyen and Verster (1984) pointed out that ferricrete formation in south eastern Kalahari is the result of the accumulation of iron on a wet bottom land situation but formed during the wet period of the Upper Pleistocene.

Further cutting down of the entire ferricrete landscape including its own bed by the Koratallaiyar river, its meandering course, and the formation of delta represents the youngest geomorphological phenomenon in the study area. This inference is supported by the deposition of deltaic sediments and also by the ^{14}C date of 6590 ± 120 yr B.P. (being published for the first time) on peat found within the deltaic sediments at the depth of 2.91–3.06 m from the surface at Kosappur located 8–10 km E–ESE of Erumaivattipalayam. This incision could have been triggered by the uplift of the area sometimes during the terminal Pleistocene and early Holocene period. The fault line trending NNE–WSW (Fig. 1) could also have activated the incision during the same period. The delta progradation and rejuvenation of the Koratallaiyar river indicates an early Holocene neotectonic uplift. The delta alluvium may have been deposited during the same period because of the rising sea level. Neotectonism has played a vital role in shaping the landscape. The area has experienced a complex geomorphic processes in relation to pedogenesis, palaeoclimate sea level changes, and neotectonism since the early Neogene period.

3. Conclusions

1. The area was subjected to events of erosion, subsequent pedogenesis and hardening into laterite because of exposure since the early late Neogene period.

2. This was followed by incision of the landscape, deposition of rubble bed and ferruginisation of the rubble bed. Furthermore, surface weathering, mass wasting, and processes of erosion brought about the deposition and exposure of lag unit.

3. Subsequent downcutting through the lag deposit, rubble bed, and the ferricrete surface could have been triggered by the uplift of the area sometime during the terminal Pleistocene and the early Holocene period.

4. This weathering and duricrusting has affected a surface of low relief, possibly close to sea level, followed by differential uplift, incision and widespread destruction of the ferricrete surface (Woolnough, 1927).

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