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Genesis of the Khanapur 'Red Beds', Maharashtra, India

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Abstract

An erosional landscape characterized the Western Ghats in the Deccan Volcanic Province of India. The upland region shows the absence of sedimentological records for the stratigraphic period from post-Eocene to pre-Pleistocene, except laterites which are extensively developed. The absence of any sedimentological records, therefore, has put severe constraint on the reconstruction of the Tertiary history of the landscape. While the major known geological events like the northward drift of Indian subcontinent, the formation of Western Ghats and the establishment of monsoon system in response to the rise of Himalayas, the repercussions of these geotectonic events on the landforms are not yet properly understood. The study of the existing records in the forms of offshore deposits, denudational surfaces, and the laterites and laterite-like materials, thus, is an effort to reconstruct the palaeoclimatic and palaeotectonic history of at least a part of the Indian Peninsula.

The semi-arid to sub-humid region of the Khanapur Plateau on the eastern flanks of the Western Ghats has shown the presence of laterite-like deposits that referred to as 'laterite' by a number of earlier workers. The so-called 'laterites' exhibit all the characters of typical 'red beds'. It observed that the 'red beds' rest unconformably over basalts that have their own weathering profile.

Keywords:"Red beds', genesis, laterites, palaeoclimatic, palaeotectonic, upland region, Western Ghats, Lateritization.

Introduction

The Western Ghats in the region of Maharashtra show extensive development of 'laterite'. The high- lands and plateaux corresponding to the crest of the Western Ghats and the low-lying coastal plain along the west coast of India show the widespread development of 'laterites' which have been respectively referred to as the high-level and low-level 'laterites' (Pascoe, 1962; Krishnan, 1982). It has been pointed by Patil (1992) that some of the 'laterites' from the region of Maharashtra are nothing but the 'red beds', which have, however, been considered as the ' secondary laterites' by a number of workers (Pascoe, 1962; Sahasrabudhe and Deshmukh, 1981; Umarjikar, 1983; Tandale, 1987; Sahasrabudhe and Rajguru, 1990). The distribution of 'laterites' and 'laterites-like' materials including 'red beds' in the Indian Peninsula, presented in Fig.1.

The problem of 'red beds' formation in different geological and morphotectonic environments, though discussed at length by many geologists world over during the last several decades, has till date, remained to be one of the most controversial and nearly unresolved problems (Elzien, 1992). A review of literature, in this regard, revealed that the 'red beds' recorded in various stratigraphic formations, represent diverse geotectonic and climatic conditions for their formation (Pye, 1983; Bestly and Turner, 1983; Van Hounten, 1961). It is further observed that the ' red beds' can develop under the marine (Ziegler and McKerrow, 1976) and terrestrial (Turner, 1980) environments. In view of this, it is necessary to understand the importance of morphotectonic set up of the Western Ghats in the Deccan Volcanic Province of India, in the formation and preservation of the Khanapur 'red beds' since the Tertiary period. In the present paper, therefore, a brief account of various factors controlling the formation of 'red beds' is given and a model of genesis for the Khanapur 'red beds', on the basis of their field, lithological and geochemical data, is proposed the light of palaeotectonic and palaeoclimatic set up of the Indian Peninsula.

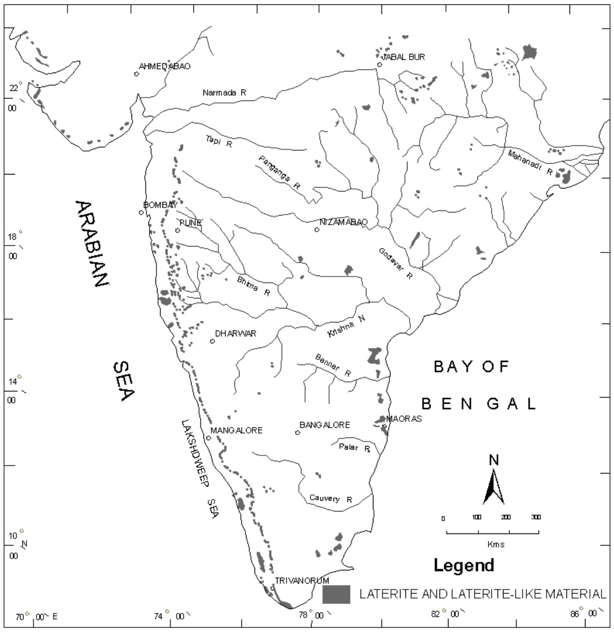

Fig. (1): Distribution of Laterites and Laterites-like Materials in Peninsula India.

Materials and Methods

The Khanapur Plateau

The Khanapur Plateau forms a part of the Western Ghats of India, which extend in an approximately NNW-SSE direction parallel to the coastline for a distance of over 1500km from the Tapi River in the north to Kanyakumari in the south. The Western Ghats are characterized by a conspicuous escarpment running parallel to their crest, the western side of these being marked by low-lying coastal plain and the eastern side by highlands referred to as the Deccan Plateau. A number of east-flowing rivers dissect the Plateau. This upland region itself constituted of a number of plateaux and one of the prominent plateaux is the Khanapur Plateau (**Fig. 2**). The Khanapur Plateau considered a denudational surface and referred to as the Khanapur surface by Kale and Gupte (1986). The Khanapur Plateau, covering an area of about 580sq.km extends in an approximately northwest-southeast direction for a distance of about 42km. It has an average width20km, the maximum width being 25km.

The region of Khanapur Plateau is included is included within the survey of India topographic sheet nos. 47 K/11. 47 K/12, 47 K/13, 47 K/15 and 47 K/16, is bounded by latitudes 17º04'06''N - 17º19'27''N, and longitudes 74º 33'35''E and 74º55'00''E. The plateau covers parts of the Khanapur and Atpati talukas of Sangli District of Maharashtra State. It is located at about 110km to the east of the Great Escarpment of the Western Ghats (**Fig. 2**) can easily approached from Pune by the National highway No. 4, connecting the cities of Pune and Kolhapur. The township of Karad is located at about 165km south of Pune on this highway and the Khanapur Plateau lies at about 60km to the east of Karad. The Khanapur Township is an important locality within the area of Khanapur Plateau

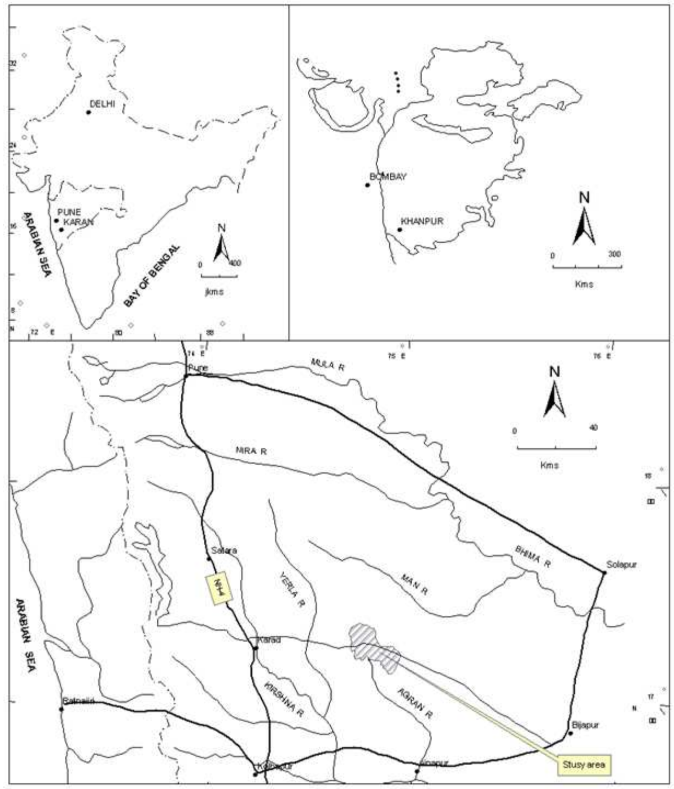

Fig (2): Location map of the Khanapur Plateau

Geology of the Khanapur Plateau

The Deccan Plateau covering parts of Maharashtra, Madhya Pradesh and Karnataka States, is constituted chiefly of basaltic lava flows related to the Deccan Volcanic activity of Cretaceous–Paleocene age (Radhakrishna, 1991). The Khanapur Plateau being a part of the Deccan Volcanic Province, over its greater parts exposes largely horizontally disposed basaltic lava flows. The lava flows in the area under study unconformably overlain by thick sequence of reddish-brown coloured sediments (Photo 1) of Paleocene (?) age. Along the courses of major streams, at the base of hill slopes and escarpments the Alluvio-colluvial sediments of Quaternary age deposited. All the above lithological units show the development of soils in their upper sections. Calcrete is essentially calcareous deposits composed chiefly of calcium carbonate, which is predominated by fine-grained low-magnesian calcite micrite (Klappa, 1983). Extensive development of calcrete observed in the Khanapur Plateau area. It occurs in a variety of forms including powder, nodular, honeycomb, laminar, platy, and tubular and hardpan types (Goudie, 1983; Patil and Surana, 1992; Elzien, 1992).

Photo 1: Isolated 'red beds' hillock unconformable rest on basalt, Menganwadi village.

Intense development of calcrete observed in the 'red beds' areas partially or totally replaced the 'red beds' or ferrallitic soils **(Photo 2 &3).** A 1.5m thick hardpan calcrete has overlain the soil profiles in the 'red beds' areas. The calcrete also occur along the joint and fracture planes in partly weathered or weathered basalt or inter-flow unit underlying the soils. Similarly, concretions of calcrete occur along the stratification or bedding planes in the 'red beds' and alluvio-colluvial deposits. A hardpan calcrete with 1.5m in thickness exposed in a stream-cut near Adsadwadi village contains fresh-water fossils, namely, *Melania Sp. and Melanoides Sp*

Photo 2: Upper section of the 'red beds' showing an intense effect of calcification, Menganwadi village

Photo 3: Upper section of the North Khanapur 'red beds' showing iron nodules embedded in hardpan calcretes.

Thick deposit of waterfall tufa composed chiefly of calcium carbonate observed at Sukh Deo, has shown the presence of a variety of plant impressions including those of Odina woodier Roxb., Diospyros metanoxylon Roxb., Tectona grandis Linn., Leea Sp. Linn., Zizphus jujube Jurs., Bambusa arundinacea Scherb, Bridelia hamiltoniania Wall. Cat. This fossil assemblage indicates that the tufas are 8.000 to 10.000 years BP in age (Pawar, et al 1988).

Methodology

In order to collect geological information, extensive field surveys carried out in the region of Khanapur Plateau. During the course of field investigation, various lithological units identified and their characteristics noted. A geological map of the Khanapur Plateau prepared using the survey of India topographic sheets of scale 1:50,000 as base. Various geomorphological units also identified and their field characters recorded. The 'red beds' areas were surveyed in detail and typical representative 'red beds' sections systematically sampled for further laboratory analysis.

The field surveys revealed the presence of salts in the form of surface encrustations especially around the springs emerging out of 'red beds' areas. In order to assess the chemical characters of 'red beds' and their contribution in imparting salinity to groundwaters, both spring and well-water and salt samples were collected during the pre-monsoon, monsoon and post-monsoon seasons for further laboratory analysis.

The samples from the representative 'red beds' profiles subjected to various types of analysis in laboratory. The colour of the 'red beds' samples compared with Standard Munsell Soil Color Charts and appropriate colour notations assigned to them. Samples subjected to granulometric analysis

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following the technique given by Carver (971).A few thin and polished sections of the representative 'red beds' samples were prepared and studied under a petrological microscope, and the polished sections studied with help of Steroscan S120 Cambrigde Scanning Electron Microscope (SEM).

The samples from the representative 'red beds' profiles crushed and powdered for chemical analysis. The chemical analysis was carried out by following the standard procedure as detailed by Shapiro and Brannock (1962). The major and trace elements concentration in 'red beds' were determined with the help of a Varian AA1275 Atomic Absorption Spectrophotometer and UV-2000 Hitachi Spectrophotometer. A Corning 400 Flame photometer used to determine the concentration of sodium and potassium. The samples from salt encrustations analyzed for major and trace elements.

A representative samples of the clay and other mineral assemblages of the 'red beds' and salts, analyzed by using X-ray Diffractographic (XRD) and Infrared Spectroscopic (IR) techniques.

Physiography of the Area

The Khanapur Plateau, largely, experiences a tropical wet-dry climate with alternate wet and dry spells. The area falls within the rain shadow zone of the Western Ghats and, therefore, receives very low precipitation during the monsoon period especially from June to October, the mean annual rainfall being 638mm. The mean maximum annual temperature of the region is 34.8ºC. The temperature may however, rise to 40.6ºC during the summer months and may fall down to 10ºC during the winter months. The Khanapur Plateau thus, exhibits more or less semi-arid to sub-humid climatic conditions with extremely low precipitation and high evaporation.

The Khanapur Plateau has sparse to scanty vegetation confined mainly to the alluviated valley floors and colluvial slopes. The areas along the plateau margin intensely erode and, therefore, hardly show the presence of any significant vegetation cover except thorny bushes and grasses. The plain areas along the banks of Agran River and its important tributaries are under cultivation.

The Khanapur Plateau with an average elevation of about 870m above MSL has marked by steep escarpment from all sides. The plateau constitutes part of the water-divide between the Krishna and Bhima rivers. The Khanapur Plateau in general exhibits a radial drainage pattern typical of the erosion residual hillocks and highlands (**Fig. 3**); however, an overall also shows dentritic to sub-dentritic drainage pattern. The Agran River (a tributary of the river Krishna) drains a major part of the Khanapur Plateau. The tributaries of Yerla River (an important tributary of Krishna River) drain the western and southwestern peripheral region of the plateau. The tributaries of Man River (a tributary of Bhima River) drain the northeastern peripheral region of the plateau. The Agran River rises near Tamkhadi village and flows in the northeast direction for about 7km. It takes southerly turn near Balavadi village and flows to the south for a distance of about 95km before it joins the Krishna River near Ainapur (**Fig. 3**).

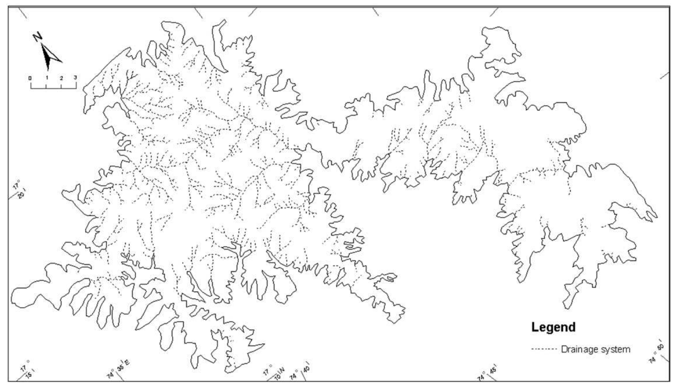

Fig.3: Drainage map of the Khanapur Plateau

The Khanapur Plateau typically presents an extensive flat surface with an average elevation of 870m above MSL. This surface characterized by a flat featureless undulating topography with level to gentle slopes (0º to 5º; Young, 1972). However, a few isolated hillocks e.g. Renavi (869m), Landgewadi (820m), Palshi (840m), Bhawani Khadi Donger (918m), Jarandi (822m) and Kundlapur (888m) dot the surface. These isolated hillocks occur as either mesa or butte. In addition to these, at a number of places, rock knobs recorded. Moderate to moderately steep slopes (5º to 18º) marks these residual hillocks dotting the Khanapur surface. Along the periphery of the plateau especially in the northern side, typical badland topography is observed in the area situated at about 3km to the north of Balavadi village, where the streams have cut more than 37m deep narrow steep sided saw-cut valleys in the 'red beds' (**Photo 4**).

Photo 4: Close up of badland topography in the 'red beds' Balavadi village

Results and Discussion

View on the 'Red beds' Formation

Various workers to explain the formation of 'red beds' have put a number of hypotheses forth. These hypotheses take into consideration the formation of 'red beds' both in marine and terrestrial environments. Although majority of the 'red beds' have developed under the continental conditions (Pye, 1983), a few of them are of marine origin and composed of either reddish-brown clay oozes in deep ocean basins (Jacobs, 1978) or reddish-brown clays in continental shelf areas (Judd et al, 1970; Swift and Boehmer, 1972). It is further evident that the red soils and/or red sediments most commonly occur both in the humid and arid environments of tropics; they are less common in temperate areas of the globe and are virtually absent in polar regions. The 'red beds' have been recorded in the parts of tropical Africa (Young, 1974), Australia (Northcote, 1971), Southeast Asia (Mohr et al, 1972), South America (FAO-UNESCO, 1971), the Mediterranean (Macleod and Vita-Finzi, 1982), and the Central America and southwest United States (Van Houten, 1972). The 'red beds' recorded in the regions of India (Rao and Srihari, 1980; Elzien, 1992; Patil, 1992), Arabia (Glennie, 1970), Sri Lanka (Dahanayake, 1978), and New Zealand (Challis, 1975).

It is evident that the in situ 'red beds' including red soils that developed in any sedimentary facies under suitable environmental conditions, are widespread in the areas of igneous and metamorphic rocks (Schafer and McGarity, 1980) as well as on many non-red sedimentary formations. The areas that promoted free drainage and oxidizing conditions characterized by pedogenetic and eogenetic 'red beds' including red ferrallitic soils (Elzien, 1992; Patil, et al, 1990a, 1991). The diagenetic processes involving mesogenesis and telogenesis, developed the 'red beds'. A number of geomorphological agencies including streams, glaciers, wind, etc., responsible for the deposition of the detrital 'red beds' (Pye, 1983) under oxidizing conditions and an inactive tectonic environment that generally favour the accumulation and reddening of the sediments as well as the preservation of the red pigment of sediments with the passage of time.

Source of Ferric Oxide in 'Red Beds' Sediments

It has been an accepted fact that the ferric compounds-chiefly hematite, impart red colour to the sediments deposited both in marine and terrestrial environments. The ferric compound in the 'red beds' sediments considered to derive from several sources (Pye, 1983). According to Krynine (1949; 1950) and Jones (1965) hematite giving red colour to the sediments, derived chiefly from the pre-existing 'red beds' and/or red soils. Van Houten (1961) is of the view that under tropical conditions, soils rich in ferric oxide formed in uplands due to intense weathering. The soils provide the source of hematite, which following dissection, transported and deposited in the low-lying areas. It is possible that the red pigment-hematite, derived from the post-depositional oxidation of ferrous oxide in groundwaters from the sediments (Schluger and Roberson, 1975). According to Czyscinski et al, (1978), ferric oxide imparting red colour to the sediments, mainly derived from such minerals as pyrite siderite, which may deposited along with other sediment- Walker (1979) is of the opinion that after the deposition of sediments, red dust containing ferric oxide added to the soils or sediments, thereby imparting red colour to them. The ferric oxide derived from iron bearing detrital minerals/lithic fragments of sediments on weathering or on pedogenesis and diagenesis under oxidizing environmental conditions.

From the chemical data **(Table 1a,b,c,&d)** of the Khanapur 'red beds' observed, that is dominating by ferric oxide (Fe_2O_3) indicating highly oxidizing conditions. The plots of Fe_2O_3 against FeO (**Fig. 4**) for the Khanapur 'red beds' have shown that the Fe_2O_3: FeO ratios are >5:1. This indicates that the 'red beds' are extremely rich in ferric oxide content on one hand and its preservation in 'red beds' under highly oxidizing conditions. Relatively higher FeO content of the non-red sediments **(Photo 5)**, especially from the lower horizons of the Menganwadi and Balavadi 'red beds' indicates that the ferric oxide has not entirely derived from the reduction of ferric oxide from the pyroxenes in the lithic fragments of basalt in the sediments. It is, therefore, possible that ferric oxide in the Khanapur 'red beds' derived dominantly from the sedimentary detrital source i.e. hematite from the pre-existing 'red beds' red soils and laterites, and not by the authigenic

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precipitation of Fe_2O_3. The mineralogical and micromorphological studies of the Khanapur 'red beds' further indicated detrital or allochthonous nature of hematite, thereby supporting this view (Elzien, 1992).

Table 1a: Chemical data (Weight percentage) for the Adsadwadi 'red beds' Khanapur plateau

OXIDES	Top →									Bottom
	A_{1-2}	A_{2-2}	A_{3-2}	A_{4-2}	A_{5-2}	A_{6-2}	A_{7-2}	A_{8-2}	A_{10-2}	A_{11-2}	A_{12-2}
SiO_2	37.18	32.80	17.99	21.71	11.38	18.28	23.92	44.75	27.80	25.33	35.14
Al_2O_3	11.41	21.09	21.15	19.34	18.55	17.51	23.14	13.27	10.95	20.41	13.22
Fe_2O_3	30.06	21.12	34.79	34.40	38.74	33.61	29.08	11.32	36.69	25.77	22.42
TiO_2	3.19	3.58	4.37	4.84	5.90	4.48	4.82	4.34	3.38	4.07	3.49
FeO	0.76	0.84	0.71	0.56	0.77	0.34	0.39	0.49	0.53	0.42	0.68
MgO	0.33	0.42	0.47	0.99	0.57	0.44	0.66	1.31	0.51	0.99	0.33
CaO	0.19	0.31	0.21	0.47	0.59	0.38	0.48	1.39	0.49	1.53	0.58
Na_2O	1.82	0.74	0.82	1.53	1.04	0.74	0.84	6.64	4.82	6.30	7.60
K_2O	0.03	0.04	0.04	0.08	0.05	0.04	0.04	0.11	0.08	0.04	ND
P_2O_5	0.008	0.006	0.006	0.079	0.019	0.005	0.008	0.150	0.143	0.181	0.172
MnO	0.08	0.10	0.19	0.17	0.21	0.22	0.24	0.13	0.25	0.13	0.08
H_2O^+	14.94	18.92	20.64	15.82	22.17	23.97	16.38	16.11	14.37	14.84	16.29
Total	99.998	99.966	101.386	100.00	99.989	100.015	99.998	100.01	100.013	100.011	100.006

Table 1b: Chemical data (Weight percentage) for the Renavi 'red beds'. Khanapur plateau

OXIDES	Tope Bottom		
	R1	R2	R3
SiO_2	28.67	2.50	16.32
Al_2O_3	6.07	8.97	13.78
Fe_2O_3	52.46	62.48	37.66
TiO_2	1.74	2.65	3.82
FeO	0.51	0.69	1.54
MgO	0.29	0.44	0.52
CaO	1.28	1.93	2.61
Na_2O	1.60	3.42	2.88
K_2O	0.002	0.003	0.004
P_2O_5	0.008	0.009	0.008
MnO	0.15	0.67	0.30
H_2O^+	7.22	16.25	20.54
Total	100.00	100.012	99.982

Table 1c: Chemical data (weight percentage) for Menganwadi 'Red Beds'

OXIDES	Top --Bottom							
	M_1	M_2	M_2c	M_3	M_4	M_4L	M_5	WB
SiO_2	5.02	28.26	5.39	6.798	16.64	21.36	8.27	23.90
Al_2o_3	11.00	11.66	10.08	10.05	17.11	19.44	17.59	13.30
Fe_2O_3	43.00	11.40	0.79	21.96	23.74	25.77	52.22	19.22
TiO_2	0.54	1.36	1.72	0.45	3.12	0.72	3.54	1.03
FeO	1.25	0.38	0.66	0.75	2.44	0.74	1.28	0.47
MgO	2.10	1.5	1.47	1.24	1.41	0.47	1.13	3.80
CaO	7.92	25.39	47.61	45.57	3.80	5.31	1.68	6.40
Na_2O	11.08	5.01	9.42	2.19	13.16	12.50	1.49	9.18
K_2O	0.04	0.01	0.017	0.006	0.018	0.020	0.007	0.011
P_2O_5	0.006	0.088	0.004	0.003	0.018	0.004	0.010	0.001
MnO	0.57	0.05	0.04	0.06	1.32	0.11	0.58	0.45
H_2O^+	17.47	15.41	22.80	10.93	17.23	13.41	12.20	22.20
Total	99.996	100.068	100.001	100.009	100.006	99.854	99.999	99.962

Table 1d: Chemical Data (Weight Percentage) for Menganwadi (N) ‘ red Beds’, Khanapur Plateau.

OXIDES	Top → Bottom						
	M_{1-2}	$M_{1-2}2$	M_{2-2}	$M_{2-2}l$	M_{3-2}	M_{4-2}	M_{5-2}
SIO_2	23.92	31.72	23.86	29.58	49.35	23.04	31.67
Al_2O_3	18.61	15.47	10.83	13.08	7.74	7.98	15.10
Fe_2O_3	35.78	18.41	50.28	38.75	22.53	49.32	16.13
TiO_2	1.57	0.94	2.43	1.65	4.49	1.21	1.69
FeO	1.43	1.42	0.74	1.5	1.32	0.27	5.68
MgO	0.86	1.38	0.46	1.07	1.05	1.52	7.79
CaO	1.60	8.99	0.98	2.50	1.23	0.81	7.61
Na_2O	2.24	1.10	1.08	3.32	3.35	1.74	2.52
K_2O	0.020	0.001	0.004	0.010	0.010	0.001	0.025
P_2O_5	0.087	0.02	0.065	0.008	0.005	0.003	0.016
MnO	1.41	.09	0.44	0.06	0.10	0.61	0.24
H_2O^+	12.46	20.45	8.82	8.90	8.82	13.53	12.61
Total	100.007	99.991	99.99	99.977	99.995	100.034	101.081

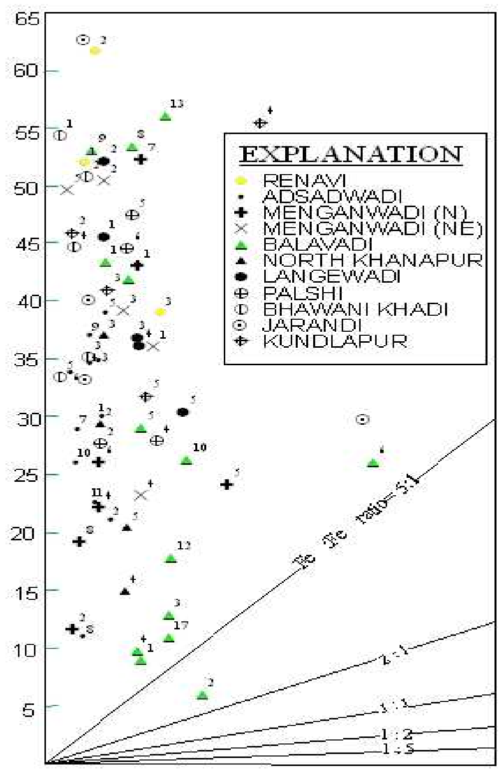

Fig. (4): Relationship between Fe_2O_3 & FeO Content of the Khanapur red beds (after Tomlinson, 1916).

The triangular plots of Al (Al_2O_3): C (CaO+BaO): Alk (Na_2O+K_2O) (**Fig. 5**) [Rosenbusch-Osnan, (1923), in Goldich (1938)] for the Khanapur 'red beds' indicated sedimentary characteristics, which is in complete agreement with observed field and mineralogical evidences for the sedimentary nature of the Khanapur 'red beds'. Further supported by the triangular plots of SiO_2: Al_2O_3: Fe_2O_3 (**Fig. 6**)

(Schellmann, 1981) for the Khanapur 'red beds' which do not exhibit any lateritization trend. However, it is likely that authigenic hematite formation might have taken place in localized areas, within the sedimentary environment, on account of diagenesis or it may have formed during pedogenesis in the upper horizons of the 'red beds'.

The Khanapur 'red beds' sediments consisting of hematite and other iron minerals derived from the red soils and laterites from the highlands along the crest of the Western Ghats and got mixed up with the basaltic debris during the transport and were deposited subsequently as the alluvial fans-like forms at the base of hill slopes and escarpments.

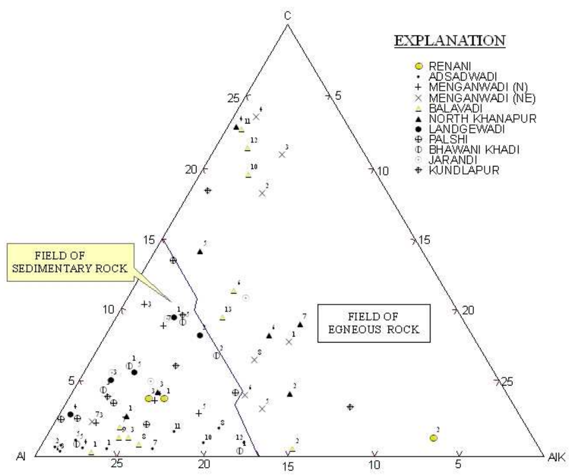

Fig. (5): Triangular Plot of Al (Al_2O_3): C (CaO+ BaO) Alk. (Na_2O+ K_2O) for the Khanapur red beds (after Rosenbusch-osann; 1923)

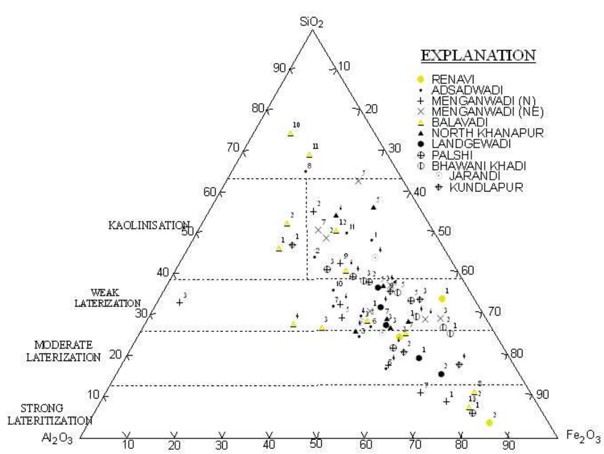

Fig (6): Triangular Plots of SiO_2: Al_2O_3: Fe_2O_3 for the Khanapur red beds (after Schellmann, 1981)

Preservation of Iron Oxide Pigment

The essential condition for preservation of transported iron oxide pigment in the sediments is the existence of oxidizing environment in the depositional basin (Van Hounten, 1961).Under oxidizing conditions; ferric oxide is stable at all but low (acid) pH values (Hem and Cropper, 1959; Garrels and Christ, 1965). Alkaline conditions also favour the preservation of ferric compounds where conditions are less strongly oxidizing (Pye, 1983).

The deep red to reddish-brown coloured Khanapur 'red beds', dominated chiefly by hematite, indicate highly oxidizing environment for their deposition and subsequent preservation of ferric oxide pigment. The existence of oxidizing conditions in the depositional basin is largely related to two controlling factors, 1/ tectonically stable set up 2/ prevalence of dry and wet climate (Van Houten, 1961). It is evident from the morphotectonic data that the region of the Western Ghats experienced cymatogenic (King, 1959) types of movements during the late Tertiary and Quaternary times (Powar and Patil, 1980; 1982; Elzien, 1992), remained, more or less, tectonically inactive and stable during the early Tertiary period. The warm and humid environment that produced red soils and laterites in the upland region of the Western Ghats during early Tertiary times, subsequently constituted an important source of iron in the 'red beds'. The changes of climatic conditions from warm, humid to cooler and drier during the Oligocene (Frakes and Kemp, 1973) could have favoured the preservation of ferric oxide in the sediments that deposited in the tectonically stable areas along the eastern flanks of the Western Ghats. The less abundant vegetation, lower water table and prolonged drier spells in the place of deposition during the Oligocene period, appear to have been the other important factors that influenced the preservation of red pigment in the sediments. The association of evaporite with the Khanapur 'red beds' suggests prolonged drier periods for salt precipitation in the 'red beds'. Alkaline conditions, generally, favour the preservation of ferric oxide pigment in the sediments (Pye, 1983).The grayish-green coloured thin lenses and layers within the deep red to reddish-brown silt and clay rich basal sections of the Khanapur 'red beds', are suggestive of reducing conditions (**Photo 5**) in some localized areas within the basin of sedimentation (Elzien, 1992). The reducing environment in the swampy or poorly drained areas not only restricts the oxidation of iron below water table, but also allows the organic matter to escape from total decay (Van Houten, 1961).

Photo 5: Bright red colored 'red beds' showing grayish-green colored at their base, Menganwadi Village.

Palaeoclimatic Implications

The red colour of the sediments or 'red beds' considered one of the indicators of wetter or drier climatic conditions (Kubiena, 1963). Pye (1983) has pointed out that the red colour of sediments or 'red beds' can be, in very general sense, correlated with wet or dry climate because 'red beds' can develop under different climatic conditions provided mineralogy and interstial environments are favourable. The red soils develop under warmer and wetter interglacial conditions (Birkeland, 1984) or under warm and humid tropical climate (Patil et al, 1990a). The red colour alone cannot regard as an equivocal evidence of climatic changes. There are several evidences, which indicate the changes in tropical deserts during the wetter phases of the Quaternary. When the dune sediments established and experienced pedogenesis (Talbot, 1980).

If one takes into account the effect of climate on reddening of the sediments and formation of 'red beds', it becomes imperative to consider palaeoclimatic changes on the global scale while dealing with the genesis of the 'red beds'. It is generally, accepted that ancient laterites must have been formed in same way as the recent and sub recent ones under similar environmental conditions. From the global distribution of laterites and bauxites (**Fig 7**), occur in different morphogenetic regions showing wide ranges of present-day climatic conditions (Elzien, 1992). The laterites of diverse geological age (ranging from Precambrian to Pleistocene) (Bardossy, 1981), occurring in different present-day morphogenetic regions of the earth (**Fig.7**), suggest that they have been inherited from the past environments.

Bardossy (1981) has pointed out that the rate of bauxite formation, in general, increase (not gradually), since the end of Precambrian. The increase exhibited a typical cyclic nature, with steadily increasing peak intensities for both laterite and karst bauxite formation. The drift of continents could have been one of the reasons for changes in climatic regimes and in turn, in the formation of laterites and bauxites. From the distribution of various continents during the mid-Eocene period, it is evident that the Indian subcontinent was near the equator. It is, therefore, likely that the Peninsular Shield experienced a tropical wet-dry climate, favouring the formation of laterites and bauxites.

Generally, accept that the rise of the Himalayas, during the late Tertiary (Powell and Conaghan, 1973), is responsible for setting up of the monsoonal climate system in the Indian subcontinent (Frakes and Kemp, 1973). From the global weather patterns for the Eocene period (Frakes and Kemp, 1972; 1973), the Indian Peninsular Shield, situated between 0° (Equator) and 20°S latitude, experienced wet-dry climate favoured the formation of laterite (Kumar, 1986). The mid-Oligocene weather patterns (Frakes and Kemp, 1972; 1973) have revealed that the Peninsular India, during this period, witnessed a tropical wet-dry climate that had favored maximum development of lateritic bauxite. According to Frakes and Kemp (1972; 1973), the Oligocene climate was cooler and drier that the Eocene one, mainly due to changes to ocean current directions. It is, therefore, likely that the laterites had formed during Eocene eventually changed into bauxites. The laterites and other red soils formed during the early-Tertiary (Paleocene) in the highland regions along the crest of the Western Ghats provided the sediments for the formation of the Khanapur 'red beds' (Elzien, 1992).

Palaeotectonic Implications

It seen from the global distribution of laterites and karst bauxites occurs in both the orogenic belts and continental platforms (**Fig. 7**). Bardossy (1981) has pointed out that about 96% of lateritic-bauxites occur on the continental platforms, while 92% of karst bauxites formed in oceanic basin areas. Amongst continental platforms, ancient shields and platforms each show about 45% of lateritic-bauxites (**Fig. 7**). It, therefore, be concluded that the laterite formation had taken place in relatively tectonically stable or episodically active ancient shield and platform areas of the earth.

The Deccan Volcanic Province of India characterized by the presence of major lineaments oriented approximately in NW-SE, NE-SW and N-S directions (Powar and Patil, 1980). The NW-SE and NE-SW trending lineaments representing shear fractures, considered developed due to N-S compression caused by northward drift of the Indian subcontinent during Miocene period. The northward drift of the Indian sub plate continued until it collided and locked up with the Eurasian plate sometimes in

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the early to middle Miocene (Powell and Conaghan, 1973). The collision of Indian sub plate with the Eurasian plate resulted into isostatic readjustment leading to vertical cymatogenic movements (Powar and Patil, 1980). Due to release of compression because of interlocking of the plates, the Indian sub plate experienced extension effects that developed N-S trending fractures/lineaments. The cymatogenic movements (King, 1959) involve regional uplift or subsidence of landmass for thousands of meters without much deformation. The, more or less, tectonically inactive Indian Peninsula became tectonically active during the late Tertiary (Neogene) and Quaternary periods. It postulated that the formation of the Great Escarpment of the Western Ghats and eastward tilting of the Indian Peninsula occurred sometimes in mid-Miocene (Radhakrishna, 1965, Krishnan, 1982).

The tectonic behavior of the source area as well as of the depositional basin is the primary controlling factor, next to climate, in the formation and preservation of 'red beds'. The formation of red soils and/or laterites under warm and humid climatic conditions in the highlands of the Western Ghats of India, provides a clue to the fact that the region remained, more or less tectonically stable during the early-Tertiary (Palaeogene) period. During the late-Tertiary (Neogene) and Quaternary periods, the western part of the Deccan Volcanic Province witnessed gradual but episodic vertical cymatogenic uplift and regional arching on N-S axis(axis of cymatogeny) with insignificant deformation of landmass (Powar and Patil, 1980; 1982). It is, therefore, likely the tectonic environment of the Deccan Volcanic Province was conductive for the formation and preservation of the 'red beds' on the Khanapur Plateau (Elzien, 1992).

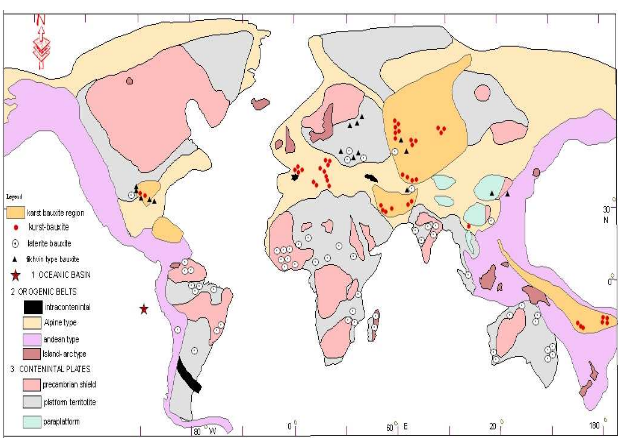

Fig. (7): Global Distribution of Laterites and Bauxites (modified after Bardossy 1981).

Palaeaogeomorphological Implications

The upland areas on either sides of the highlands of the Western Ghats corresponding to the cymatogenic axis (arch), witnessed episodic fluvial sedimentation during Tertiary period. The episodes of clastic fluvial sedimentation may alternate with the periods of non-depositional and soil formation and the soils formed earlier may be buried and preserved without fluvial modifications or sometimes they partially reworked by trenching and gulling (Gile and Hawley, 1966). The factors like tectonic uplift, climatic change, intrinsic geomorphological instability or complex response to extrinsic changes (Schumm, 1973; Schumm and Parker, 1973) influence the episodic fluvial deposition and soil formation on fluvial fans. The episodic fluvial sedimentation in the upland areas (plateaux) on the eastern flanks of the Western Ghats, thus, resulted in the development of thick sequence of 'red beds' (Elzien, 1992).

The rapid dissection of landmass during the Quaternary attributed to changes in climate from drier to wetter. The drainage lines became more prominent along the structurally weak zones, which is evidenced by the structurally controlled courses of major rivers in this region (Powar and Patil, 1980; Patil and Bhosale, 1985).The 'red beds' along with basalt flows dissected with the reorganization of the present-day drainage network and eventually separated into isolated outcrops capping the basalt.

The Khanapur 'red beds' sediments exhibit insignificant effects of post-depositional lithification and diagenesis, the sediments especially in their upper sections, are indurated with calcium carbonate, silica or ferric oxide under pedogenic environment during the Quaternary period. The poorly lithified and weakly cemented silt-clay rich 'red beds' show the development of badland topography characterized by steep sided gullies. Similar badland topographies developed on thick red sandy-silts derived by erosion from upland terra rossa soils during the last glacial period observed at many places in glacially affected areas (Harris and Vita-Finzi, 1968; Macleod and Vita-Finzi, 1982; Talbot and Willams, 1978).

'Red Beds' –Evaporite Facies Association

The association of evaporite minerals with the 'red beds' does not appear to be an uncommon phenomenon. Since the 'red beds' reported from different stratigraphic sequences representing diverse depositional environments, marine (Ziegler and McKerrow, 1975), glacial and lacustrine (Dunham, 1953), show the presence of evaporite minerals. The processes responsible for the formation and preservation of evaporite minerals in the 'red beds' not yet well understood. The high solubility of evaporite other than the calcium carbonate and sulphate minerals precludes their long-term preservation at the surface in all but very arid environments (Watson, 1983). It is likely that the preservation of both the 'red beds' and the evaporite on the Khanapur Plateau imply that the climatic and drainage conditions have remained conducive and favourable since their deposition (**Photo 3**) (Elzien, 1992).

Model of Landscape Evolution

Various workers proposed models in an attempt to explain the origin of 'red beds'. The model of 'red beds' formation as suggested by Walker (1967a) takes into account intrastratal alteration. The post-depositional ageing of brown detrital ferric oxide, oxidation of ferrous oxide and/or pedogenesis under oxidizing conditions considered to be the key factors in the genetic model of 'red beds' formation proposed initially by Van Houten (1961, 1964) and later adopted by many geologists.

The model of landscape evolution with special reference to the development of the Khanapur 'red beds', suggested in the present paper, takes into consideration the importance of both the palaeotectonic and palaeoclimatic conditions in the Peninsular India, in the formation and preservation of the 'red beds'(Elzien, 1992). A brief description of the events in the developmental history of the Khanapur 'red beds' given in the following paragraphs:

Pre-Miocene Events

During the late-Cretaceous and Paleocene period, the Indian Peninsula witnessed a spectacular fissure type of volcanic activity leading to the formation of a thick pile of basaltic lava flows constituting the Deccan Volcanic Province of India in the west-central parts.

The region of Indian Peninsula experienced a tropical wet-dry climate that resulted into the development of laterites and red soils in the highlands of the Western Ghats (**Fig. 8A**).

Mid-Miocene Events

During the Mid-Miocene, the Peninsular Shield witnessed rifting and normal faulting along its western margin that led to the development of the Great Escarpment of the Western Ghats. The laterites and red soils from the highlands, with a change in climate, eroded, transported and deposited in fan-like forms on either sides of the crest of the Western Ghats. A series of alluvial fan-like deposits made up of laterite and basalt debris, and red soils, later developed into 'red beds' (**Fig. 8B**).

Early Pleistocene Events

With the reorganization of the drainage network along structurally weak zones, the Western Ghats landscape subjected to rapid erosion. The fluvial erosion dissected the 'red beds' and separated them into isolated patches capping the basalt flows on the eastern flanks of the Western Ghats (**Fig. 8C**).

Holocene Events

The fluvial erosion progressed rapidly leading to deep dissection of landscape because of changes in climatic conditions. This has left isolated patches of laterites in the highlands along the crest of the Western Ghats and of the 'red beds' sediments in the upland areas (plateaux) on the eastern flanks of the Western Ghats as erosional remnants (**Fig 8D**).

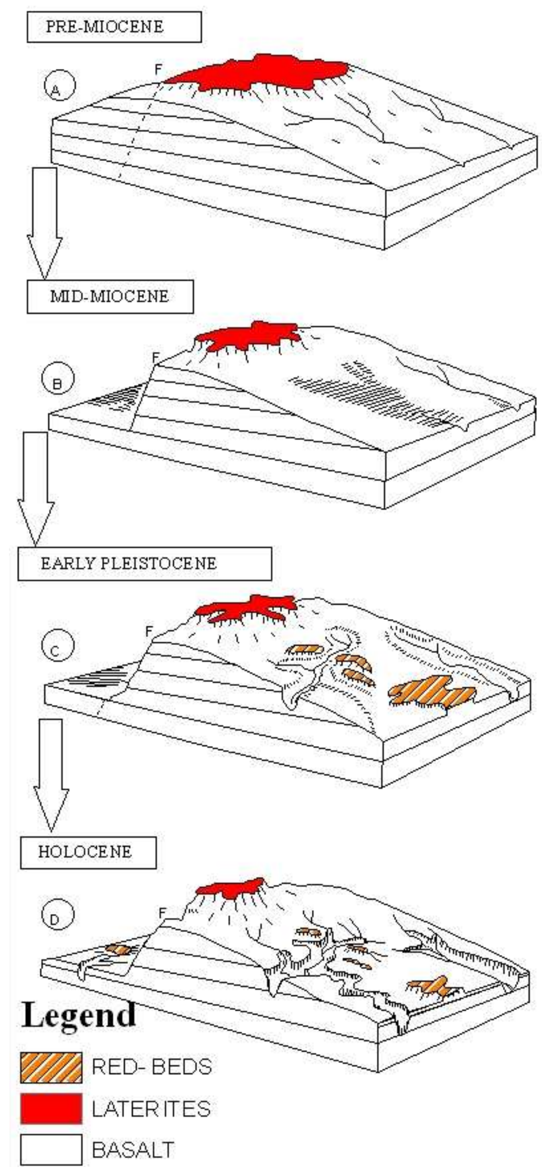

Fig. (8): Mode of Landscape Evolution

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Conclusion

It is thus evident from the field, mineralogical and chemical data for the 'red beds' on the Khanapur Plateau that the 'red beds' are of sedimentary origin and their formation and preservation appears to have controlled by the tectonic and climatic conditions prevailed during the Tertiary times. The sediments, derived from the pre-existing 'red beds', red soils, laterites and basalts from the highlands along the crest of the Western Ghats, were transported down the valleys and deposited subsequently on the eastern flanks of the Western Ghats to form the 'red beds'.

The preceding discussion has clearly brought the different stages in the evolution of the landforms in this part of the Deccan Volcanic Province. The model envisages the formation of laterites under suitable tectonic and climatic conditions during the Tertiary period. This phase of extensive and intensive leaching and the formation of laterites and red soils and later bauxite, followed by major shift in drier climate response to change in the geomorphic processes. Under such changed conditions, a gradational process became dominant and the red soils and the lateritic duricrusts stripped and transported along with basalt debris down the valley and deposited on the eastern flanks of the Western Ghats. During the Quaternary period, the wet climate again disrupted the grade conditions resulting into intense dissection and reorganization of the drainage. Deep valleys were carved and the indurated patches of the 'red beds' left on the high ground giving rise to the present landscape, where the 'red beds' occur on the plateaux tops, as erosional remnants.

In the proposed model, there are several missing links and the process not understood clearly. It is likely that the conditions, under which the 'red beds' formed and preserved, might have been very different from the ones inferred in the present paper. Nevertheless, the present data clearly point out the sequence of 'red beds' (**Table 2**). Therefore, the present hypothesis needs detailed studies in other part of the Deccan Plateau to support or disapprove. Absolute dates will further facilitate in the regional correlation and in the proper understanding of the Cenozoic geomorphic history of this erosional landscape of Deccan Plateau.

References

[1] **Bardossy, Gy., (1981)** Palaeoenvironments of laterites and lateritic bauxites-effect of global tectonism on bauxite formation. Lateralization Processes, Oxford and IBH Publishing Co., New Delhi, pp. 287-294.

[2] **Besly, B. M. and Turner, P. C., (1983)** Origin of red beds in a moist tropical climate (Etruria Formation, Upper Carboniferous, U. K.) In Wilson, R. C. L. (ed.): Residual Deposits: Surface Related Weathering Processes and Materials. Geological Society of London, Published by Blackwell Scientific Publications, Oxford, pp. 131-151.

[3] **Birkeland, P.W., (1984)** Soils and Geomorphology. Oxford Univ. Press, New York, 372p.

[4] **Carver, R. E., (1971)** Procedures in Sedimentary Petrology. A Division of John Wiley and Sons, New York, 653p.

[5] **Challis, G. A., (1975)** Pyrite-hematite alteration as a source of colour in red beds and regolith, Nature, 255: 471-472.

[6] **Czyscinski, K.S.; Byrens, J. B and Pedlow, G.W., (1978)** In situ red beds development by the oxidation of authigenic pyrite in a coastal depositional environment, Palaeogeog. Palaeoclimatol. Palaeoecol. 24: 239-246.

[7] **Dahanayake, K., (1978)** Red earth occurrences on Miocene limestone resources of Sri Lanka, In Nutalaya, P. (ed.): Geology and Mineral Resources of Southwest Asia., Asian Institute of Technology, Bangkok, pp.43-46.

[8] **Dunham, K. C., (1953)** Red colouration in desert formation of Permain and Triassic age in Britain 19th Int. Geol. Cong., Algeria (1952), CR Sect VII, F VII, pp. 25-32.

[9] **Elzien, M. E., (1992)** Genesis of 'Red Beds" from the Khanapur Plateau Maharashtra, India, Unpublished Ph.D. thesis, University of Poona, Pune 411007, 135p.

[10] **Eugster, H. P. and Jones, B. F., (1979)** Behavior of major solutes during closed basin brine evolution, Am. J. Sci., 279: 609-631.

[11] **FAO-UNESCO, (1971)** Soil Map of the World, 1:5.000.000. Vol. IV, South America (Map and Memoir). Paris.

[12] **Frakes, L. A. and Kemp E. M., (1972)** Influence of continental positions on early Tertiary climates. Nature, Vol. 240, No. 5376, pp. 97-100.

[13] **Frakes, L. A. and Kemp E. M., (1973)** Paleogene continental positions and evolution of climates. In Traling, D.H., and Runcorn, S.K (eds.): Implication of Continental Drift to the Earth Sciences. V. I, Academic Press, London, pp. 535-558.

[14] **Garrels, R. M. and Christ, C.L., (1965)** Solutions, Minerals and Equilibria. Harper and Row, New York, 450p.

[15] **Gile, L.H. and Hawley, J.W., (1966)** Periodic sedimentation and soil formation on an alluvial-fan piedmont in Southern New Mexico, Proc. Soil Sci. Soc. Am., 30: 261-268.

[16] **Glennie, K.W., (1970)** Desert Sedimentary Environments, Development in Sedimentology, No. 14, pp. 173-208.

[17] **Goldich, S.S., (1938)** A study of rock weathering, Jour. Geology, 46: 17-57.

[18] **Goudie, A. S., (1983)** Calcrete, In Goudie, A. S. and Pye, K., (eds.): Chemical Sediments and Geomorphology, Academic Press, London, pp. 92-131.

[19] **Harris, D. R. and Vita-finzi, C., (1968)** Kokkkinopolos; A Greek badlands, Jour. Geog. 134: 537-545.

[20] **Hem, J.D. and Cropper, W.H., (1959)** Survey of ferrous-ferric chemical equilibria and redox potentials, U.S. Geological Survey Water Supply Paper No. 1439A, 30p.

[21] **Jacobs, M.B., (1978)** Red clay, In Fairbridge, R.W. and Bourgeois, J. (eds.); Encyclopedia of Sedimentology. Dowen, Hutchinson and Ross, stroudsberg, Pennsyvania, 612p.

[22] **Jones, G.P., (1965)** Red beds in northeastern Nigeria, Sedimentology, 5: 235-247.

[23] **Judd, J.B. Smith, W.C. and Pilkey O.H., (1970)** The environmental significance of iron-stained quartz grains on the southeastern United States Shelf, Mar. Geol., 8: 355-362.

[24] **Kale V. S. and Gupte, S. C., (1986)** Some observation on the denudational surfaces of the upper Godaveri and Krishna basins (Maharashtra). Trans. Inst. Indian Geographers, 8(1): 51-58.

[25] **King, L.C., (1959)** Denudational and tectonic relief in southeastern Australia, Trans. Geol. Soc. S. Africa, 62: 113-138.

[26] **Klappa, C. F., (1983)** A process-response model for the formation of pedogenic calcretes. In Wilson, R. C. L., (ed.): Residual Deposits : Surface Related Weathering Processes and Materials, Geological Society of London, Published by Blackwell Scientific Publications, Oxford, pp. 211-220.

[27] **Krishnan, M. S., (1982)** Geology of India and Burma. CBS Publishers and Distributors, New Delhi, 536p.

[28] **Krynine, P. D., (1949)** The origin of 'Red Beds'. Trans., New York Academy of Sciences. Series II, 2(3): 60-68.

[29] **Krynine, P. D., (1950)** Petrology, Stratigraphy and origin of the Triassic sedimentary rocks of Connecticut, Bull. Connecticut State Geol. Nat. Hist. Surv., 73: 247.

[30] **Kubiena, W.L., (1963)** Palaeosols as indicators of palaeoclimates, Arid zone Res., UNESCO, Paris, 20: 207-209.

[31] **Kumar, A., (1986)** Palaeolatitudes and the age of Indian laterites, Palaeogeograpr. Palaeoclimatol. Palaeoecol., 53: 231-237.

[32] **Macleod, D.A. and Vita-finzi, C., (1982)** Environment and provience in Epirus, NW Greece Earth Surf. Process. Landf., 7: 29-44.

[33] **Matthess, G. and Harvey, H.W., (1982)** The Properties of Groundwater. John Wiley and Sons, New York, 397p.

[34] **Mohr, E.C.J., Van Baren, F.A. and Van Schuylenborgh, J., (1972)** Tropical Soils: A Comprehensive Study of their Genesis, Moutan-Lachitar Baru-Van-Hoeve, The Hague, Paris 481p.

[35] **Northcote, K.H., (1971)** A Factual Key for the Recognition of the Australian Soils, Rellim Tech. Pubs., Adelaide (3rd eds.).

[36] **Pascoe, E. H., (1962)** A Manual of the geology of India and Burma. Vol. III. Govt. of India Publication, 2129p.

[37] **Patil, D. N., (1991)** Basalt weathering and related chemical sediments and residuals from the Deccan Province, Maharashtra, India. Tropical Geomorphology Newsletter, No. 11: pp.1-3.

[38] **Patil, D. N., (1992)** Laterites from the semi-arid regions of Deccan Volcanic Province, India: A reappraisal. Tropical Geomorphology Newsletter, No. 13, pp. 8-10.

[39] **Patil, D. N. and Bhosale, V.N., (1985)** Geomorphic evolution of the Kas river basin, Ahmednagar district, Maharashtra, Proc. 5th Indian Geol. Congr., Bombay, pp. 357-365.

[40] **Patil, D. N. and Surana, A. P., (1992)** Origin of calcrete deposits of Saswad – Nira area, Western Maharashtra, India, Jour. Geol. Soc. India, 39(2): 105 – 117.

[41] **Patil, D. N. and Bhosale, V.N. and Kulkarni, A.V., (1990a)** Clay mineralogy

of the soils of Indrayani river basin, western Maharashtra, India, Jour. Geol. Soc. India, 35 (4): 421-432.

[42] **Pawar, N. J., Kale, V. S., Atkinson, T. C. and Rowe, P. J., (1988)** Early Holocene waterfall tuff from semi-arid Maharashtra plateau (India), Jour. Geol. Soc. India, 32: 513-515.

[43] **Powar, K.B. and Patil, D.N., (1980)** Structural evolution of the Deccan Volcanic Province: A study based on LANDSAT-1 imageries, Proc. 3rd Ind. Geol. Cong., Pune, pp. 235-253.

[44] **Powar, K.B. and Patil, D.N., (1982)** The tectonic framework and structural evolution of parts of Deccan Trap Province of Western Maharashtra, India: A study based on remote sensing techniques. In Singhal, B.B.S. (eds.) Engineering Geosciences, Sarita Prakashan, Merrut, pp. 3-33.

[45] **Powell, C. McA. and Conaghan, P.J., (1973)** Plate tectonics and the Himalayas, Earth and Planet Sci. Letters, 20: 1-12.

[46] **Pye, K., (1983)** Red beds, In Goundie A. S. and Pye, K. (eds.): Chemical Sediments and Geomorphology. Academic Press, London, pp.227-265.

[47] **Radhakrishna, B.P., (1965)** The Western Ghats of the Indian Peninsula, Proceedings of the Seminar on Geomorphic studies in India, Centre of Advanced study in Geology, Sagar, pp. 5-14.

[48] **Radhkrishna, B. P., (1991)**. An excursion into the past- ' the Deccan Volcanic episode', Current Science, 61, (9&10): 641-647.

[49] **Rao, N.V. and Srihari, Y. (1980)** Clay mineralogy of the late Pleistocene red sediments on the Vishakapatanam, region, east coast of India, Sed. Geol., 27: 213-228.

[50] **Rosenbusch-Osnan, (1923)** Instuttgrat (ed.): Elemente der Gesteinslehre (4th ed.), pp. 100-104.

[51] **Sahasrabudhe, Y. S. and Deshmukh, S. S., (1981)** The laterites of the Maharashtra State. Lateritization Processes, Oxford and IBH, Publishers, Co., New Delhi, pp. 209-220.

[52] **Sahasrabudhe, Y. S. and Rajaguru, S. N., (1990)** The laterites of the Maharashtra State, Bull. Deccan College Research Institute, 49: 357-370.

[53] **Schafer, B.M. and McGarity, J.W., (1980)** Genesis of red and dark brown soils on basaltic parent materials near Armidale, N.S.W., Geoderma, 23: 31-48.

[54] **Schellmann, W., (1981)** Consideration on the definition and classification of laterite. Lateritization Processes, Oxford and IBH, Publishers, Co., New Delhi, pp. 1-10.

[55] **Schluger, P.R. and Roberson, H.E., (1975)** Mineralogy and Chemistry of the Patapsco formation, Maryland, related to the groundwater geochemistry and flow system: A contribution to the origin of red beds, Geol. Soc. Amer. Bull., 86: 153-158.

[56] **Schumm, S.A., (1973)** Geomorphic threshold and complex response of drainage system. In Morisawa, M. (ed.): Fluvial Geomorphology, State University, New York Binghmpton , Pub. in Geomorphology, No. 4, pp. 299-310.

[57] **Schumm, S.A. and Parker, R.S., (1973)** Implications of complex response of drainage system for Quaternary alluvial Stratigraphy, Nature, Phy. Sci., 243: 99-100.

[58] **Shapiro, L and Brannock, W. W., (1962)** Rapid analysis of silicate, carbonate and phosphate rocks, U. S. Geol. Surv. Bull. No. 1144-A, No.56p.

[59] **Swift, D. T. P. and Boehmer, W.R., (1972)** Brown and gray sands on the Virginia shelf: Colour as a function of grain size. Geol. Soc. Amer. Bull., 83: 877-893.

[60] **Talbot, M. R., (1980)** Environmental responses to climate change in the West Africa Sahel over the past 20.000 years. In Williams, M.A.J. and Faure, H., (eds.): The Sahara and the Nile, Balkema and Rotterdam, pp. 37-62.

[61] **Talbot, M. R. and Williams, M. A. J., (1978)** Erosional of Fixed dunes in the Sahel, central Niger, Earth Surf. Process, 3: 107-114.

[62] **Tandale, T. D., (1987)** Geotechnical Study of Laterites and Lateritic Soils of Western Maharashtra, Unpublished Ph.D. thesis, University of Poona, Pune 225p

[63] **Turner, P., (1980)** Continental red beds, Elsevier, Amsterdam. 534p.

[64] **Umarjikar, S. V., (1983)** Quaternary Geology of the Upper Krishna Basin. Unpublished Ph.D. thesis, University of Poona, Pune 188p.

[65] **Van Houten, F. B., (1961)** Climatic significance of red beds, In Nairn, A. E. M. (eds.): Descriptive Palaeoclimatology. Interscience Publications, New York, pp. 89-139.

[66] **Van Houten, F. B., (1964)** Origin of red beds- some unsolved problems, In Nairn, A. E. M. (eds.): Problems in

 ISSN: 2277-9655

Palaeoclimatology. Interscience Publications, New York, pp. 647-661.

[67] **Van Houten, F. B., (1972)** Iron and clay in Tropical Savanna alluvium, northern Colombia: A contribution to the origin of red beds, Geol. Soc. Amer. Bull., 83: 2761-2772.

[68] **Walker, T.R., (1967a)** formation of red beds in modern and ancient deserts, Geol. Soc. Amer. Bull., 78: 353-368.

[69] **Walker, T.R., (1979)** Red colour in dune sand, In Mckee, E.D. (ed.): A study of global sand seas. U.S. Geological Survey, Prof. Pap. No. 1052, pp. 62-81.

[70] **Watson, A., (1983)** Evaporite sedimentation in non-marine environments, In Goundie, A. S. and Pye, K., (eds.): Chemical Sediments and Geomorphology. Academic Press, pp. 163-187.

[71] **Young, A., (1972)** Slopes. Oliver and Boyd. Edinbergh, 288p.

[72] **Young, A., (1974)** Tropical soils and Soil Survey, Cambridge University Press, Cambridge.

[73] **Ziegler, A. M. and Mckerrow, W. S., (1976)** Silurian marine red beds, Amer. J. Sci., 275: 31-56.

Table 2: Major Morphotectonic events in the history of landscape evolution in the Western Ghats region of Indian Peninsula

<table>
<tr><th colspan="3">Events and processes → / Stratigraphic period ↓</th><th>Tectonic Environment</th><th>Climatic Conditions</th><th colspan="2">Landforms and Depositional features</th></tr>
<tr><td rowspan="2" colspan="2">QUATERNARY</td><td>Holocene</td><td rowspan="2">Weak cymatogenic movements</td><td rowspan="2">Tropical, alternate wet-dry, monsoonal type, Glacial and interglacial periods</td><td rowspan="2">Indurations of, red beds, Erosion of landscape, Reorganization or the drainage, deep dissection leading to isolation or 'red beds' as erosional remnants on plateaux to tops, Formation of black soils.</td><td rowspan="2">Recession of Western Charts</td></tr>
<tr><td>Pleistocene</td></tr>
<tr><td rowspan="5">TERTIARY</td><td rowspan="2">NEOGENE</td><td>Pliocene</td><td rowspan="2">Collision of Indian. Sub plate with Eurasian plate and rise of Himalayas, Development of the Western Ghats Escarpment, Eastward tilting of the Indian Peninsula, Strong cymatogenic movements.</td><td>Tropical, alternate wet-dry. Monsoonal type</td><td rowspan="2">Formation of Deccan plateau, stripping of red soils and laterites from highlands, Erosion in uplands region and deposition of sediments on the eastern flanks of the Western Ghats, Dissection by streams, Exhumation of the Palaeogene topography.</td><td>Recession of Western Charts</td></tr>
<tr><td>Miocene</td><td>Wet-dry monsoonal type</td><td>—— ——</td></tr>
<tr><td rowspan="3">PLAEOGENE</td><td>Oligocene</td><td rowspan="2">Northward drift of Indian subcontinent</td><td>Cool and dry</td><td>Laterite and Bauxite formation in highlands.</td><td rowspan="3">Fluvial erosion and sediment deposition</td></tr>
<tr><td>Eocene</td><td>Warm and moist</td><td>Red soil and laterite formation in highlands.</td></tr>
<tr><td>Paleocene</td><td rowspan="2">Northward drift of Indian subcontinent, Deccan Volcanic activity and spread of lava flows</td><td>Warm and moist</td><td>Weathering of lava flows, Red soil and laterite formation in highlands.</td></tr>
<tr><td colspan="3">UPPER CREATACEOUS</td><td>—— ——</td><td>—— ——</td><td>—— ——</td></tr>
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