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Red Bed Sands of Visakhapatnam District: A Review of Their Formation, Sedimentology, Mineralogy, Weathering Processes, and Polygenetic Depositional Environments.

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Abstract: The red bed sands of the Visakhapatnam coastal region form one of the most distinctive Late Quaternary sedimentary archives along the East Coast of India. These ferruginous deposits, characterized by their red to reddish-brown colours imparted by iron bearing minerals of hematite and goethite coatings, exhibit a multicyclic and polygenetic origin caused by deep weathering of Eastern Ghats crystalline rocks, fluvial transport, aeolian reworking, and coastal geomorphic adjustments. Four major litho-units—yellow sands, reddish-brown sands, brick-red sands, and light-yellow sands reflect marked variability in grain size, sorting, heavy-mineral assemblages, and pedogenic features such as duricrusts and calcretes. Textural and petrographic characteristics indicate that the basal yellow sands were deposited under high-energy fluvial conditions, whereas the overlying reddish-brown and brick-red sediments record enhanced chemical alteration of Fe-bearing minerals and semi-arid pedogenic episodes. The upper light-yellow sands, resembling modern coastal dune deposits, reflect aeolian reworking during phases of lowered oxidation. The combined influence of monsoonal climate, sea-level oscillations, neotectonic uplift, and coastal processes contributed to the complex stratigraphic architecture of these red sands. This review synthesizes existing sedimentological, mineralogical, and geomorphic studies to clarify the origin, weathering pathways, and depositional environments of the Visakhapatnam red sands, while identifying key research gaps for future geochemical, chronological, and provenance analyses.

Key words: Red bed sands of Visakhapatnam, Eastern Ghat Mobile Belt, polygenic origin, bad land topography, tropical weathering, depositional environment

I. INTRODUCTION

Red bed sands are ferruginous, red-colored sediments formed under oxidizing environmental conditions, iron oxide coating gives the reddish appearance of these sand grains (MüCke, 1994). Red beds are sediments and sedimentary rocks with hues ranging from 2.5YR to 5R, displaying reddish pigmentation in surface and subsurface layers. Although colour mottling is very common and some layers may lack red tones, the characteristic coloration arises from fine-grained hematite (<2 μm) formed within the weathering zone or just below the soil profile. (Abdel-Gawad & Kerr, 1963)**.** These red sediments were described as "bad lands" by (King, 1986), and also described, the red sediments of Visakhapatnam to Bhimunipatnam are denudational remnants of the great sand bank of the late pliocene based on topography. (Mahadevan & Sathapathi, 1949) and (M. V. Rao & Rao, 1968) have referred to the them as "highlands" and inferred that the red-coloured sediments were formed through the combined action of wind and running water. These sediments are now termed "coastal red sediments" (A. T. Rao, 1978). On the view of (Kakani et al., 2014) various micro relief and depositional horizons with in the unconsolidated sediments indicating their multicyclic and polygenetic origin. These sediments are loosely packed and are separated from the sea by the modern beaches and dune sands. Two types of red beds Continental and Coastal red beds, the Continental red beds form in inland fluvial or floodplain settings where iron-rich coatings develop during weathering and diagenesis (He et al., 2022), whereas coastal red sands occur along beaches and dunes, in which well-sorted quartz grains gain thin iron-oxide films through surface oxidation. Thus, continental red beds are highly compacted with different texture, while coastal red sands are loose, well-sorted, and shaped by reworking of wave or wind action (Parcerisa et al., 2006).

Globally, red beds have been reported from a different geological period, ranging from the Proterozoic to the Recent, and occur across various tectonic settings including intracratonic basins, rift basins, foreland basins, and coastal plains. Typical examples include, the Permian–Triassic red beds of Europe (Germany, United Kingdom) (Ramsay, 1871), late Palaeozoic and Mesozoic red sandstones of the southwestern United States (Colorado Plateau) (Heaton, 1950), Triassic red beds of China (Jiang et al., 2017), and Paleozoic red strata of South America (Harrington, 1962), Their widespread

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occurrence through geological time emphasizes their strong association with continental environments characterized by warm, oxidizing, semi-arid to tropical climates. The Coastal red beds of NE spain (Parcerisa et al., 2006) . The coastal red sediments are three formations in South Asia, there are in Southern Sri Lanka, Tamil Nadu (Teri Sands), and red sediments of Visakhapatnam to Bhimunipatam coast. Cenozoic continental red beds of the Himalayan foreland basin in NW India (Singh et al., 2021). The Chronology and weathering history of red dunes (Teri Sands) in the southwest coast of Tamil Nadu, India (Alappat et al., 2016). The red sediments of Visakhapatnam are the rare natural wonder along the coastal region, took a lot of time to produce these sediments, it is about 10 km^2 from the backshore zone to 2.5 km inland, and the elevation is up to 90 m above mean sea level (MSL). These features are geologically significant and designated as heritage sites, because they preserve prominent features of the geological history of the late Quaternary period and carry the imprints of the fall of sea level and its subsequent rise, the impact of climate, and geological processes of the sediments (Kakani et al., 2014). Erra Matti Dibbalu (Red Sand Dunes), Visakhapatnam was declared a National Geoheritage Site in 2014 by the Geological Survey of India (GSI) (Ranawat, 2020). The red sands of Visakhapatnam on the East Coast of India have been the focus of numerous studies by several researchers, (Udaya Bhaskara Rao, 2022) (Prudhvi Raju et al., 1985) (N. V. N. D. Rao & Srihari, 1980) (Gaitan Vaz et al., 1998).

The present objective is to integrate and critically review the existing studies on the red sands of Visakhapatnam, East Coast of India, with emphasis on their lithology, mineral composition, Weathering Processes, and Polygenetic Depositional Environments, assess the influence of Eastern Ghats weathering and coastal dynamics on their formation, and identify key research gaps to guide future sedimentological and geochemical investigations.

II. REGIONAL GEOLOGICAL SETTINGS

The Visakhapatnam District lies in the northeastern part of Andhra Pradesh state and also forms part of the Eastern Ghats Mobile Belt (EGMB). The EGMB is a high-grade metamorphic terrain dominated by high grade metamorphic rocks like, khondalites, charnockites, garnet–sillimanite gneisses, and quartzites. It is a curvilinear mobile belt with 700 kms length and less than 60 km width. The western margin of the Belt is bounded by the Archean Bastar Craton in the south, while the Archean Singhbhum Craton lies adjacent to its northern extremity. The contact between the EGMB and the Bastar–Dharwar cratons is interpreted as a major thrust boundary, indicating the tectonic superposition of the mobile belt over the older cratonic blocks. The EGMB comprises metamorphosed supracrustal sequences of granulite-facies grade along with granites, charnockites, anorthosites, and alkaline complexes, accompanied by minor calc-silicate rocks, marbles, and quartzites. Migmatites are also common in several sectors of the belt. Pressure–temperature (P–T) studies from different regions of the EGMB reveal a metamorphic evolution characterized by near-isobaric cooling from peak conditions of approximately 950°C at ~9 kbar, followed by near-isothermal decompression and subsequent near-isobaric cooling from around 900°C at 8.4 kbar (Tani et al., 1998)**.**

These ancient crystalline rocks effected by intense tropical weathering, producing abundant ferruginous material that creates the sediments forming red bed regions. Toward the east, the rugged Eastern Ghats uplands grade into gently sloping coastal plains composed of laterites, red soils, alluvium, and beach-ridge sands**.** The red beds of Visakhapatnam typically occur within this transition zone, where erosional products from the uplands are transported by short, seasonal rivers and deposited under oxidizing conditions across the piedmont slopes, valley fills, and coastal terraces. The combined action of high-grade metamorphic source rocks, monsoonal climatic conditions, fluctuations in sea-level, and dynamic coastal processes provides a favourable environment for the formation of ferruginous red sands and red bed sequences in the district (Paul & Paul, 2023).

III. MINERALOGY, LITHOLOGY & PETROGRAPHY OF RED BED SANDS

The red bed sands of the Visakhapatnam coast exhibit pronounced lithological variability, comprising four distinct sand units i.e. a lower coarse- to medium-grained yellow sand, a medium- to fine-grained reddish-brown sand containing iron concretions, a fine-grained brick-red sand, and an upper light yellow, fine-grained horizon. These sands display variable thicknesses up to 30 m and are interlayered with duricrust levels and occasional pebble beds, reflecting multiple depositional cycles. Lithologically, the red sands are dominantly quartz-rich, with grain sizes ranging from fine to medium and showing moderate to good sorting (Kakani et al., 2014)**.** According to *Krishna et al. (2017)* the Coastal red sediments exhibit unique feature with bad land topography with area comprising deeply gullied nature abundantly occur near to the INS Kalinga area. Also described the vertical litho-section of the red sediments are categorized into (a) yellow sediments (b) reddish brown sediments (c) brick red sediments and (d) light yellow sediments. The heavy mineral assemblage in all these red bed sedimentary units with decreasing abundance is ilmenite+magnetite, sillimanite, rutile and zircon and trace amounts of garnet, kyanite, monazite and other heavy minerals like leucoxene, sphene, and epidote. Mineralogy of the red beds is characterized by abundant monocrystalline quartz with subordinate feldspar grains that commonly exhibit

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alteration features, along with opaque minerals and iron-oxide coatings responsible for the reddish colours. Petrographic observations suggest ferruginous cementation and hematite/goethite staining on grain surfaces, indicating intense chemical weathering and oxidation under fluvial, marine-influenced, and aeolian environments. The presence of duricrusts and pebble horizons further points to episodic pedogenesis, fluctuating energy conditions, and polycyclic sedimentary reworking controlled by sea-level changes, neotectonics, and coastal geomorphic processes. The Visakhapatnam region is underlain by granulite-grade metamorphic rocks, predominantly garnet–sillimanite gneisses (khondalites) and garnet–biotite gneisses (leptynites), which form the principal source material for the coastal sediments. These high-grade gneisses exhibit multiple generations of folding and contain abundant quartz veins as well as associated Gondwana sandstones. The petrographic character of the area is therefore dominated by quartz-rich and garnet-bearing metamorphic assemblages, reflecting the intense metamorphic history and structural deformation of the Eastern Ghat Mobile Belt (Kakani et al., 2014).

IV. ORIGIN, AGE AND DEPOSITIONAL ENVIRONMENTS OF THE RED BED SANDS

The studies of *Krishna et al. (2017)* and *Udaya Bhaskara Rao (2022)*, The red bed sands of the Visakhapatnam–Bhimunipatnam coast exhibit a polygenetic origin, shaped by multiple cycles of weathering, fluvial transport, aeolian reworking, and coastal geomorphic processes. The basal yellow sediment unit, which lies directly on the khondalite basement, contains rounded pebbles, trough cross-bedding, fining-upward sequences, and medium-to-coarse sands. These features which clearly indicate high-energy fluvial deposition under turbulent flow conditions. As energy decreased upward, cross-laminated and planar-laminated sands formed, indicates a shift from channel flow to calmer overbank or waning-flow environments. The overlying reddish-brown and brick-red sediments are fine to very fine sands, poorly sorted, and enriched in silt and clay due to chemical weathering of Fe-bearing minerals, producing ferric oxides that impart the characteristic red colour. The presence of micritic calcretes in these units' points to evaporative conditions and carbonate precipitation, suggesting intermittent semi-arid pedogenic phases.

In contrast, the upper light-yellow sediments are well-sorted, medium-to-fine sands whose grain-size parameters closely resemble modern dune sands, indicating a dominantly aeolian origin under low-oxidation conditions where Fe hydroxides, rather than hematite, imparted the yellow colour. Overall, the vertical succession, from fluvial yellow sands to aeolian light yellow sands, combined with pebble beds, calcretes, cross-bedding, and variable sorting, demonstrates that the red bed sands of Visakhapatnam formed through interacting fluvial, aeolian, and minor fluvio-marine processes, modified by late Pleistocene–Holocene neotectonic uplift, sea-level changes, and coastal dissection. Their Late Quaternary age reflects a complex interplay of different geomorphic agents, produced the multi-cyclic, texturally diverse sedimentary framework characteristic of the region's red sediments.

V. CONCLUSION

The red bed sands of the Visakhapatnam–Bhimunipatnam coast constitute a unique Late Quaternary sedimentary archive shaped by tropical weathering, fluvial deposition, aeolian reworking, pedogenesis, and coastal geomorphic adjustments. Their characteristic four-unit lithology, yellow, reddish-brown, brick-red, and light-yellow sands, captures a polygenetic and multi-cyclic history influenced by variations in depositional energy, chemical alteration of Fe-bearing minerals, and oscillations in sea level and climate. These ferruginous sands not only record the denudation history of the Eastern Ghats and regional paleoenvironmental transitions, but also preserve imprints of neotectonic uplift along the East Coast of India. However, this geological heritage is increasingly threatened by both natural and anthropogenic forces. Gully erosion, slope failure, rainfall-induced sediment washouts, and coastal wave action are rapidly altering the morphology of these fragile deposits. Concurrently, human activities such as unregulated sand mining, urban expansion, vegetation clearing, infrastructure development, and land-use modification have accelerated sediment removal, destabilized slopes, and disrupted natural drainage, collectively placing the long-term preservation of these red bed sequences at severe risk.

Future research must therefore integrate geological, geomorphological, and environmental approaches to protect and better understand these vulnerable red sand landscapes. High-resolution chronological tools such as OSL (Optically Stimulated Luminescence) and IRSL (Infrared stimulated Luminescence) dating are needed to constrain depositional phases, while geochemical and provenance studies can explain weathering pathways and sediment sources. Drone-based mapping, LiDAR, and geophysical imaging should be utilized to monitor gully progression, slope instability, and coastal erosion under changing climatic conditions, including intensified monsoon rainfall and cyclonic events. Also the evaluation of anthropogenic impacts on sediment budgets, groundwater dynamics, and landscape stability, alongside the development of restoration strategies involving controlled land use, vegetation rehabilitation, and erosion-control measures, is essential to safeguard the Visakhapatnam red bed sands.

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Conflict of interest(s)

The authors declare there is no conflict of interests.

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