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Luminescence dating of fluvial and coastal red sediments in the SE coast, India, and implications for paleoenvironmental changes and dune reddening

R. Jayangondaperumal [a,*], M.K. Murari [b,1], P. Sivasubramanian [c], N. Chandrasekar [d], A.K. Singhvi [b]

[a] Wadia Institute of Himalayan Geology, Dehradun, India
[b] Physical Research Laboratory, EPSD, OSL lab, Ahmadabad, India
[c] Department of Geology, VOC College, Tuticorin, India
[d] Centre for Geo Technology, M.S. University, Tamil Nadu, India

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ABSTRACT

The Holocene and late Pleistocene environmental history of the teri ('sandy waste' in local parlance) red sands in the southeast coastal Tamil Nadu was examined using remote sensing, stratigraphy, and optically stimulated luminescence (OSL) dating. Geomorphological surveys enabled the classification of the teri red sands as, 1) inland fluvial teri, 2) coastal teri and, 3) near-coastal teri dunes. The inland teri sediments have higher clay and silty-sand component than the coastal and near-coastal teri, suggesting that these sediments were deposited by the fluvial process during a stronger winter monsoon around >15 ka. The coastal teri dunes were deposited prior to 11.4 ± 0.9 ka, and the near-coastal dunes aggraded at around 5.6 ± 0.4 ka. We interpret that the coastal dunes were formed during a period of lower relative sea level and the near-coastal dunes formed during a period of higher sea level. Dune reddening is post deposition occurred after 11.4 ± 0.9 ka for the coastal teri dunes and after 5.6 ± 0.4 ka for the near-coastal teri dunes. Presence of microlithic sites associated with the coastal dunes suggest that the cultures existed in the region during 11.4 ± 0.9 ka and 5.6 ± 0.4 ka.

1. Introduction

Coastal dunes represent a fragile ecosystem and have an amplified response to minor perturbations in land–sea configuration (i.e., changes in relative sea level; Carter, 1991). Though not directly controlled by climate, the landward movement of coastal dunes is facilitated by arid and semi-arid conditions. Strong onshore winds are as important as reduced rainfall (Sarnthein, 1978). Coastal aeolian systems form by deposition and reworking of sediments exposed on continental shelf during periods of lower relative sea levels (Giannini et al., 2007) and a relationship between the coastal aeolian system and the relative sea-level (RSL) elevation can be anticipated (Thomas and Leason, 2005; Giannini et al., 2007). Though complex, this relationship can be elucidated using chronological data from the coastal dune fields (Pye, 1984; Carr et al., 2006; Lees, 2006). Kocurek (1998) demonstrated that a long-term response of desert aeolian systems to climate changes in different environments are determined by an optimal combination of sediment production and availability, transportation capacity, and preservation. This was seen explicitly in Thar Desert (Singhvi and Kar, 2004; Singhvi et al., 2010a).

Numerous studies inferring paleoclimatic conditions through luminescence dating of dryland dune systems exist (Lancaster, 2008; Singhvi and Porat, 2008). Combining dune trends with OSL dating enables reconstruction of past wind directions (Glennie and Singhvi, 2002; Lancaster et al., 2002; Lancaster, 2008). This study explores the potential use of coastal dune systems in reconstruction of past environments.

Teri sand ('sandy waste' in local parlance) is used here for weathered coastal reddened dunes. Two types of aeolian deposits, red and white dunes, were identified along the southeast coast of Tamil Nadu, India (Fig. 1b; Foote, 1883). The white dunes are found along the modern shoreline, whereas red dunes sit inland in large patches, stratigraphically above the marine calcareous grit of Pleistocene age (Gardner, 1986; Figs. 1 and 2).

Red beds are not necessarily indicative of tropical or subtropical climates, as evidenced by the red sediments of North America (Raymond, 1927). The degree of color development has been used to estimate the relative age and the environmental history of the deposits. However, these ages carry large uncertainty as the dunes can form and redden rapidly depending upon the source rock, grain size, iron content, and ambient environmental conditions (Van Houten, 1973).

The origin of teri sands has been debated. Foote (1883) proposed a detrital origin of reddening of the teri sands derived from the red earths of the eastern foothills of Western Ghats as a result of aeolian

* Corresponding author at: #33 GMS Road, Wadia Institute of Himalayan Geology, Dehradun, India.
E-mail address: ramperu.jayan@gmail.com (R. Jayangondaperumal).
[1] Presently at Department of Geosciences, University of Cincinnati, Cincinnati, USA.

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transport by westerly and southwesterly winds during the summer monsoon (Fig. 1b). Gardner (1981b, 1986) suggested that the sands originated as coastal dunes by easterly and northeasterly winds during the winter monsoon, and were subsequently reddened in-situ due to weathering of feldspars, garnets, and some opaque minerals. This led to the formation of a deep red matrix enriched in kaolinite, hematite and illite in the clay fraction (Gardner, 1986; Joseph et al., 1999; Thrivikramaji et al., 2008). Gardner (1981a, b; 1986) described the relative ages of teri sands on the southeast Tamil Nadu coast (Fig. 2) and reconstructed the late Quaternary environment. Association of the teri sands with microlithic artifacts led Gardner and Martingell (1990) to suggest that these deposits are contemporaneous with red dunes in coastal Sri Lanka (Singhvi et al., 1986) (Fig. 1a). However, the luminescence ages of teri sands with microlithic tools in-situ from Sri Lanka was ~28 ka. Given that microlithic cultures in peninsular India are considered to be relatively younger, it suggests that the teri sands along the Tamil Nadu coast were significantly younger.

Till the early 1980s, absolute radiometric dating of red sediments along the southeast coast of India was difficult to date by any radiometric techniques (Gardner, 1981a, 1981b). Gardner (1981a, b) used radiocarbon ages for aragonitic land snail shells, a unit of Poochikkadu Series that underlies a Teri Series (teri sands) and in the south east coast of Tamil Nadu between $21{,}000 \pm 400$ ^{14}C yr BP and 25, 000 ± 750 ^{14}C yr BP (Table 1) to suggest that the observed reddening process of teri red sands occurred during the last 20,000–25,000 ^{14}C yr BP. This estimate is significantly higher compared to the reported reddening duration of 7.5 ka for dunes in a humid tropical climate of northeast Australia (Pye, 1981). Van Houten (1973) suggested that in areas with high rainfall, high temperature, and suitable source rocks, dune reddening could occur rapidly, over hundreds of years. Using few radiometric dates Gardner (1986) inferred the relative chronology of teri red sediments, association of microlithic culture, and subsequent climate-environmental changes in the southeast coast of India. Successful luminescence dating of teri sands in Sri Lanka (Singhvi et al., 1986) formed the basis of the present study.

This study presents the first set of OSL (optically stimulated luminescence) ages on quartz grains from the Indian teri sand dunes (Fig. 1) with the objective of:

1. clarifying the role of the changing sea level on dune formation,
2. determining the age and evolutional history of dunes and their reddening, and
3. constraining the chronology of the microlithic culture along the southeast Tamil Nadu coast.

2. Study area

The study area is located along the southeast coast of Tamil Nadu between Tirunelveli (8°43′58.80″N; 77°42′0.00″E) and Kanyakumari (8°5′5.69″N; 77°32′30.47″E), extending ~15 km inland from the coast (Fig. 1a). Teri deposits occur along whole length of the coastline of southeast coast Tamil Nadu. Extensive teri sand deposits occur as coastal dune fields comprising barchan and transverse dunes, and blowouts (of varying sizes and orientations) near Sattankulam (8°26′10.61″N; 77°54′43.44″E) and Kudiramoli (8°31′51.86″N; 78°00′18.47″E) (Fig. 1b). Teri deposits are continuous in north of the study area and discontinuous in the south.

3. Geological setting

The teri sands cover an area of ~500 km^2, and thicknesses reach up to 12 m (Gardner, 1986). In the western realm of the inland plain near the eastern foothills of Western Ghats, red earths, rich in kaolinite and hematite (Murali et al., 1974; Figs. 1 and 2) were formed by mass wasting and fluvial process (Joseph et al., 1997). Detailed stratigraphy and associated processes are illustrated in Figure 2 (Gardner, 1986). The oldest coastal deposits in the study area are the Ovari Series that sits unconformably on basement igneous and metamorphic rocks. These comprise coarse marine sandstones, corals and siltstones and shell fragments of near-shore shallow-water marine facies; are widespread in and around Ovari, Tisaiyanvillai, and Panamparai; and occur in patches along most of the coastline (Figs. 1 and 2). The Idindakarai Series overlies the Ovari Series and comprises terrigenous grains of gravel and sand size, and shell fragments of shallow marine origin. The marine shells gave U-series ages of ~112 to ~124 ka (Fig. 2, Brückner, 1988, 1989) and therefore define a sea-level highstand during the last interglacial. The Kanyakumari Series that overlies the Idindakarai Series consists of fossil coastal dunes cemented by calcium carbonate (aeolianite). The overlying Poochikkadu Series comprises of calcrete and some marine sediment. The top part of calcrete has layers of land snail shells (Helix vittata); at Kayamoli and Poochikkadu villages these shells gave radiocarbon ages between 26,162–24,081 cal yr BP ($21{,}000 \pm 400$ ^{14}C yr BP) and 31,244–28,694 cal yr BP ($25{,}000 \pm 750$ ^{14}C yr BP, Table 1). These ages on land snail shells provide a minimum estimate for the host sediments.

The Teri Series (teri red dunes) occur inland in large patches and are stratigraphically above the marine calcareous grit of Poochikkadu Series (Figs. 1 and 2). The teri deposits are overlain by marine deposits of Mandapam Series. In the shoreward direction, Teri sands rest on either of the crystalline basement, Ovari marine sandstone, aeolianite of Kanyakumari or the Poochikkadu Series (Fig. 2; Gardner, 1986; Joseph et al., 1997).

Using textural observations, Joseph et al. (1997) inferred that the teri deposits were derived from the exposed continental shelf during periods of low relative sea level, transported by high landward winds. Mineralogically, the sands are rich in heavy minerals, such as ilmenite, rutile, zircon, garnet, monazite and sillimanite, suggesting their provenance from Precambrian khondalite, charnockites and granite gneisses rocks (Chandrasekharan and Murugan, 2001).

Chronometric studies to date consist of 1) a few uncalibrated radiocarbon dates for exposed corals on the Rameswaram foreshore (Loveson and Rajamanickam, 2001), 2) radiocarbon dating of land snails from Kayamoli and Poochikkadu villages (Gardner, 1986), 3) radiocarbon dating of rhizolithic calcrete located near Sattankulam, SE coast Tamil Nadu, India (Thrivikramaji et al., 2008), and 4) radiometric ages of marine shells from the Sri Lankan coast (Katupotha and Fujiwara, 1988). The published uncalibrated radiocarbon ages (^{14}C yr BP) were calibrated using the Calib Rev.6.0.1 and the Intcal 98 (Reimer et al., 2004, 2009) and are labeled cal yr BP for comparison with the optical ages. The ages are listed in Table 1.

3.1. Climate

The study region is in the rain shadow zone of the Western Ghats. The present climate is semi-arid with an average annual rainfall of ~700 mm. 60% of the precipitation occurs during the winter monsoon, and the remaining 40% falls during the summer monsoon (Dhar et al., 1982; Sontakke et al., 2008). During summer monsoon months, strong westerly and southwesterly winds occur (http://www.imdchennai.gov.in). During the winter monsoon, the winds are from northeasterly and easterly direction with a composite mean velocity of 4–5 m/s (NCAR, http://www.cdc.noaa.gov) (Fig. 1a). The annual average minimum and maximum temperatures are 19°C and 41°C; maximum and minimum rainfall during winter monsoon are 427 mm and 336 mm, and the average relative humidity ranges between 49% and 75%. The winter rain occurs in 2- to 4-day spells with intervening longer periods of dry weather and characterized by tropical cyclones wind toward southeast, while the summer monsoon maximum and minimum rainfall are 370 mm and 69.8 mm (http://www.imdchennai.gov.in). The near-coastal dunes are active and oriented in the northeast direction. The rivers are seasonal with higher flows and flooding during winter rainfall periods.