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Mid-Holocene climate and land–sea interaction along the southern coast of Saurashtra, western India

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ABSTRACT

The relict mudflat from the southern Saurashtra coast of Gujarat was investigated using geochemical and palynological analyses supported by radiocarbon dating to understand whether climate fluctuations and sea-level operated in tandem during mid-Holocene. The study revealed that the Saurashtra coast experienced relatively wet climatic conditions with simultaneous occurrence of marginally high sea-level between 4710 and 2825 cal yr BP. Subsequently, a gradual onset of aridity and lowering of the sea-level was observed between 2825 and 1835 cal yr BP, and further a slight decrease in aridity is observed after 1835 cal yr BP. The present day coastal configuration was probably achieved after around 1500 cal yr BP. Considering the tectonic instability of Saurashtra coast (land level changes), the effective mid-Holocene sea-level was estimated to be ~1 m higher than the present. The study demonstrates that sea-level changes, climate variability and land-level changes were coupled during the mid-Holocene.

1. Introduction

Unlike the glacial and interglacial cycles where the boundary conditions changed dramatically, the mid-Holocene did not experience such an extreme climatic perturbations. The factors responsible for the observed mid-Holocene climate variability are ascribed to the redistribution of solar energy caused due to the changes in orbital parameters. This in turn influences both temporal and spatial shift of the Inter Tropical Convergence Zone (ITCZ) (Yancheva et al., 2007). The ITCZ dictates the position of the monsoon front (Prasad and Enzel, 2006). For example, pronounced weakening of the monsoon systems in Africa and Asia (increasing aridity and desertification) was caused due to the progressive southward shift in the ITCZ (Wanner et al., 2008). Thus, there exists a fairly good agreement in the causes of the temporal changes in moisture variability during the Holocene. However, compared to this, the Holocene sea-level records are fraught with lack of regional geological investigations and tectonic setting (tectonic upheaval or hydro-isostatic warping) of the coastal tract (Williams et al., 1998; Antonioli et al., 2002). This is considered to be one of the reasons for Holocene sea-level discordance at regional scale (Li et al., 2012). Therefore, it has been suggested that instead of adopting regional Holocene sea-level curve, site specific sea-level curves should be generated (Hashimi et al., 1995). There exists studies from the eastern coast (Bhaskara Rao and Vaidyanathan, 1975; Prudhvi and Vaidyanathan, 1978; Bhattacharya and Banerjee, 1979; Banerjee, 1993; Kunte and Wagle, 2005; Vora et al., 2006) and the western coast of India (Nair, 1974; Nambiar et al., 1991; Nigam et al., 1993; Wagle et al., 1994; Vora et al., 1996; Saha et al., 2011). Although, these studies have indicated the presence of high sea-level during the Holocene, however, they lack adequate observations on the issues pertaining to climate–tectonic interactions during the Holocene sea-level fluctuations.

Studies suggest that the coastal landscape of Saurashtra, western Gujarat, India is an outcome of two major controlling factors viz. the eustatic sea-level changes and neo-tectonism (Ganpathi et al., 1982; Pant and Juyal, 1993). Earlier studies along the Saurashtra coast were based on mapping of raised terraces, wave cut notches and the distribution of the biogenic carbonates (miliolite) (Desai and Pandya, 1982; Baskaran et al., 1987; Pant and Juyal, 1993). Attempts were also made to chronologically constrain various high strands. Gupta (1972) based on dated raised beaches and dead coral reefs suggested that the Holocene sea level in the region was ~2–3 m high. Juyal et al. (1995) based on the dated dead oyster and shell samples concluded that there has been high sea level stand of ~2 m during 3 ka with an over printing of land component. Based on the sedimentology, geochemistry, optical and radiocarbon dating, Tyagi et al. (2012) invoked a marginally high sea strand (compared

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to present) during 5.5 and 2 ka in the western Great Rann of Kachchh. Holocene sea-level reconstruction based on archaeological sites around Gulf of Kachchh suggested that present day sea-level was attained ~1000 yr BP, which resulted in the submergence of the historical sites (Gaur et al., 2007).

There are fairly good number of studies pertaining to Holocene climate variability from Gujarat. For example based on the isotopic studies, from Nal Sarovar lake sediment (Central Gujarat) a wet climatic condition was inferred between 4.8 and 3 ka, followed by an arid climate that persisted till ~2 ka (Prasad et al., 1997). In the Mahi Estuary (mainland Gujarat), pollen and phytolith based studies suggest a coupling between summer monsoon and enhanced winter precipitation between 3400 and 3000 cal yr BP followed by an arid climate from 2850 cal yr BP onwards (Prasad et al., 2007). Sridhar (2007) based on slack water deposits from Mahi River basin identified four events of enhanced monsoon viz. >5 ka, 4.6 ka and between 4.6 and 1.7 ka. A more recent study in the lower Narmada valley, indicated a sub-humid conditions during 3 ka followed by two drier events during 2.1 ka and 1.3 ka respectively (Laskar et al., 2013). A multiproxy data obtained from a lake deposit from mainland Gujarat revealed a dry climate between 5560 and 4250 cal yr BP followed by a gradual strengthening of summer monsoon after 3500 cal yr BP. A dry climate (weak monsoon) was inferred between 3238 and 2709 cal yr BP (Prasad et al., 2014). Summarizing these studies presented above it can be suggested that although there exists reasonable database pertaining to the mid-Holocene monsoon variability, but majority of the studies are confined to the mainland Gujarat. And most importantly, these studies do not address the coupling between the monsoon variability and the land–sea interactions.

Along the southern Saurashtra coast, at many places, the intertidal zone is characterised by the presence of tidal mudflats and salt marshes. These mudflats occur in sheltered location protected from high energy environments such as estuaries and lagoons which develop during the regressive and prograding conditions (Singh, 2007). The estuarine mudflat sediments are considered to have responded in accordance with the pace of sea-level and coastal changes during the Holocene, which can be used to reconstruct regional climate variability (Allen and Haslett, 2002, 2006; Bardhan et al., 2011).

Therefore, the present study is an attempt to reconstruct the history of mid-Holocene climate variability and sea-level/land-level changes in the southern part of Saurashtra coast. Towards this, a relict mudflat located behind Diu Island has been investigated (Fig. 1).

2. Regional setting

2.1. Study area

The study area is located near a Vasoj village (20°45′1.7″N; 71°0′14.3″E) ~10 km northeast of the Diu Island (Fig. 1) separated from the Diu Island by a 250 m wide swampy creek (Mathur and Verma, 1979). The mudflats are surrounded by biogenic carbonate rocks (miliolite) dated to ~178 ka (Baskaran et al., 1987). Presently, the *Avicennia marina* (Avicenniaceae) is one of the major mangrove species found in the intertidal zone and occurs ~8 km inland from the coast line (elevation ~3 m from the mean sea-level). The modern tidal flat sediments are dominated by clay, whereas the beach sediments are dominated by biogenic carbonate (Hardas and Patel, 1982).

2.2. Climate and vegetation

The mean annual rainfall of the Saurashtra region is ~600 mm with majority of it received during the southwest summer monsoon (Farooqui et al., 2013). The mean maximum and minimum temperature varies between 34 °C and 19 °C respectively (Gundalia and Dholakia, 2013). Based on the forest type classification (Champion and Seth, 1968), the study area falls under 5A/C-1a (very dry teak forest) following Sub-type 5/DS1 (dry deciduous scrub forest) and 5/DS1 (dry savannah). The dry deciduous mixed forest comprises of *Acacia catechu*, *Terminalia crenulata*, *Ficus* sps. Open scrub forest constitutes of *Acacia leucophloea*, *Acacia nilotica*, *Zizyphus* spp. Riverine forest includes *T. crenulata*, *Emblica officinalis*, *Tamarindus indica*, *Vitexnigundu*, *Ficus racemosa*, *Syzygium* sp. The dry deciduous teak forest constitutes *Diospyros melanoxylon*, *Wrightia tinctoria*, *Tectona grandis*, *Terminalia chebula*. Savannah includes *Acacia*, grasses such as *Sehima nervosum*, *Dicanthium annulatum*, *Cymbopogon*, *Chrysopogon*, *Apludamutica*, *Heteropogon*, *Aristida*. Thorn scrub forest consists of *A. nilotica*, *A. catechu*, *A. leucophloea*, *A. marmalos*, and *B. aegyptica* (Farooqui et al., 2013). The modern vegetation growing in the vicinity of the study site is dominated by *Avicennia alba*, *A. marina*, *A. officinalis* with fringes of *Aegiceras corniculatum*, *Acanthus ilicifolius*, *Suaeda nudiflora* and *S. maritime*, but other core mangrove species

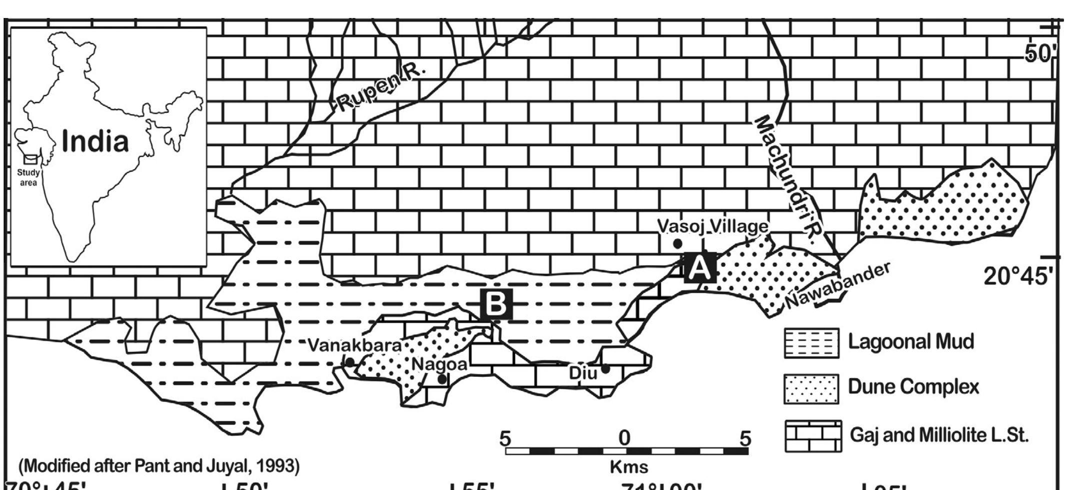

Fig. 1. Location and geological map of the study area. The southern Saurashtra coast mainly comprises miliolitic limestone. [A] and [B] are the sampling site for relict and active mudflat respectively.