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Geological, geophysical, and inherited tectonic imprints on the climate and contrasting coastal geomorphology of the Indian peninsula

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ABSTRACT

The Indian subcontinent comprises accreted cratonic fragments that underwent subsequent rifting–subduction–collision processes along major mobile belts. It is also a storehouse of a prolonged history of crustal evolution involving repeated episodes of magmatism, volcanism, sedimentation, and metamorphism, and the formation of intracratonic and foreland basins. The geologic–geomorphic evolution of the Peninsula is recorded in relic faults/suture zones that confine Paleozoic, Mesozoic, and Cenozoic sedimentary basins and landforms. In addition, escarpments, plateaus, waterfalls, deltas, planation surfaces, and strandlines are either aligned parallel and/or formed over them. Asymmetric relief across the western–eastern parts of the Peninsula, orographic effect on the precipitation pattern and climatic zones provide important constrains on the geologic and geomorphic evolution of the region. Though extensive continental and coastal deposition occurred during Permo-Triassic and Early Cretaceous, only the downwarped grabens of Gondwana basins preserved the sedimentary records. Occurrences of extensive Cenozoic deposits offshore and Neogene–Holocene deltaic deposits along the entire east coast as opposed to the absence of comparable deltaic sequences in the west coast are linked to intense and recurrent episodes of denudation indicating first-order control of basement structures over landscape evolution.

Inheritance and continuum of basement structures over climate, and landscape evolution of Peninsular India can also be witnessed by the unique and diverse drainage patterns of major rivers. While most of the major rivers follow a general easterly direction, the landscape morphology of their catchments indicates youthful character and tectonically active nature. The east flowing rivers show an asymmetry between the areal extents of drainage basin size and delta, whereas the west-flowing rivers are short and straight and their catchments are miniscule in comparison with the rivers flowing toward east. The Western Ghats Escarpment forms an orographic barrier and acts as the main divide between these two drainage systems. There is a disparity between the quanta of sediment discharge as well. In addition, the eastern and western parts of India, across the Western Ghats Escarpment, show significant differences in terms of climatic zones (humid to per-humid on the west while it is arid to subhumid on the east). The west coast is characterized by >3000 mm/year annual rainfall, that often reaches >5000 mm/year, dominance of SW monsoon winds, occurrence of narrow (<60 km), rocky, crenulated and coastal cliffs and pocket beaches, and net southerly long shore sediment transport. In contrast, the east coast is characterized by several hundred kilometers wide deltaic low lands built by major rivers. These rivers show trellis to dendritic stream patterns and follow major basement faults that are associated with geologic–historic–recent seismic activity. The sedimentary basins and delta heads, strandlines, and active delta lobes whose western boundary is always limited by basement faults have shown activity since the formation of the Gondwanan supercontinent. The eastern coastal region is also different from the west in terms of active NE monsoon, long shore sediment transport (toward north), and the formation of extensive lagoon-beach barrier systems since Neogene that in turn continue to occur until recent.

Here we propose a conceptual tectono-geomorphic model demonstrating the inheritance and continuum of Gondwanan structural trends on the transient landscape of Peninsular India.

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Contents

1. Introduction

The modes of extension and thinning of continental lithosphere control evolution of passive margins and thus investigations on the evolution of passive margins help to establish the genetic link between tectonics, geomorphology, and sedimentation (Dev et al., 2012). This is because denudation, sediment supply, and the resultant topographic and structural responses are intrinsically and dynamically linked (Campanile et al., 2007). Tectonics and climate play first-order controls on landscape evolution (Goodbred, 2003; Zhang, 2005), whereas lithology and slope provide subsidiary controls. In the coastal regions, shoreline dynamics as a result of complex interactions between sea level–climate–tectonics–subsidence–sediment influxes play a crucial role in landscape evolution. Geomorphic processes interact with tectonics and climate as an integrated system (Goodbred, 2003; Zhang, 2005). Until recently, geomorphology and tectonics were studied separately and drainage systems were analyzed in a fixed framework, with explanations involving only regional tectonics. Only a few studies related the evolution of drainage systems to plate movements, although drainage-controlled topographic feedbacks affected large-scale tectonics (Brookfield, 1998; Zhang, 2005).

The Indian subcontinent (Fig. 1) is an assemblage of rifted and welded polyhistoric cratons, intracratonic basins, mobile belts, and foreland basins. It is a storehouse of >3.8 Ga of geological history spanning from the Eoarchean to Recent (Santosh et al., 2014, 2015), involving extensive volcanism, plutonism, metamorphism, sedimentation, and tectonic deformation. India has a 7517 km long coastline (Guleria and Edward, 2012) including the mainland coast line of ca. 5400 km. Extensive deltas occur only along the east coast and no comparable deltas occur along the west coast (Fig. 2a). Although both eastern and western coasts of India represent rifted passive continental margins (Chatterjee et al., 2013), it is unique and ironic that the rivers that originate at few tens of kilometers from the west coast travel thousands of kilometers to drain at the east coast, whereas only estuaries and tidal creeks that deliver sediments directly into the shelf (Wagle et al., 1994; Vora et al., 1996) characterize the west coast. Migration of axial river systems in response to lateral ground tilting by basement tectonics is known from many large continental river basins (Peakall et al., 2000; Valdiya, 2001a, 2001b). The Indian peninsular drainage is antecedent to the Western Ghats uplift (Sheth, 1999; Gunnel et al., 2003), which is interpreted to be a post-Deccan trap feature (Sheth, 2007) caused by the cymatogenic upwarp of the crust along an axis west of the present-day Western Ghats Escarpment (WGE)—(Fig. 1) and resultant easterly tilt of the Indian plate (Radhakrishna, 1993). The presence of extensive deltas along the east coast and their absence in the west coast, development of failed rifts, occurrences of Gondwanan (this term is utilized hereinafter in the context of all those features "inherited" from the Gondwana supercontinent, of which the Indian subcontinent was an integral part; Collins et al., 2014 and references therein) sedimentary basins, development of Late Jurassic–Early Cretaceous rift basins coeval with rifting of the Gondwana supercontinent (hereinafter referred to as "Gondwanaland" for the landmass prior to Permian–Triassic rifting, following Collins and Pisarevsky, 2005) are all major features of this region, although received only scant attention on a spatially restricted scale (e.g., Kale, 2014; Kale and Vaidyanadhan, 2014; Tandon et al., 2014). Previous studies focused on the structural (Gombos et al., 1995) and geomorphic evolution of the Western Continental Margin (WCM) and WGE (Gunnel et al., 2003), respectively.

The Indian subcontinent encompasses a variety of geological formations ranging from Archean to Recent (Fig. 2b), and preserves tectonic structures, topographic features, and climatic zones related to the complex evolutionary history of these periods. Since 130 Ma, India had crossed southern latitudinal and climatic zones from polar region–tropic–northern latitudes, experienced largest continental flood basalt eruption events, orogenic events, and sustained seismicity (Fig. 2c). Thus, envisaging a simple easterly tilt and resultant drainage alignment and geomorphic evolution may not be appropriate for the prevailing structural–geomorphic and climatic complexity. Extensive studies have been carried out on the tectonic (Acharyya and Lahiri, 1991; Balakrishnan, 2001; Banerjee et al., 2001; Biswas, 2005; Banerjee et al., 2008; Lal et al., 2009; Dev et al., 2012), geomorphic (Reddy and Shah, 1991; Agarwal et al., 1996; Nair, 1999; Allison et al., 2003; Avinash et al., 2013), and basin evolution (Banerji, 1984; Mathur and Nair, 1993; Chari et al., 1995; Radhakrishna et al., 2000; Jayalakshmi et al., 2004) histories of the Indian sedimentary and river basins, coastal deltas, and offshore regions. Although these studies applied a variety of tools (e.g., Singh et al., 1998; Ramkumar, 1999; Kunte and Wagle, 2000; Ramkumar, 2000; Ramkumar et al., 2000; Karisiddaiah et al., 2002; Ramkumar, 2003; Ramkumar et al., 2004, 2005; Bhatt and Bhonde, 2006; Campanile et al., 2007; Ramkumar, 2008; Sensarma et al., 2008; Ramkumar et al., 2011, 2013; Kale and Vaidyanadhan, 2014; Sinha and Tandon, 2014), there has not yet been a systematic synthesis to understand the coastal geomorphic evolution at a continental scale. Elsewhere, control of inherited structures on sedimentation