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Research paper

Forced regressive wedge in the Mesoproterozoic Koldaha Shale, Vindhyan basin, Son valley, central India

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A B S T R A C T

The present paper highlights the sequence development within the Mesoproterozoic Koldaha Shale Member of the Kheinjua Formation, Vindhyan Supergroup which records the occurrence of a forced regressive wedge and associated discontinuity surfaces at the base of the wedge. Nine lithofacies have been identified within the study area that are grouped into three lithofacies associations varying in depositional setting from outer shelf, through shoreface-foreshore-beach to continental braidplain. The outer shelf sediments are aggradational to slightly progradational representing highstand systems tract. The rapidly progradational, wedge-shaped shoreface to foreshore-beach succession occurs sharply or erosively above the outer shelf sediments and is bounded by a regressive surface of marine erosion (RSME) at the base and by a subaerial unconformity at the top. This, along with its downstepping trajectory, supports deposition of this sedimentary wedge during falling sea level. A laterally extensive soft sediment deformation zone occurs at the base of the wedge.

The forced regressive wedge is incised by fluvial braidplain deposits that rest on an erosive surface representing a sequence boundary. The thin braidplain deposits are the product of aggradation during a subsequent early rise in relative sea level, and thus, they are inferred to represent a lowstand systems tract. The constituent architectural elements that characterize the braidplain deposits are downstream accretion elements and small channel elements. Further landward, the base and top of the shoreface wedge merge to form an unconformity across deposits that rest directly on the outer shelf sediments. The identification of forced regressive wedges has significant economic importance in view of the potential occurrence of hydrocarbons within the Proterozoic formations.

1. Introduction

Forced regression can be defined as shoreline advance under dominance of fall in relative sea-level (Hunt and Tucker, 1992; Posamentier et al., 1992; Ainsworth and Pattison, 1994; Posamentier and Morris, 2000). Over the past two to three decades, studies carried out on active and passive margins demonstrated that the deposits of the continental shelves mostly consist of lowstand and transgressive systems tract deposits (Suter and Berryhill, 1985; Suter et al., 1987; Tesson et al., 1990, 1993; Saito, 1991; Okamura and Blum, 1993; Trincardi and Correggiari, 2000). It is argued that highstand deposits are rarely preserved on outer shelves; they commonly occur on the inner part of the basins and form thick wedges thinning significantly basinwards. Moreover, the preservation of highstand deposits is often difficult in the outer shelf, possibly due to the erosive action of waves and currents (Aiello and Budillon, 2004). Evidently, dominance of relative sea-level falls on the inner shelf, subsequent to phases of rising, are more prominent and often cause partial erosion of highstand deposits, along with sediment reworking in the coastal areas (Field and Trincardi, 1992; Gensous et al., 1993). Nevertheless, the large-scale stratigraphic architecture of forced regressive deposits has been addressed in many previous studies (e.g., Posamentier et al., 1992; Posamentier and Allen, 1999; Posamentier and Morris, 2000). Moreover, evidence of outer shelf forced regressive deposits is not rare, and a variety of forced-regression deposits has been documented from the Plio–Quaternary settings (Trincardi and Field, 1991; Ercilla et al., 1994; Sydow and Roberts, 1994;

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Morton and Suter, 1996; Gensous and Tesson, 1996; Somoza et al., 1997; Chiocci et al., 1997; Naish and Kamp, 1997; Berné et al., 1998; Massari et al., 1999; Rodero et al., 1999; Haywick, 2000; Chiocci, 2000; Pomar and Tropeano, 2001; Berné et al., 2002; Amorosi et al., 2004; Cantalamessa and Di Celma, 2004; Cantalamessa et al., 2006). Despite the vulnerability of the forced regressive deposits to erosion during sea level fall and subsequent early rise (Posamentier and Morris, 2000), in recent years, considerable work has been carried out on forced regressive deposits due to their potential for hydrocarbon reservoirs (Posamentier et al., 1992; Plint and Nummedal, 2000; Posamentier and Morris, 2000; Hunt and Gawthorpe, 2000; Lee et al., 2007; Zecchin and Catuneanu, 2015). The relatively thin and detached occurrence of these sand bodies may be the reason for their limited identification and description in the literature (Plint, 1988; Proust et al., 2001). The small thickness of these forced regressive wedges is possibly related to the limited availability of time for their deposition, marked foreshortening during forced regression, and transgressive ravinement processes (Zecchin et al., 2011; Catuneanu and Zecchin, 2013). Thick and extensive forced-regression deposits include a significant amount of fine-grained material and form multi-storey progradational/regressive sequences in many Quaternary margins, reflecting the periodicity of climate-driven sea level cycles (Ridente and Trincardi, 2005). High-resolution seismic analysis is useful in understanding the forced regressive deposits; such analysis in the Quaternary shelf-edge deltas of the Gulf of Lions and the Gulf of Mexico, provides insights into the stratigraphic organization of forced regressive deposits (Hart and Long, 1996; Tesson et al., 2000; Anderson and Fillon, 2004; Serge and Gorini, 2005; Gwenael et al., 2006).

The studies on the forced regressive deposits are mostly confined to Phanerozoic formations. Only a few examples are focused on Precambrian settings (cf. Chakraborty and Paul, 2008). Despite the paucity of examples in the literature it is pertinent to note that the slow subsidence and low-gradients inferred for many Proterozoic epeiric basins (Bose et al., 2001; Sarkar et al., 2005, 2008; Taylor et al., 2001; Eriksson et al., 2002, 2008) make them ideal situations for understanding the response of falling stage systems tracts in such basins. In other words, the Proterozoic formations were more significant in forming falling-stage systems tracts. High-resolution sequence stratigraphic observations and modelling are limited in the Precambrian basin-fills, and have been attempted mostly on low resolution 'layer cake' lithostratigraphy at different scales of observation (Christe-Blick et al., 1995; Catuneanu and Eriksson, 1999). Thus it is necessary to revisit the shallow marine epeiric deposits, and also those on the preserved outer shelf settings of these basins to understand the high resolution sequence architecture of these basin-fills in time and space.

The present paper uses depositional facies, facies associations and transitions of facies associations for understanding palaeoenvironments and their shift with time and space. Correlation of palaeoenvironments has been made by using field evidence of major erosion surfaces (unconformities) and other correlative surfaces to build-up sequence architecture for understanding a Meoproterozoic forced regressive deposit in the Koldaha Shale Member, Vindhyan Supergroup, central India. The outcrop-based study aims at identifying depositional discontinuities/unconformities through high resolution sequence analysis, characterizing the highstand, forced regressive and lowstand products (rising stage, falling stage and subsequent early rise), and documentation of sequence architecture of the marine and terrestrial deposits in the Koldaha Shale Member. Documentation of outcropping shelf-edge sand bodies ideally requires continuous lateral exposures from terrestrial basin margin, across the shelf to palaeo-shelf edge, and further exposure also of slope to basin deposits, which are only rarely available (Surlyk and Noe-Nygaard, 2005). The present study investigates a fortuitous long continuous outcrop of the Koldaha Shale and allows us to understand the stratigraphic architecture of the Koldaha Shale that records a falling stage systems tract in this Mesoproterozoic formation. In the study area the Koldaha Shale can be subdivided into two major intervals: marine and terrestrial. The marine interval can further be subdivided into an entirely muddy unit of offshore origin below and a dominantly sandy wedge of shallow marine origin above (Fig. 1). A terrestrial interval of dominantly fluvial origin unconformably overlies this shallow marine interval. The transition of the argillaceous to arenaceous intervals shows that the change is sharp and erosional in the present study area. Three depositional sequences have been established that record highstand, falling stage and lowstand systems tract in the Mesoproterozoic Koldaha basin.

2. Geological background

The Vindhyan Supergroup in central India (Fig. 1), ranging in age from Palaeo-to Neoproterozoic, is dominantly composed of siliciclastic and carbonate sedimentary rocks. The entire Vindhyan Supergroup is only mildly deformed (Bose et al., 2001) and covers an area of 104,000 km^2. The Supergroup is roughly 4.5 km thick and divided into two parts, the lower Vindhyan, also known as the Semri Group, and the upper Vindhyan, separated by an unconformity laterally passing into a conformity surface (Fig. 1). The lower Vindhyan sedimentation commenced in an intracratonic rift setting that later transformed into a sag basin during upper Vindhyan time (Bose et al., 2001). The Semri Group outcrops in a fairly continuous exposure along the southern limb of a westerly plunging broad syncline in and around the valley of the Son River, whereas the exposures are discontinuous on the northern limb (Fig. 1).

Within the Semri Group, the Kheinjua Formation is divisible into two Members, the Koldaha Shale and the Chorhat Sandstone (Fig. 1), in a sedimentation continuum (Bose et al., 2001). The Koldaha Shale has a gradational contact with the underlying Porcellanite Formation and also conformably passes into the overlying Chorhat Sandstone (Bose et al., 2001; Banerjee and Jeevankumar, 2005). The interpreted palaeoenvironment of the Koldaha Shale is dominantly offshore (Banerjee, 2000) while the Chorhat Sandstone is seen as shallow marine, ranging in palaeogeography from subtidal to supratidal-erg margin through an intertidal setting (Sarkar et al., 2006). The Kheinjua Formation is dated as 1.63–1.60 Ga on the basis of U/Pb SHRIMP dating of zircon grains in the tuffaceous layers bounding the Formation immediately below and above (Rasmussen et al., 2002). A relatively younger age of 1205 ± 233.6 Ma has been assigned to the Koldaha Shale by the fission track (F-T) dating method (Srivastava and Rajagopalan, 1988). Detailed review of recent literature indicates that the age of the Koldaha Shale can be assigned as Mesoproterozoic (Sarkar et al., 1995, 1996, 2002a; Ray et al., 2002: Schieber et al., 2007 and references therein).

Excellent exposures of the Koldaha Shale occur in and around the Chorhat area, on either side of the Son River, upon which this study is, based (Fig. 1). A comprehensive palaeogeographic analysis including temporal variations has been carried out by Bose et al. (2001) in a study that also provided a general outline of sequence stratigraphic architecture of the Semri basin in central India. Despite these broad palaeoenvironmental interpretations (Bose et al., 2001), in-depth sedimentological analysis of the Vindhyan Supergroup has been initiated only lately. This paper utilizes the spectacular preservation of sedimentary structures and lithologies of both terrestrial and marine segments of the Mesoproterozoic Koldaha Shale Member to reconstruct the depositional mileu in detail, and to use the inferred palaeogeography and its temporal variations to provide a detailed sequence stratigraphic framework