Relationship between localization of shale bulges/toe thrusts and basement structures

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Summary

Toe thrusts and shale bulge structures dominate the Krishna-Godavari basin from Paleocene to Late Pliocene. There are two phases of deformation, the older giving space for the younger. These contractional structures develop above basement ridges or along steep slopes within the basement and at the boundary between continental and oceanic crust.

Introduction

Shale cored detachment folds/thrusts are of common occurrence in passive margin settings worldwide. The extent, localization and amplitude of these structures are a function of the basin sedimentation pattern and shelfal geometry (Rowan and Vendeville, 2004). Tertiary sedimentation on the offshore Krishna-Godavari basin has generated different episodes of shale-cored structures from Paleocene to Pliocene (Murty and Ramakrishna, 1980, Sastri et al., 1973, Kumar, 1983, Biswas and Chandra, 1992, Mohinuddin et al., 1993, Rao, 1993, 2001). A spatial relationship is observed between the location of these shale cored structures and the basement within the continental crust and at the ocean-continent boundary (Stuart and Hickman, 2001, Sinha et al., 2006).

Methodology

Figure 1: Location of the analyzed profiles in the Krishna-Godavari basin

Eight representative profiles have been chosen to understand the localization of the thrusts/shale bulge events and their likely relationship to basement highs and/or basement escarpments (Figure 1). The profiles are a constitution of depth converted 2D and 3D seismic data with key horizons interpreted and biostratigraphically constrained as far as possible. Some of the profiles have also been modeled using the structural modeling package, 2DMove, to understand the timing of movement and relationship between the extensional and contractional regions.

Observation on Profiles

The Krishna-Godavari basin showcases different geometries of shale cored structures from south to north.

Profile 1 - Down south in the Penner basin, the basin margin has a steep basement escarpment which develops likely post rift. The Cretaceous sedimentation was controlled by basement architecture and episodic reactivation events. A major onlapping surface is present at the end of Lower Miocene and a sedimentary wedge forms on the deepwater part of profile. The toe thrust complex broke off from Paleocene top and continues to move till present day, fueled by basin margin tilt and basement reactivation.

On this profile, thrust sheets are present within the Paleocene to Late Pliocene sediments over a detachment at the top Paleocene level. The tectonic activity continues to the present day in the southern part. These are probably slump related deformations, with some growth strata and indistinct faulting, piling up at the lower slope over a steep escarpment, controlled by basement scarp. Compaction related folding induces a change of gradient over the scarp, and helps in the localization of the bulge (Figure 2).
Figure 2: Section along profile 1 in the Penner basin; arrow indicate location of basement scarp. Note the present day activity of the thrust sheets

Profile 2 & 3 - Gentle basin margin faults and a prolific growth complex dominates the south Krishna Basin. Cretaceous sedimentation is present along half graben structures, controlled by the basement faults. The Miocene wedge, so characteristic in the Krishna-Godavari basin, is obliterated by the growth-thrust complex in this region. A broad neutral zone separates the contractional and extensional structures over the rotated listric half grabens in the basement.

Figure 3: Section along profile 2 in the south Krishna basin; arrow indicate location of basement scarp. The thrusts form an antiformal stack in this section; to the north they show imbricate structure

Imbricate thrust sheets are formed over a steep basement escarpment towards the basinal side, as a result of Oligocene growth faulting along a Paleocene detachment. The growth and consequent thrust activity stopped at Lower Miocene, marked by a truncation of the thrust crest (Figure 3). The localization of the thrust complex is initiated by a change of gradient over the fault scarp, probably due to added compaction on the basinward side. Slightly northward, the detachment falls to the Cretaceous level, and this first phase of deformation continued up to early Oligocene, marked by a truncation of the thrust crests. It is then succeeded by a reactivation of the same faults during Late Oligocene to Early Miocene, depositing growth strata of the same age in the space provided by the first, with the formation of a shale bulge over the thrust complex, along a probable Lower Oligocene décollement; both above the same basement escarpment (Sinha et al., 2006).

Profile 4 & 5 - The north Krishna basin shows similar characteristics to the southern part, and a continuation of the same features are observed.

Figure 4: Section along profile 4 in the north Krishna basin; arrow indicate location of basement scarp. The section shows both the Paleocene and Mio-Pliocene thrusts

Two sets of deformations are observed - the older growth faults on the landward side detaches along the top Cretaceous surface, forming thrust sheets within the Paleocene strata above a basement escarpment. The younger basinward growth faults detaches along the top Paleocene/Eocene surface, forming thrust sheets affecting the Mio-Pliocene surfaces. Further north in the same basin, the detachment probably climbs up to Lower Oligocene, and produce three prominent, concentric thrust sheets active from Mio-Pliocene to the present day, over a steep gradient in the basement (Figure 4). All the deformations commenced due to rapid change in slope over the basement escarpment.

Profile 6 - The southern Godavari basin represents a typical passive margin setting with gentle basin margin, listric growth faults in the shelfal part over Cretaceous half graben sediments, and shale bulges in the lower slope detaching along top Cretaceous.

Rapid sediment loading during Early-Middle Miocene along the growth faults results in the development of highly overpressured shale units. The fluid pressure within the shale layer reduces basinward, resulting in a normally pressured décollement, and consequent piling of the sediments in the region of maximum change in slope, at the slope break in the continental-oceanic crustal boundary. A shale bulge forms over a basement slope in response. Further sedimentation and delta progradation during Early
Pliocene results in a landward bulge along the same detachment over a basement high (Sinha et al., 2006). The overlying sediments bulged upward due to post-rift basement reactivation, producing a high mimicking that below, which acts as a buttress, restricting the basinward expansion of the sediment. It has been breached by minor thrust faults along local Early Miocene detachments during continued sediment loading in Late Pliocene, and is still active today (Figure 5).

Figure 5: Section along profile 6 in the south Godavari basin; arrow indicate location of basement high. Note the buttress action of the high at the proximal bulge and formation of the distal bulge over a basement scarp at the continent-ocean boundary

Profile 7 & 8 - Further north in the Godavari basin, the basement is dominated by horst-graben structures within larger half grabens. The shelf edge is still unstable and collapse is evident in the present seabed. Growth faulting is relatively minor, and prominent Miocene sediment wedge is present in the deeper part. A mid-basinal basement horst separates the basin into shallow and deeper parts.

Three shale bulges develop in the lower slope over the same Cretaceous detachment as a continuation of the distal bulge in the southern part. The shale bulges develop during Miocene and again during Pliocene as a result of reactivation of the landward growth faults. A pre-existing basement high increases the steepness of the detachment and helps in the development of the shale bulges at that position (Sinha et al., 2006); the initiation of the shale bulge is marked by a basement escarpment at the continent-ocean boundary (Figure 6). Further north, only the first shale bulge is present, and a clear continent-ocean boundary is observed at the escarpment, indicating reactivation of this rheological boundary (Figure 7).

Figure 6: Section along profile 7 in the north Godavari basin; arrow indicate location of basement escarpment. The escarpment is probably reactivated along the continent-ocean boundary

Figure 7: Section along profile 8, further north in the Godavari basin; arrow indicate location of basement escarpment. Note the presence of the first shale bulge only, and reactivation of the continent-ocean boundary

Discussions and Conclusions

In general, the Paleocene-Oligocene growth activity in the southern part of the Krishna-Godavari basin (upto KGVD3) gives space for Late Oligocene-Early Miocene activity, producing two phase deformation. In the northern part Early-Middle Miocene growth activity does the same to the Early Pliocene activity, and produce two distinct bulges in the south Godavari; in the north, however, only one of the shale bulges got promience due to spatial restriction of the Early-Middle Miocene Raava depocenters (Figure 8).

The above observations along profiles suggest a definite linkage between the shale bulges/thrusts and the basement architecture underlying them. These contractional structures seem to develop at positions of maximum gradient change along the basement, and their localization is possibly a combined result of overpressure distribution within the mobile shale unit above the décollement and the basement slopes. The shale bulges occur where there is some obstruction to downslope expansion, as in the case of basement ridges and highs in the Godavari basin, while the thrust sheets develop due to sudden change in gradient along fault scarps.
Figure 8: Synopsis of detachment levels and growth history along the Krishna-Godavari basin from south to north; note continuation of growth faulting and toe thrusts/shale bulges upto the present day

References


Sinha, N., Singh, R. J., Choudhuri, M., Guha, D., Dutta, A. and Sinha, S., 2006, Spatio-temporal variations and kinematics of shale mobility in the Krishna-Godavari basin, India, Poster presentation at AAPG Hedberg Conference, Port of Spain, Trinidad & Tobago, 5th-7th June, 2006


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