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The Deepwater Paleocene Godavari Dispersal System, Krishna – Godavari Basin, India

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Abstract

Deepwater dispersal systems are objects of intense study as they host major petroleum systems, discovered during the past decades world over. The Krishna – Godavari (KG) deep-water basin is under focus, in the past decade, due to discovery of major hydrocarbon reserves, in thermogenic and biogenic petroleum systems. Reservoirs in these petroleum systems are either syn-rift or are related to channel-splay complexes, along the continental slope and abyssal plain.

The present study, deals with a Paleocene basin floor channel–levee frontal splay complex over a length of nearly 300km in the distal part of the KG basin, nearly 250km away from the present day shelf edge. Oceanic crust underlies the study area and the volcanic 85°E Ridge flanks it towards the east and southeast. The channel – splay system is mapped with 2D and 3D seismic data sets. Depositional elements have been delineated with attribute analysis (mainly RMS Amplitude).

In the proximal part of the studied area, the multi-storied, low sinuosity channel is confined by levees. The width of the channel belt, in these parts, is <5km while the depth is up to 400ms twt. In the distal part, the levee height reduces, the channel bifurcates into distributaries and the degree of confinement by the levees reduces. Positive relief over the channel tops is observed in some tracts, indicating presence of coarse clastic fills as opposed to surrounding mud dominated deposits. In this part the channel width is >5km, and depth is around 200ms twt. In the distal most part the channel splays into several distributaries, with frontal lobes, cut across by later unconfined channels. Sinuosity is lost in these parts and the terminal distributaries are relatively straight.

Implications of such a major channel–splay system prograding into the distal parts of the basin are several. During Paleocene proximal part of the basin is dominated by muddy deposits, while this system seems to have the capacity to transport reservoir prone coarse clastics into distal areas. The presence of distinct levees indicates that sediments were initially rich in mud fractions, which deposit outside the channel along its course. The mud rich fraction depositing out of suspension could concentrate source material, if present, while the coarser channel fills and splays would be high quality reservoirs.

Introduction

Deep water dispersal systems originating from major rivers have been a topic of research in the past quarter century (1, 2, 3 & 4).The Krishna Godavari basin, located along the passive Eastern Continental Margin of the Indian plate is fed by the sediments from Krishna and Godavari rivers and their distributaries. The depositional environment of this basin varies from continental to deep water abyssal, passing through the shelf slope complex (5). In the last decade, due to discovery of major hydrocarbon reserves in offshore deep waters, the basin emerged as major petroleum province. The basin has yielded significant biogenic and thermogenic hydrocarbon reserves in Neogene deepwater channel- levee complexes and in Mesozoic syn-rift to early post-rift systems, respectively. Though presence of reservoirs in the intervening Late Cretaceous to Paleogene passive margin sediments is known, no major reserves have been discovered.

The study area is located 150-250 km southeast of the Godavari Delta (Fig. 1), in the proximal to distal parts of the KG basin abyssal plain. The passive continental shelf-slope complex is present to the west and northwest of the area, while the volcanic 85° E Ridge borders it to the east and southeast. The study area is underlain by oceanic crust and volcanics related to the eruption of the 85° E Ridge. More than 4km thick sedimentary column deposited over the area which ranges in age from the Early Cretaceous to

Recent times. These sediments are sourced from the K-G dispersal system in the Cretaceous and major part of Paleogene. During Late Paleogene to Recent times sediments are sourced mainly from the rapidly prograding Bengal Fan, while contribution from the K-G dispersal system is confined to the western parts due to the rapid aggradation of the Bengal Fan. The present study deals with a major Paleocene dispersal system and its significance for exploration.

Data and Methodology

The area covered with several vintages of 2D seismic and three volumes of 3D seismic data in the time domain, which have been interpreted. The interpreted data includes around 17,000 lkm 2D data and 5,500 sq km 3D data. While the 2D data revealed the regional course of the Paleocene dispersal system, the 3D data helped in imaging of the depositional elements of the system, through attribute analysis. The thickness of the Paleocene succession in the area varies between 200 to 400ms twt. Ages of major seismic events were calibrated from wells drilled near the study area. Nine horizons, at significant stratigraphic levels, from Basement to Sea Bed have been interpreted regionally based on the 3D and 2D seismic data.

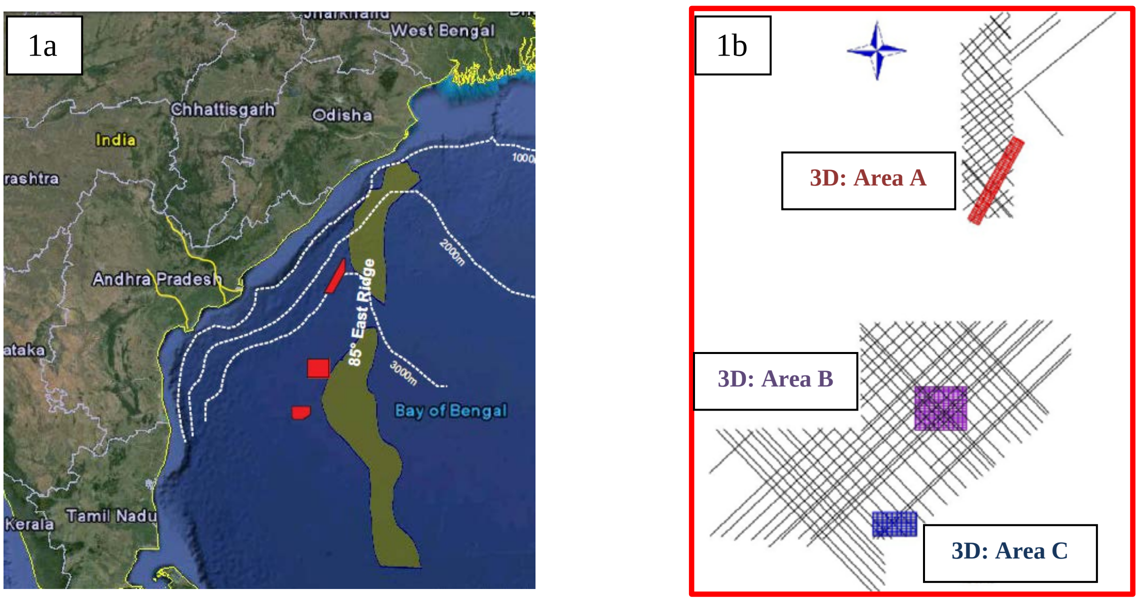

Figure 1: Location map of the study area: a) Major physiographic elements, 3D seismic data in red b) 2D and 3D seismic data studied.

Data Analysis and Results

The oldest continuous reflection correlated corresponds to the top of volcanics belonging either to the 85°E eruptions, or to the basalts of the Oceanic Crust (6). The next high amplitude refection events occur near the Cretaceous top. The intervening interval between these shows a chaotic low amplitude discontinuous response interpreted to be mainly as mudflow deposits. The overlying interval is defined by two relatively high amplitude continuous events, interpreted to correspond with the Paleocene and Eocene tops. Erosional cuts and oblique or sigmoidal seismic events are seen between the Cretaceous and Paleocene tops, in discrete areas, suggesting deposition by non-cohesive turbidity driven inputs form a channelized dispersal system, while in other areas the reflection pattern is mainly low amplitude sub-parallel relatively continuous events suggesting pelagic or suspension fallout depositional mechanism. The overall thickness of the sediments from the Paleocene top to the Eocene top interval is relatively low, indicating relatively starved conditions and low sediment supply to the basin during these times. The Paleocene dispersal system shows multistoried character with deep cuts and well developed levees in the headward part to the north (3D Area A, Fig. 2), while towards the south the channels are broader and of low relief (3D Area B). In the southern most area (3D Area C) only solitary low relief channels confined to single seismic events are present. Channel sinuosity is interpreted in the northern areas due to asymmetrical flanks and variable development of levees on the flanks, though in the portion imaged in the Area A, a relatively straight trajectory is seen.

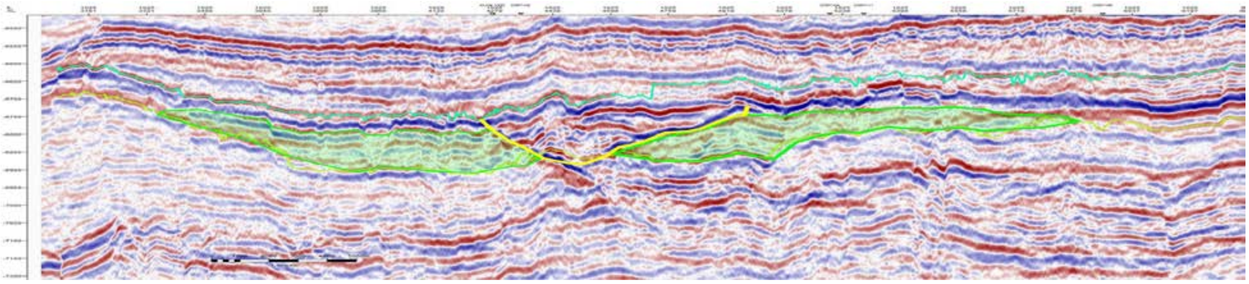

Figure 2: NW-SE line, 3D Area A, showing Paleocene multistoried channel with well-developed levees. Positive compactional relief within channel, indicating presence of coarser clastics.

Seismic Attribute Analysis

Variations in the dimensions and characters of the dispersal system are traced from the northern extremities to the southern limit. In the northern parts, the system is in the form of a confined channel belt with multistoried aggradation, up to 400ms twt thick. This gradually gives way to broader channels with lower thickness and probably decreasing sinuosity. Finally the channels straighten out and deposit splays. The imaged variations in depositional elements are discussed in detail in this section.

Area A: This 3D volume is situated in the relatively proximal area of the dispersal system A wide channel belt is present flowing towards the SSE (Fig. 3 a&b). The channel belt is apparently straight, in the imaged portion, but shows asymmetric flanks (Fig. 2), indicating that it may be a part of a meande belt. Confinement of the channel is achieved due to levee aggradation on either side. The channel belt is more than 8 km wide with member channels varying from 0.5 – 2.5 km in width. RMS slice near the top of the channel (Fig. 3a) reveals that the channel strings towards the west are more active than those towards east at this level. Individual channels and their associated levees, within the belt are imaged with an amplitude extraction slice 40ms from the top of the belt. The channel belt in this sector is approaching the N-S 85° E Ridge, just to the east of the 3D volume, wherein it takes a turn towards south, thereafter flowing parallel to the Ridge.

Though, there is a data gap in the sector between the Area A and the 2D data set to the south, the channels are picked up in the 2D lines and 3D volumes in the southern sector (Figure 4 a, b & c). Progressive decrease in the channel heights with accompanying increase in the channel width to height ratio is observed from NE towards SW. The channel belt which is confined (Fig. 4a), becomes unconfined, further to the SW (Fig. 4b) and finally deposits a frontal splay.

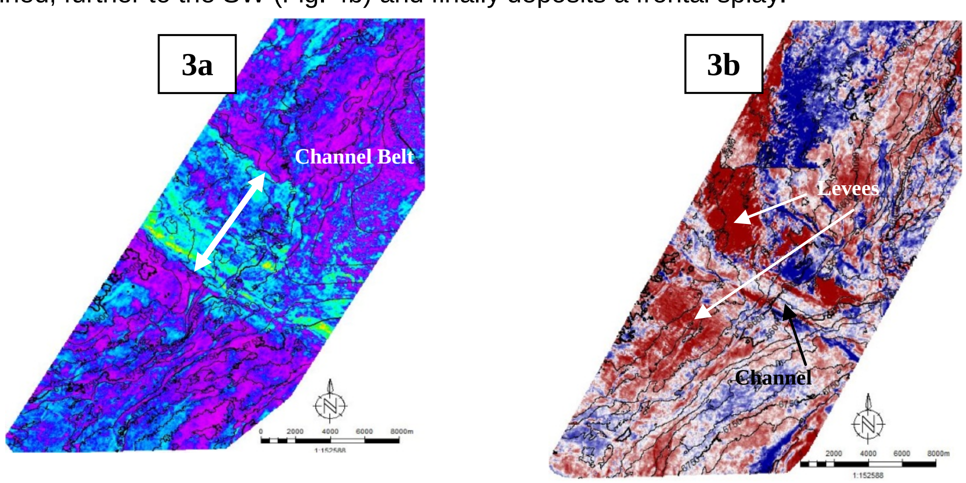

Figure 3: a) RMS amplitude at Paleocene Top (window: +20ms to -20ms). 3b) Amplitude extracted in a 10ms window, 40ms below Paleocene Top.

Area B: RMS Amplitude slice were generated with a 20ms window from 100ms below to 40ms above the top of the Paleocene event (Figs. 5a to d). The deepest slice, 100ms to 80ms below the Paleocene top (Fig. 5a) shows feeble channels flowing towards south, cutting across lobate bright amplitude areas which are interpreted to be frontal lobes. The channels are relatively straight and due to low amplitudes they are interpreted to be mostly clay filled. Some channels show weak development of higher amplitudes (white to red colors), indicating presence of some proportion of coarser clastics. The lobes however show higher amplitudes and are likely to contain coarse clastics. RMS Amplitude slices from 60ms to 40ms below Paleocene top (Fig. 5b) shows relatively wider and straight channel and brighter lobes as compared to the underlying slice. The channels branch and flow towards south and southeast. The channels also cut across the earlier frontal lobes. This is interpreted to indicate progradation of the system over the area with increasing sediment loads.

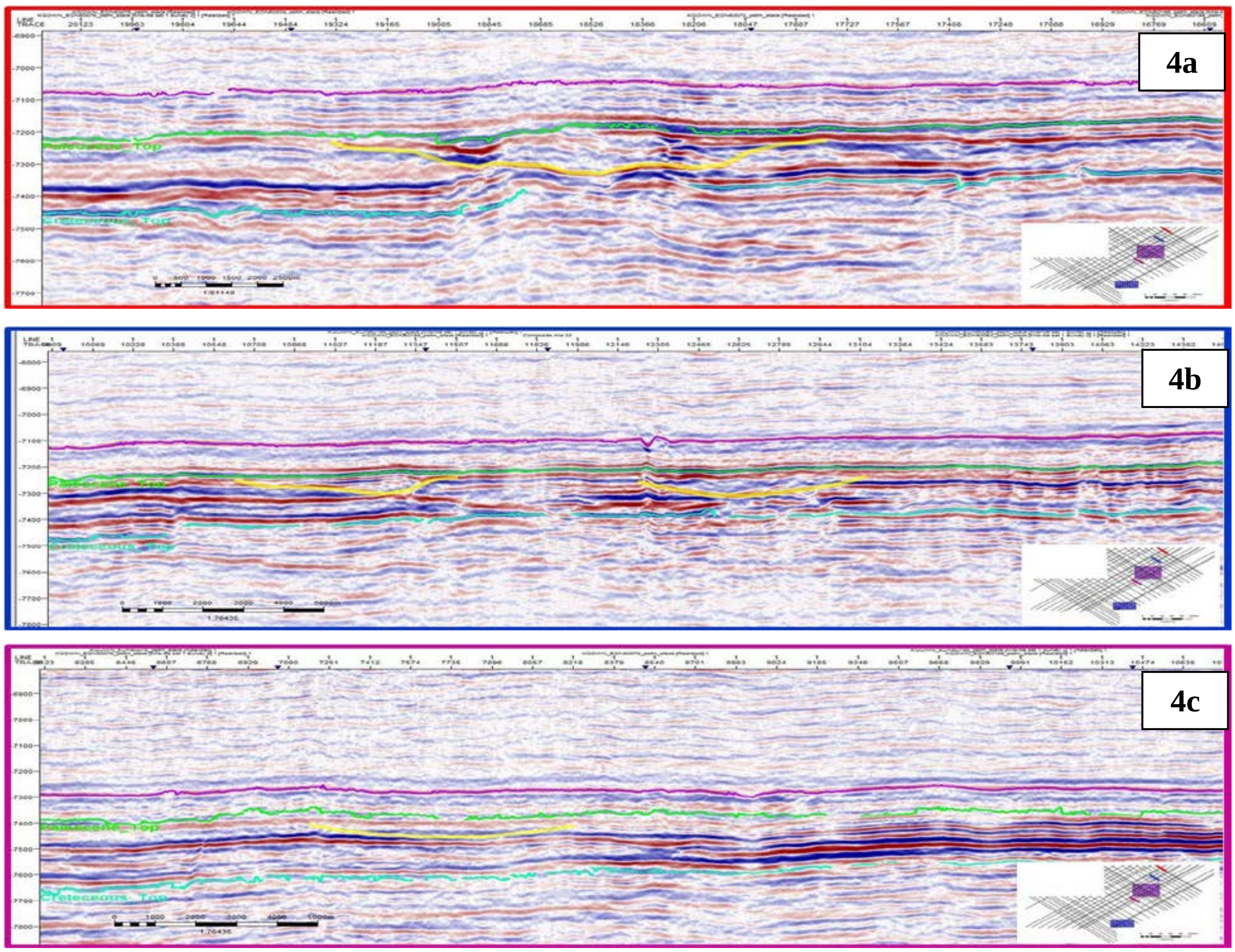

Figure 4 a-c: 2D seismic lines (NW-SE), from northeast to south west, showing progressive confinement reduction and increasing width to height ratio in channel belt.

Further up in the sequence slice at 40ms to 20ms below Paleocene top (Fig. 5c) shows further progradation of the channels. The channel density in the area increases with the channels forming distributaries and fanning to south and south east from in-between the earlier deposited frontal lobes in the northern part. The channels are interpreted to be mostly passively filled by clays, the major sediment load bypassing this sector and deposition further downstream. The shallowest slice illustrated, is between 20ms to 40ms above the Paleocene top (Fig. 5d). Only a few remnant channels are observed flowing across a monotonous low amplitude area. This is interpreted to represent retrogradation of the dispersal system and abandonment of the channels and dominantly pelagic deposition.

The channel flow towards south seems to be controlled by the physio-geographic relief of the 85°E ridge, which extends in the NE-SW direction in the southeastern corner of the study area. The deposition of the frontal lobes and the channel directions suggest the higher relief area to the SE, underlain by the 85° E Ridge seems to be the cause for the incoming flow to lose its energy and deposit the sediment load.

Area C: The southernmost progradation of the dispersal system is recorded here. Only a solitary relatively straight channel is seen flowing towards SW, parallel to the NE-SW extending 85° E Ridge (Fig. 6). In seismic sections this channel is discernable only as an anomalous bright amplitude feature, within a single seismic event. The remaining part of the area is free of any other discernable depositional elements. Other bright amplitude areas seen in the slice are related mainly to faults and some fluid escape structures (not illustrated and discussed in the present communication).

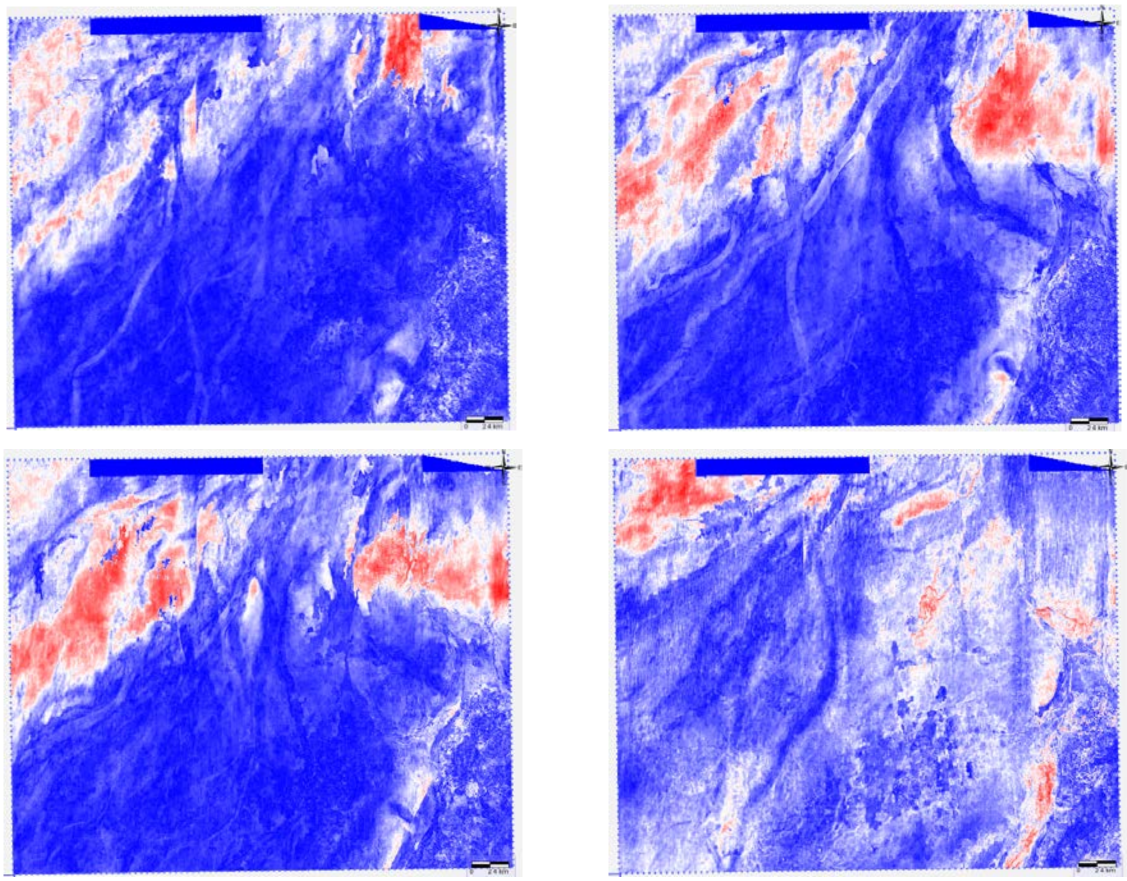

Figure 5: RMS Amplitude horizon slices a) 100ms to 80ms below Paleocene Top. 5b) 60ms to 40ms below Paleocene Top. 5c) 40ms to 20ms below Paleocene Top. 5d) 20ms above Paleocene Top to 40ms above it.

Discussion

The Mahanadi, Godavari, Krishna and Cauvery are the four major rivers which have been flowing into the nascent Indian Ocean, from the time of the break-up of Gondwanaland. The deepwater dispersal systems associated with these rivers have been studied in detail in the recent years due to increasing pace of exploration along the Eastern Continental Margin of India. Present data indicates that these deepwater dispersal systems form fan complexes extending for up to tens of km beyond the base of the continental slope in the early stages of evolution of the passive margin (1). The sediments derived from these systems are mostly mud dominated, with limited sand supply, with the exception of the Krishna system which is known to be relatively rich in coarser clastics.

The mapped Paleocene dispersal system can be traced for a distance of more than 300km along its presently mapped length. Though we have not been able to map its headward source, we deduce that the system originates from the Godavari as it is the only known major river system in the conjugate continental part. The system is believed to be rich in coarse clastics as deduced by the observed positive compactional relief in several areas along its course. A system, which is able to carry sediments for such long distances can definitely carry continent derived organic matter along with the clastic sediments. These are expected to be concentrated in the overbank areas of the system and can constitute an important source for hydrocarbons. This is especially significant as the distal areas of the KG Basin, underlain by oceanic crust have been observed to be lean in their overall organic carbon content and hence deemed to have a poor source potential. Demonstration of the possibility of having hydrocarbon prone source matter into these areas will definitely help in bringing focus to exploration.

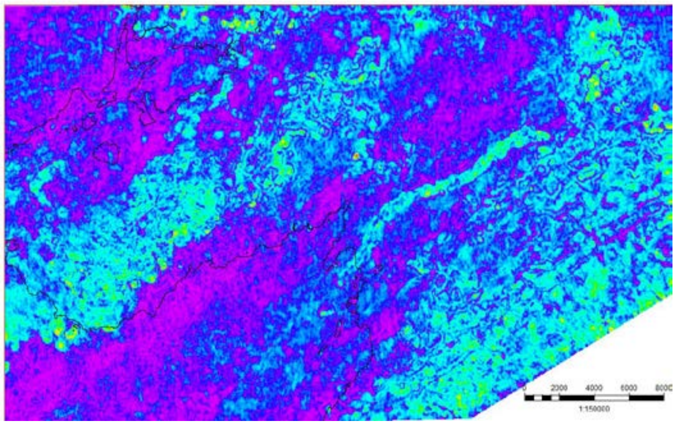

Figure 6: RMS Amplitude slice of 40ms below Paleocene Top.

Conclusions

Ancient deep water depositional systems extending for long distances beyond base of slope are rare. The present record of a Paleocene dispersal system in the KG Basin extending for a distance of over 300km is a unique example. A dispersal system capable of transporting and concentrating source prone organic matter onto distal abyssal areas underlain by oceanic crust is significant. Maturity of such source rocks, deposited in conjunction with reservoirs is possible in this part of the basin, due to the thick (>4 km) overburden available, in spite of fast decaying low heat flows over ancient oceanic crusts. Such source reservoir couplets can constitute a petroleum system that needs attention.

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