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Paleogene low stand deepwater canyon fill deposits in Mahanadi Offshore Basin: can it prove to be the elusive major hydrocarbon discovery?

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Summary

Mahanadi Deepwater Offshore Basin has been the focus of active exploration under the aegis of large number of multinational companies for more than a decade now. Extensive 3D seismic coverage in many exploration blocks in the basin along with several deepwater drilled wells information so far have helped to unravel the subsurface tectonics, structure and stratigraphy of the basin to a great detail. The major deepwater depositional elements in the basin consist of channel-levee complexes, crevasse splays, meandering cut-off bars, slope and basin floor fans, mass transport complexes, shelfal carbonate platform, reefal carbonate growth, prograding carbonate complexes etc out of which some of the Mio-Plio channel levee complexes have already proved to be gas bearing, charged mainly by biogenic gas. Recently, evidence of thermogenic gas has also been established in Paleogene sandstone reservoirs of one of the exploration block indicating the probable presence of thermally rich source rocks either in the Mesozoic rift related sediments or in Early Tertiary deepwater shales.

While many of the pervasively occurring channel levee complexes apart from most of the above depositional systems in the entire Tertiary section of Mahanadi deepwater offshore basin still remain to be tested, the recent Paleogene discovery in the basin opens up the possibility of an interesting hydrocarbon play consisting of low stand deepwater canyon fill deposits that promises to be a very attractive target from focused exploration efforts. The present paper analyses the evolutionary processes that have helped generate such prospective deepwater reservoir facies from close scrutiny of a high resolution Q-marine 3D seismic dataset in conjunction with drilled well information of the first discovery well of thermogenic gaseous hydrocarbon from the Mahanadi basin.

Introduction

Mahanadi Basin, located in the northeastern part of eastern passive continental margin of India, falls in between Bengal basin to the northeast and Krishna Godavari basin to the southwest (Fig. 1). The present study area falls in one of the deepwater blocks of the basin, close to the present day shelf.

The bathymetry ranges from few tens of metres to about 1200m. General geology & hydrocarbon prospects of Mahanadi basin is comprehensively dealt by Fuloria (1993). There have been several biogenic gas discoveries in thin channel sand reservoirs within the Mio-Plio sediments, one example of which from the study area is presented in (Fig. 2a) and many more such channels in the entire basin

have not been tested yet (two examples from elsewhere in the basin shown in Fig. 2b & 2c).

However, recent success in one deepwater well where thermogenic gas has been discovered in the Paleogene sands have highlighted the possible presence of high organic rich source sediments contained within the Mesozoic rift sediments or Late Cretaceous-Paleocene pro delta shales and deepwater marine shales. This paper presents a detailed study based on a high-resolution Q-marine 3D seismic data set in conjunction with well data, of how large canyon cuts during major low stand could have played a vital role in this particular petroleum system. The results of the study could also open up a vast area that is believed to have promising but untested hydrocarbon potential.



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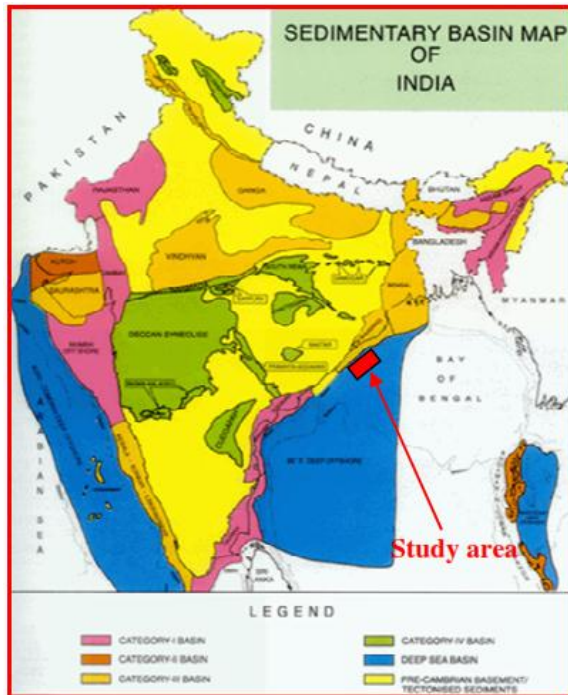
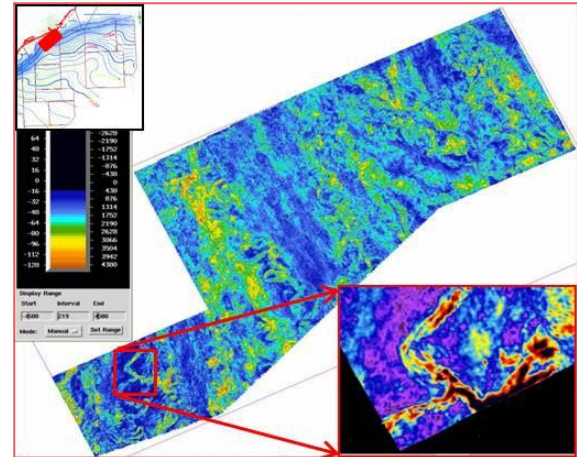


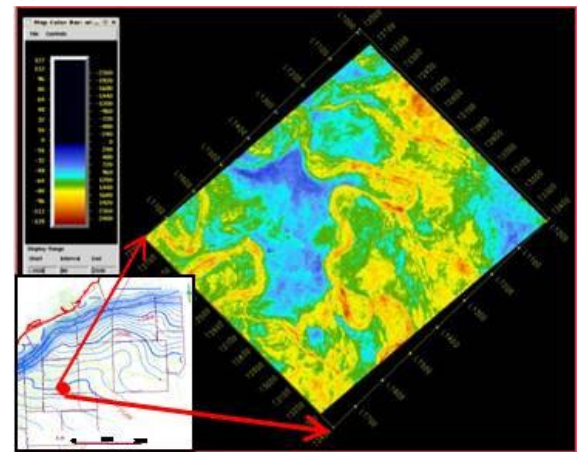
Fig. 1 Location details of the study area.

Regional setting

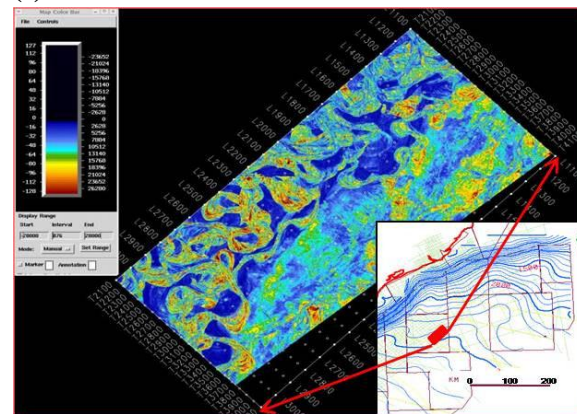
On Precambrian basement, Late Jurassic to Early Cretaceous rift sediments have been deposited in tilted half grabens (Fig. 3) followed by Early Cretaceous basaltic flow, contemporaneous with Rajmahal and Sylhet tyraps. The overlying Cretaceous sequence consisting of clastic sediments is unconformably overlain by Paleocene-Eocene sediments which are characterised by dominantly carbonates inter bedded with clastics related to a major transgressive and minor regressive cycles. A major regressive cycle is present at the onset of Late Eocene and continued till end of Oligocene causing absence of Late Eocene-Oligocene sediments in a vast area including the shelf and part of upper slope. In the deeper part of the basin Oligocene may be present. Mid Eocene is unconformably overlain by Mio-Pliocene clastic sediments. Channel-levee complexes in Mio-Plio sediments are observed pervasively throughout the basin (Fig. 2). Pliocene onward till recent, Mahanadi basin experienced higher sedimentation rate than the rate of fall of base level which resulted in prograding complexes. The generalized stratigraphy of the area is summarized in Table-I.



(a)



(b)



(c)

Fig. 2 Channel-levee complexes occurring pervasively in Mio-Plio sediments of entire Mahanadi Offshore basin; (a) Proved to be biogenic gas bearing in the study area, (b & c) CLC in ultra deepwater area elsewhere in the basin but untested so far. All based on amplitude attribute maps.



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Table-I

STATIGRAPHY OF MAHANADI OFFSHORE BASIN

TIME	EVENTS	LITHOLOGY
Pleistocene to Recent	9. Progradation of clastic sediments with no subsidence.	Slope channels and canyons
Mio-Pliocene	8. Subsidence and progradation of clastic sediments	Slope channels, canyons and basin floor fans
Oligocene	7. Period of non-deposition or erosion	Absent on the shelf. Present in the deep basin.
Eocene	6. Developed shelf-slope break with further tilt towards east. 5. Collision of Indian plate with Asian plate.	Transgressive clastic starved sequence.
Paleocene	4. Drifting continued with basinal tilt and shelf-slope development.	Deltaic sedimentation through protoMahanadi
Late Cretaceous	3. Drifting continued with basinal tilt towards E with initiation of shelf-slope.	Sand in the upper and shale in lower part
Early Cretaceous-Late Jurassic	2. Rajmahal trap volcanism. 1. Rifting followed by drifting.	Rift fill sequence followed by volcanics
PreCambrian	Pre-rifting	Basement

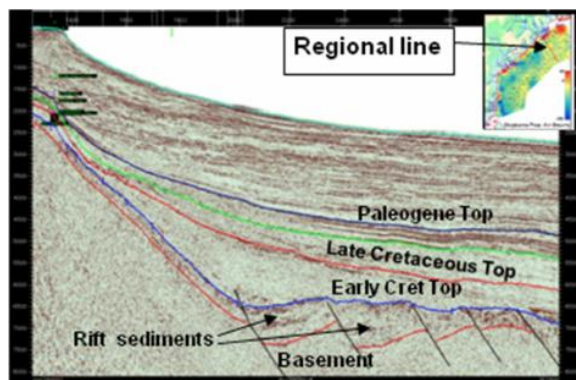


Fig. 3 Regional 2D seismic line showing passive margin rift fill sequence

Early Cretaceous carbonaceous shales and coals deposited in a paralic to possibly lacustrine environment probably represent the best candidate source facies in the Cretaceous. The absence of late Cretaceous in the onshore part as observed in some drilled wells suggests lowering of sea level thereby brightening the chance of presence of fans in the deep offshore. Shelf-slope break started developing by Late Cretaceous.

The first soft collision took place in Early Paleocene as continental India collided with the Eurasia Continental margin. Rifting had ceased and northward drifting was

initiated. Eastward flowing rivers along the East Coast of India deposited Paleocene sediments that filled Late Cretaceous topography. Marine transgression continued through Paleocene. However occurrence of Paleocene sediments in only two wells drilled on shore one on Konark Uplift located relatively basin ward and the other in Chandbali Depression, seaward part of the Cuttack-Chandbali Depression, suggests that the sequence is represented by shales, sandstones and thin limestones deposited in the shallow marine environment. In the offshore part however, it is represented by a dominant argillaceous limestone, shales, siltstone and sandstone deposited under deltaic to shallow marine conditions.

Based on the well data, it can be surmised that there was polarised sedimentation with a paucity of clastic supply into some part of area and more clastic supply to other part of area resulting in the deposition of limestone in the present day shallow offshore or shelfal part and mixed calciclastic with siliciclastic in cut and fill features present in deeper part. During Late Paleocene, Mahanadi shelf experienced deltaic sedimentation through proto-Mahanadi flowing through Eastern Ghat and Central Indian Cratons producing deltaic to pro-deltaic clastics, interbedded with shelf carbonates.

Early-Middle Eocene experienced further basin ward tilt followed by gradual transgression and high stand of sea level. During a part of Eocene period, Mahanadi shelf became clastic starved hence mainly limestone with interbedded clastics were deposited. This sequence is marked by pronounced shelf-slope break grading into basinal shales/clay. Oligocene is found to be absent in the shelf part as evident from the drilled data and probably indicating period of non-deposition or erosion throughout the shelf part of the basin.

Seismic expression of the low stand canyon-fill deposit

The high quality 3D Q-marine seismic data (size: 853 sq.km) has been investigated in close details after tying to the deeper pay encountered at the recent well. Fig. 4 shows the seismic Inline (A: uninterpreted; B: interpreted) and Fig. 5 shows the seismic Crossline (A: uninterpreted; B: interpreted) passing through the well which encountered the deeper Paleogene pay. The Paleogene pay is



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encompassed within the seismic sequence bounded by two surfaces corresponding to the canyon top and bottom. The close up view of the seismic to well tie is presented in Fig. 6A & 6B. The velocity from VSP data has been utilised to tie seismic to log data at the well.

The large no. of canyon cuts is believed to have been formed during Mid to Late Eocene major relative base level fall. The new hydrocarbon play envisaged in the study area basically involves low stand canyon fill deposits within the Paleogene section. Instantaneous amplitudes extracted for the zone encompassed between the above two surfaces, canyon top and canyon bottom, is presented in Fig. 7. A three dimensional perspective diagram of the amplitude attribute generated for the interval between the Canyon Top surface and one proportional slice between the Canyon top and Canyon Bottom surfaces and is presented in Fig. 8.

The large canyons that have cut into the Paleogene outer shelf and slope have down the slope created huge valleys like features. These valleys seem to have been filled up by later low stand deposits. The amplitude attribute maps suggest fan like morphology of these canyon fill deposits down slope in the deeper part of the basin. Possible play is developed within these Palaeogene low stand canyon fill deposits which are likely to contain good reservoir facies in carbonate debris eroded from outer shelf and upper slope areas mixed with siliciclastics. Following this period of low stand, highstand deepwater facies are observed onlapping on to the major erosional unconformity surface. These highstand healing phase deposits are expected to be fine grained clastics, mainly shales and hemipelagic clay, which could act as effective seal facies.

Hydrocarbons generated either within the rift fill source rich sediments almost vertically beneath the southern edge of the study area or within early marine source rich facies can be expected to charge these reservoirs.

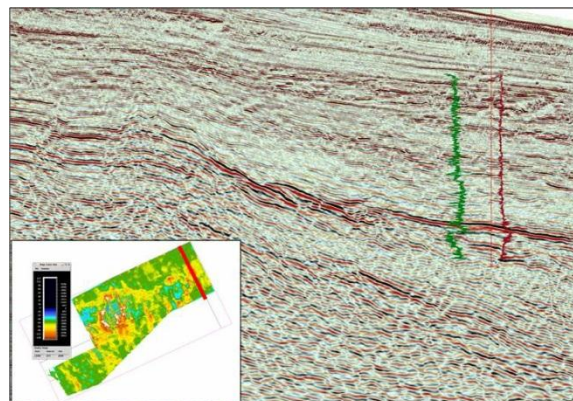


Fig. 4A Uninterpreted seismic Inline passing through the well.

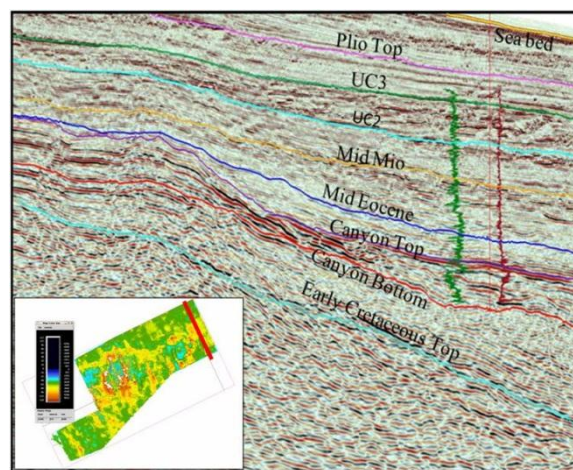


Fig. 4B Interpreted seismic Inline passing through the well.

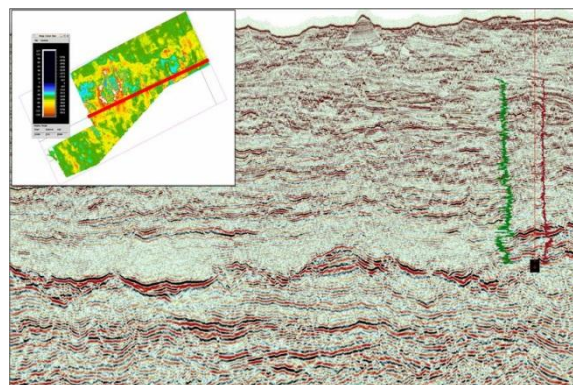


Fig. 5A Uninterpreted seismic Crossline passing through the well.

Figs. 10A to 10E are presented to show sequentially the down slope evolution of the canyon cuts that form the basis of the processes that finally lead to the above described canyon-fill deposits. These canyons are



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believed to have been formed during the Mid – Late Eocene relative base level fall causing wide spread erosional cuts into the carbonate outer shelf and upper slope areas.

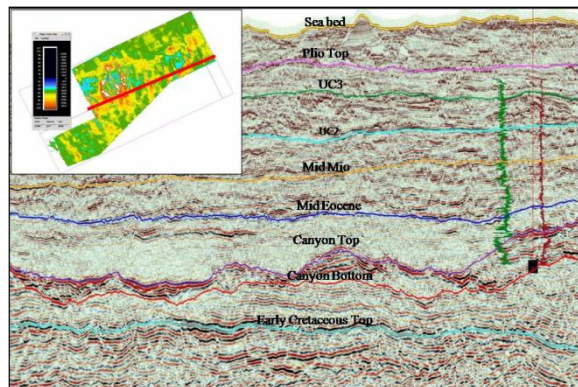


Fig. 5B Interpreted Seismic Crossline passing through the well.

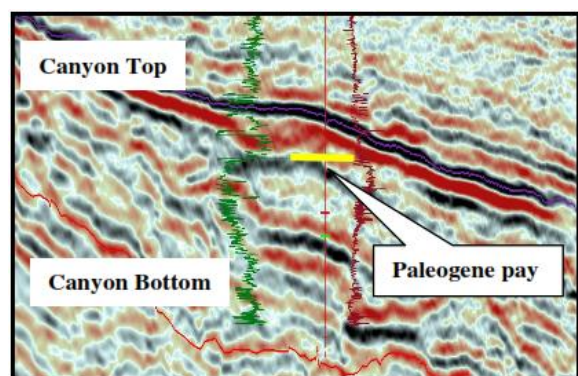


Fig. 6A Part of the 3D seismic Inline showing the seismic to well tie at the Paleogene pay level.

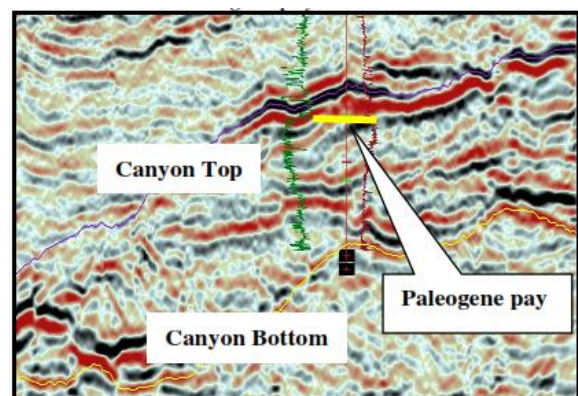


Fig. 6B Part of the 3D seismic Crossline showing the seismic to well tie at the Paleogene pay level.

The seismo-stratigraphic model as envisaged in the area is presented in Fig. 9. The hydrocarbon play discussed in details in the above paragraphs corresponds to the Late Eocene canyon fills as shown in the Fig. 9. Considering the fact that the well XYZ has proved to be gas bearing at the Palaeogene level and the new approach to explain this hydrocarbon find suggests that there remains a huge potential still untested in those low stand valley-fill reservoirs. All the elements of petroleum system including source, reservoir and seal seem to be favourable for this new untested hydrocarbon play.

Although there seems to be clear indication of more than one major episode of base level fall, exposure of shelf, incision, canyon cuts, incised valley formation, no well has been drilled yet to probe the fan shaped canyon fill deposits down slope where they have been found. The discovery well XYZ is at the eastern end of the study area (Fig. 7) where very thin sands of the order of 2-3m have been proved to be gas bearing. The thin pay sands are believed to be within this low stand canyon fill complex (built over more than one episode of base level fall) and migrated hydrocarbons generated from thermally mature source rocks further down below.

However, the large canyon cuts filled with low stand deposits are expected to be better developed in the central and west central part of the study area. Fig. 10A and 10B are presented to depict the typical seismic expression of the canyon fill deposits where they are best developed. Velocity modeling based on VSP data and other drilled information of five wells within the study area have brought out velocity inversion effect at the well XYZ and the same effect is also observed at the place where the low stand canyon fill deposits are expected to be best developed.



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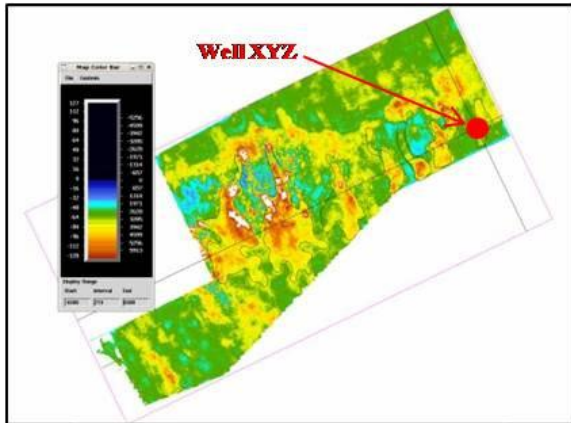


Fig. 7 Instantaneous Amp extracted within the zone bounded by Canyon Top and Canyon Bottom.

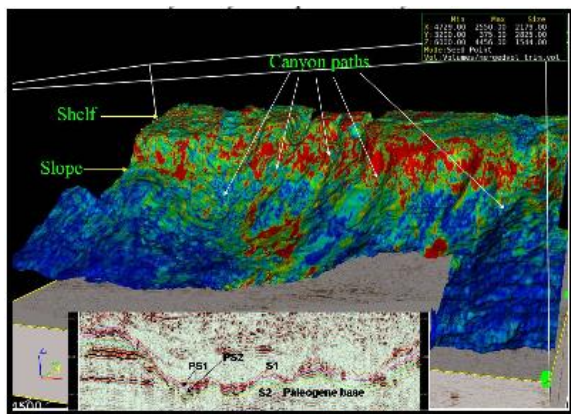


Fig. 8 AAA map extracted within Canyon Top and proportional slice PS1 below

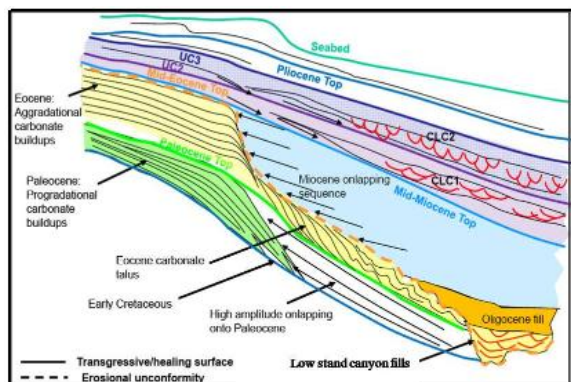


Fig. 9 Seismo stratigraphic model showing the various depositional elements as observed in the study area.

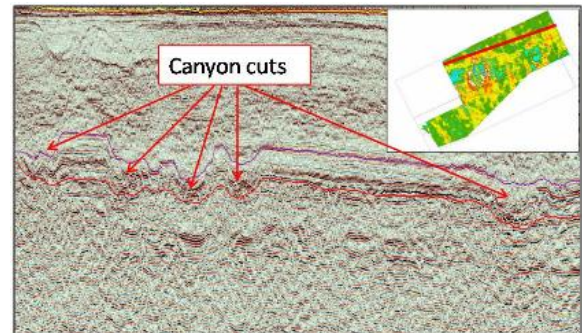


Fig. 10A RC line showing five large canyon cuts formed during Mid – Late Eocene erosional unconformity, eroding and cutting deep into the shelf.

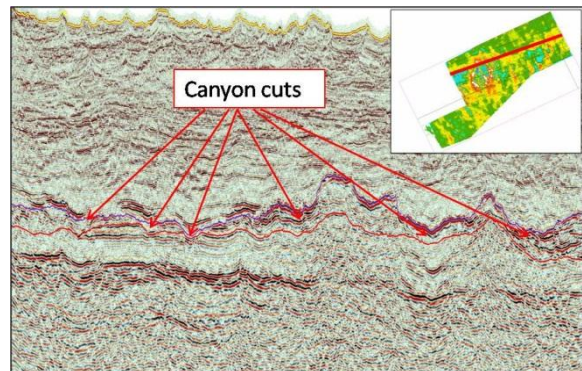


Fig. 10B RC line showing down slope evolution of the canyons of 7A and some new ones developed.

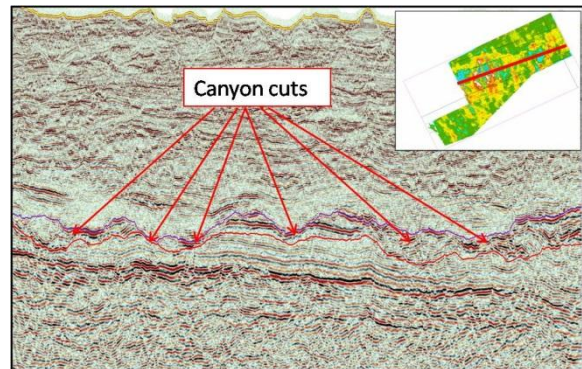


Fig. 10C RC line showing down slope evolution of the Canyons showing change in aspect ratio.



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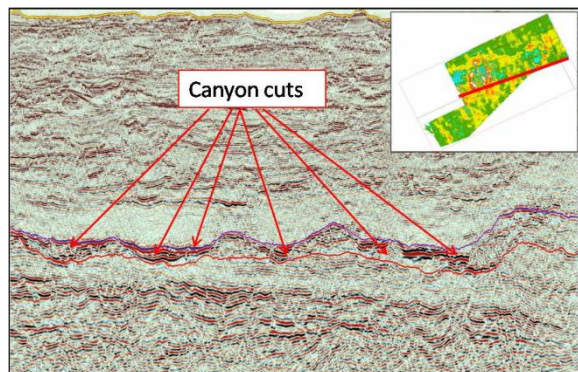


Fig. 10D RC line showing the Canyons further down slope with further change in aspect ratio.

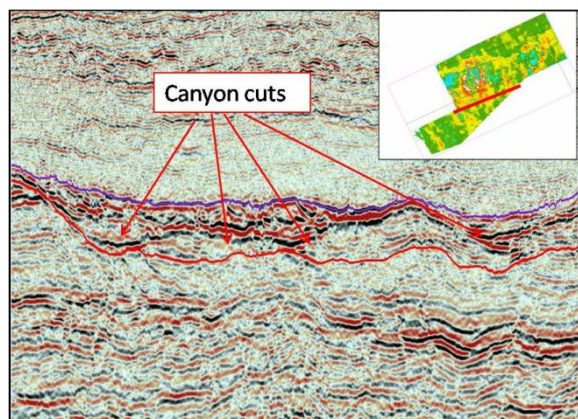


Fig. 10E RC line showing down slope evolution of three main canyons that show coalescing effect and further change in aspect ratio

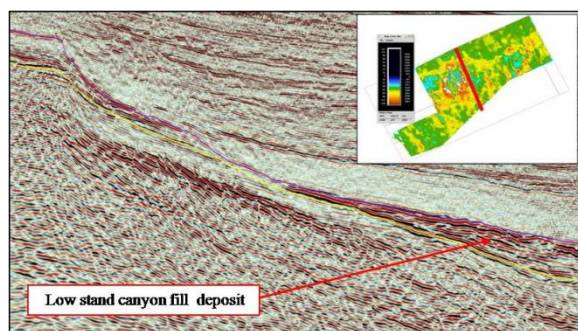


Fig. 11A Seismic Inline passing through the low stand canyon-fill deposit where it is best developed.

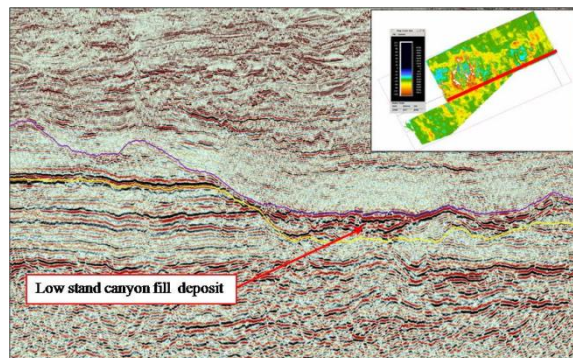


Fig. 11B Seismic Crossline passing through the low stand canyon-fill deposit where it is best developed.

Conclusions

- Even though Mahanadi Deepwater Offshore Basin has been under active exploration for more than a decade without a major discovery so far, barring few biogenic gas discoveries, the recent Paleogene discovery of thermogenic hydrocarbons from a drilled well raises the hope of a major future discovery.
- The Mahanadi Deepwater Offshore basin exhibits large number of deepwater depositional elements which can act as good reservoirs but many of such reservoir elements that can be part of the active petroleum system have not been probed yet.
- The high-resolution 3D seismic data have brought to the fore one such interesting hydrocarbon play consisting of low stand canyon fill deposits taking a lead from the recent hydrocarbon discovery in the Paleogene sands of at drilled one well.

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References

Fuloria, R.C., 1993, Geology and Hydrocarbon Prospects of Mahanadi Basin, *In: Proceedings of Second Seminar on Petroliferous Basins of India (Eds: Biswas et. al)*, vol. I, p 355-355.

Unpublished well completion reports of ONGC Ltd of Mahanadi and KG Deepwater offshore basins.

Assessment study for the discovery fields of the blocks MN-OSN-2000/2 and MN-DWN-98/3 in Mahanadi Basin, India, Unpublished ONGC report, 2010.

Weimer, Paul, and Slatt Roger M., 2007, *An introduction to Petroleum Geology of Deepwater Settings*, AAPG Studies in Geology.