Sequence Stratigraphic Approach for Identification of Hydrocarbon Plays in Mahanadi Offshore Basin

Pinakadhar Mohapatra
Exploration and Development Directorate, ONGC, Dehradun.
E-mail: p_mahapatra@ongc.co.in

Summary

Mahanadi basin is the least understood of the East coast basins of India, in terms of its stratigraphic setting and hydrocarbon plays. Though the wells drilled in the basin have indicated hydrocarbon shows during drilling, the basin still lacks a systematic understanding of its petroleum potential.

The present study has focussed on understanding the sequence stratigrphic framework of Mahandi offshore basin along with the identification of system tracts for visualising various hydrocarbon plays.

This analysis has brought out several new plays viz. Oligocene low stand deposits, Middle Miocene basin-floor fans & force regressive packages and Upper Miocene - lower Pliocene shingled turbidites & channel-levee complexes, which promise high potential for further exploration in the basin.

Introduction

Mahanadi basin located in the eastern coast of India extends from Jagannathpur in the north to Chilka Lake in the south, in the state of Orissa, further extending to the offshore in the Bay of Bengal (fig.1).

The aerial extent of the basin is about 2,60,000 Sq.km including deep waters. Tectonically, the basin extends from Damra-Wheeler lineament in the north to 85º E ridge in the south (fig.2). In the west, the basin continues with Hasdo-Mahanadi Gondwana graben.

Exploration for hydrocarbons in this basin has been undertaken in several phases, starting from 1965. The recent initiatives by Govt. of India, through offer of blocks in NELP rounds, have led to a spurt in exploration activity in the basin. Large volumes of geoscientific data have been acquired recently which have provided significant insight into the hydrocarbon plays of the basin.

Exploratory wells drilled so far in the offshore part of Mahanadi basin primarily targeted the Eocene carbonates, which did not yield success. However, based on the recently acquired data, it is believed that the basin has good potential for discovering hydrocarbons in the Oligo-Miocene and Pliocene sequences, primarily in the stratigraphic traps. For this the understanding of the plays in the sequence stratigraphic framework has been immensely useful.

Fig.1 : Location of Mahanadi Basin

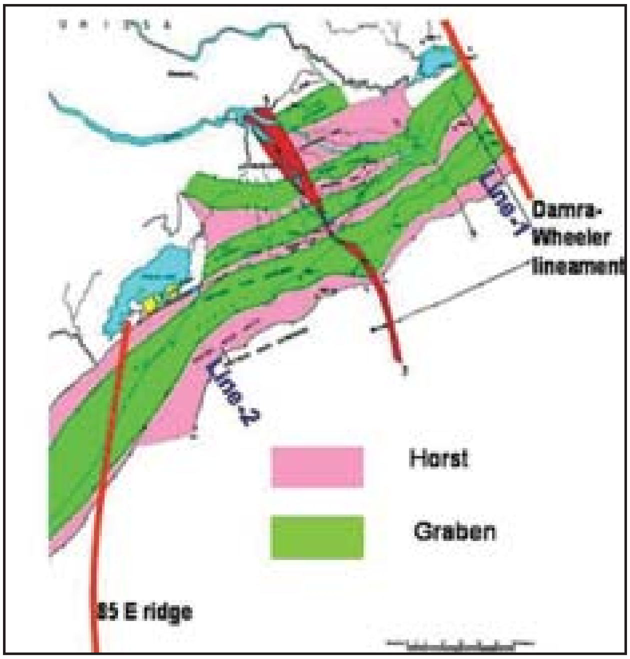

Fig.2 : Tectonic map of Mahanadi basin

Exploration history and geoscientific data available

Hydrocarbon exploration in the basin was initiated by ONGC in the late sixties with acquisition of gravity-magnetic data followed by 2D seismic during 1973-75, in the onshore part of the basin. NGRI carried out air borne magnetic surveys in the basin (both onshore and offshore), covering 32,250 Sq.km. NGRI also carried out DSS surveys in onshore Mahanadi basin. Oil India Ltd. (OIL) acquired nearly 11000 LK of 2D seismic data both in the onshore and offshore parts of the basin. These geoscientific data indicated presence of thick sedimentary section of Mesozoic and Tertiary age.

In the onshore part of the basin, four exploratory wells were drilled by OIL with hydrocarbon shows in Cretaceous sediments. Similarly, in the offshore Mahanadi basin, eight wells have been drilled by OIL and hydrocarbon shows have been observed in Miocene sands and Eocene carbonates in a number of wells. In view of lack of commercial discoveries from the initial exploratory efforts, there was a pause in exploration activity in the basin in the 1990s.

With the award of exploration blocks under NELP since 1999, in the onshore, shallow water and deep water sectors of the basin, there has been a spurt in the exploration activity in the basin. Massive quantities of the seismic data, both 2D and 3D have been acquired during the last five years.

Sequence stratigraphy

The spatio-temporal distribution of source and reservoir facies within a sequence is related to eustatic variations, tectonic subsidence, rate of sediment influx and climate. An attempt, has therefore, been made to draw a sequence stratigraphic framework for the offshore part of the basin and bring out the hydrocarbon play-fairways.

a. Methodology adopted

Ten regional seismic transects, seven in dip direction and three in strike direction were made in the offshore part of the basin. The available biostratigraphic, lithological and electrolog data of the eight wells drilled in offshore were tied up with the regional transects.

Five type-I unconformities were identified based on the reflection terminations (Vail, 1987) and drastic change in reflection pattern. These surfaces indicate significant fall in the base level and are therefore associated with truncations below and onlap above.

Biostratigraphic studies carried out by Raju (1986) were utilized to corroborate the regional unconformities identified from the seismic data and also to assign geological age to these surfaces. The regional unconformities identified, represent periods of drastic shallowing of sea level in the biostratigraphic data, and therefore are interpreted to be surfaces of subaerial exposures in some part of the basin. These unconformity surfaces and their correlative conformities were correlated throughout the entire Mahanadi offshore basin, through the ten regional transects.

Based on these bounding surfaces or sequence boundaries, the entire sedimentary succession of the basin has been divided into six 3rd order sequences.

Within each sequence, various system tracts- low stand, transgressive and high stand - representing conformable reflectors were identified based on bounding surfaces, position within sequence, and stacking patterns. The identification of the system tracts helped in further confirming the sequence boundaries, which corroborate either with the base of the low stand system tract or the top of the high stand system tract, characterizing depositional sequence –II (Haq et al.,1987 and Posamentier et al., 1988). The system tracts identified have helped in visualizing areas of source rock development and also dispersal pattern of the reservoir facies in the basin.

b. Results and discussion

Six depositional sequences have been identified within the Late Cretaceous and Tertiary section of the basin. Gondwana sediments below the Rajmahal trap are not identifiable from the available seismic data. Hence the study has focused on the post trappean assemblages. The sequences, their geological age as well as significance and the system tracts identified in each sequence is depicted in (fig.3).

The sequences identified are briefly discussed below:

- **Sequence-I(Upper Cretaceous)**

  The oldest recognizable depositional sequence in the offshore Mahanadi basin is of Upper Cretaceous age. Top of Rajmahal trap forms the base of the sequence and the K-T boundary the top. This sequence, consisting of Campanian-Maastrichtian sediments is about 400m thick in the grabenal areas and is thin over the horsts. The poor quality of seismic data, possibly due to absorption of energy by the overlying carbonate unit, does not permit identification of the system tracts in this sequence.

  The sequence consists of argillaceous package at the basal part, sandy section in the middle and a high gamma ray section of alternating sand and shale towards the top. Biostratigraphic data is suggestive of shallow marine sedimentation in the study area during the sequence.

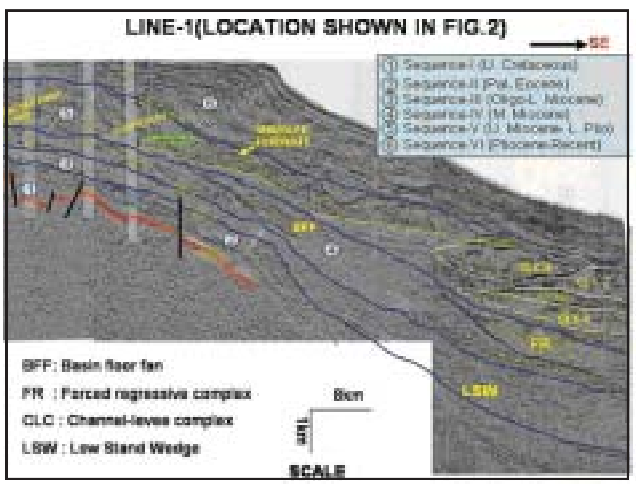

Fig.3 Sequence architecture of Mahanadi offshore (Line-1 as shown in fig.2)]

- **Sequence-II (Paleocene - Eocene)**

  The base of the sequence coincides with K-T boundary, a major unconformity associated with base level fall and hiatus of 5-6 my during Danian period (Lower Paleocene). Subsequent rise in base level during Upper Paleocene brought this area under marine influence; probably high stand condition, in response to which a prograding delta system developed (Rao et al, 2002).

  Progressive reduction in the clastic supply in response to peneplanation of the provenance led to development of carbonates in the area during Upper Paleocene and Eocene. This sequence is 300-800m thick. The bottom part of this sequence consists of a thick package of alternating sand and shale, representing deltaic deposits in high stand system tract. The top part consists predominantly of carbonates interspersed with thin sandstone layers.

  The top of this sequence is defined by a pronounced erosional unconformity and subaerial exposure with long hiatus, as the entire Oligocene section is absent over the major area of Mahanadi offshore basin. This sequence is characterized by a series of continuous, high amplitude reflectors corresponding to carbonates.

- **Sequence-III(Oligocene- Lower Miocene)**

  The base of the sequence is marked by a pronounced erosional unconformity, marked by erosional truncations of the older strata against this surface, created by a major base level fall at the end of Eocene. In response to this base level fall, the depositional milieu shifted basin ward, beyond the Eocene shelf break. The Oligocene strata onlap the Eocene top unconformity and form a thick low stand wedge (fig.4).

  The Oligocene low stand culminated in a maximum regressive surface, which is clearly discernible in the seismic data. The base level rise during Aquitanian period marked the onset of transgressive phase, which inundated the entire basinal area and has formed a transgressive system tract, characterized by onlapping seismic events on the shelf, followed by a highstand system tract. The sequence consists of discontinuous, low amplitude seismic events characterizing argillaceous facies as observed in the wells drilled in

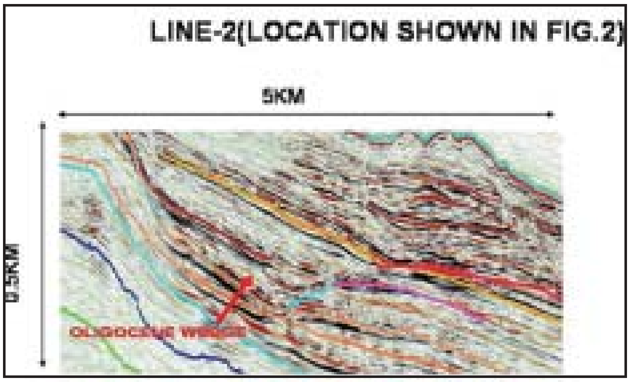

Fig.4. Oligocene low stand wedge in Sequence-III (Line-2 as shown in fig.2)

the basin. The thick shale package belonging to the high stand system tract of this sequence has fair-good source rock potential.

This sequence lacks offlapping/prograding events associated with high stand system tract. Instead, a few singled clinoforms are observed in the top part of the sequence, indicating lack of a river dominated delta system in the study area.

- **Sequence-IV (Middle Miocene):**

This sequence consisting of Langhian and Serravallian sediments is bounded by erosional unconformities both at the base and at the top. A major base level fall is indicated during this sequence by the biostratigraphic data. Prominent offlapping prograding systems, corresponding to the base level fall and high sediment supply from rising provenance, defines the falling stage system tract (Catuneau, 2002) within the sequence.

Towards the base of this sequence, a well defined low stand system tract is present in the basinal area. The sequence culminates with a forced regressive package at the top, caused by high sediment supply and base level fall.

The drilled wells in the offshore areas in the basin indicate excellent sand layers in this sequence. Integration of the seismic and well data is suggestive of deposition of these sands as basin floor fans on the continental slope.

The forced regressive package observed towards the top of the sequence, characterized by mounded events, may contain reservoir quality sands to form an exploratory target in the basin.

- **Sequence-V(Upper Miocene –Lower Pliocene):**

A base level rise is indicated in the Tortonian period, onsetting a transgressive phase, as indicated by onlapping events on the Serravallian top unconformity surface. In response to this, the sequence-V initiated with a low stand wedge and finally gave way to transgressive and highstand system tracts.

Towards the upper part of the sequence, during the high stand period a strong easterly supply of sediments from the elevated provenance in the Indian mainland caused remarkable progradation of the depositional packages. Integration of the lithological data from the drilled wells with the seismic events indicates a major delta system operative in the basin during this period bringing in massive sand, which formed the delta front lobes on the shelf, with deposition of argillaceous facies on the slope.

In the basin plain set-up, down dip of the slope areas, continuous, high amplitude seismic events are observed which appear to pinch out against the up-dip slope clays. These are interpreted to be shingled turbidities (fig.5), which may form a major exploration target in the basin, in view of their excellent reservoir quality with large aerial spread.

Further basin ward, the shingled turbidite unit rests over a package of mounded events having lobate morphology. Three lobes are clearly discernible in the study area. Each of the lobes consists of a narrow zone of stacked high amplitude events, flanked on both sides

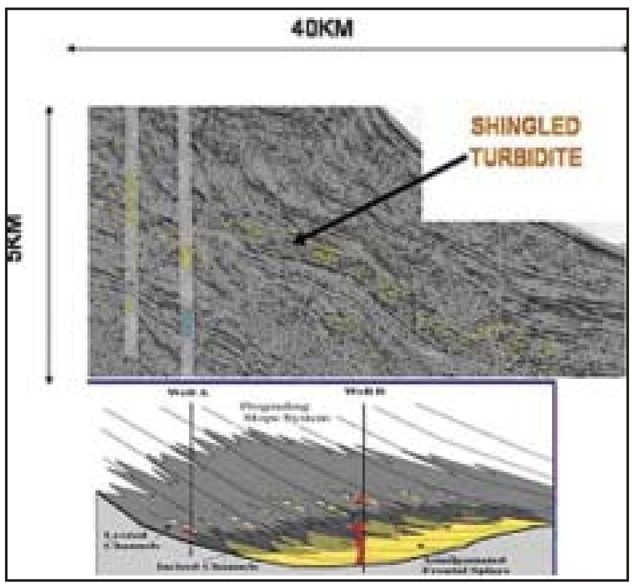

Fig.5 Part of line-1 showing Shingled turbidite in Sequence-V

by reflection free zones. These lobes represent channel-levee complexes (fig.6), generated by mud rich Bengal deep sea fan.

The stacked high amplitude events represent channel sands, where as the flanking reflection free zones the levee clays. The channel- levee complex of mud rich Bengal fan is in contrast to the shingled turbidites of sand rich Mahanadi system, indicating deposition of both in the same sequence.

- **Sequence-VI (Pliocene-Recent):**

A major base level fall in Zanclean period (Lower Pliocene) caused an erosional unconformity, which formed the base of Sequence-VI. This sequence representing sediments from Pliocene-Recent consists of input mainly from Mahanadi system as the Bengal fan prograded much to the south of the study area.

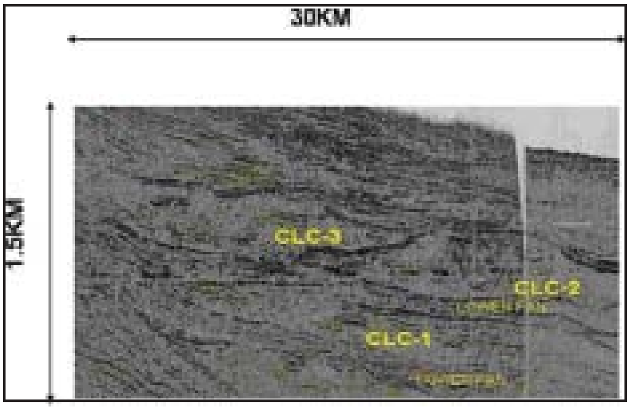

Fig. 6 5 Part of line-1 showing Channel-levee complexes in Sequence-V

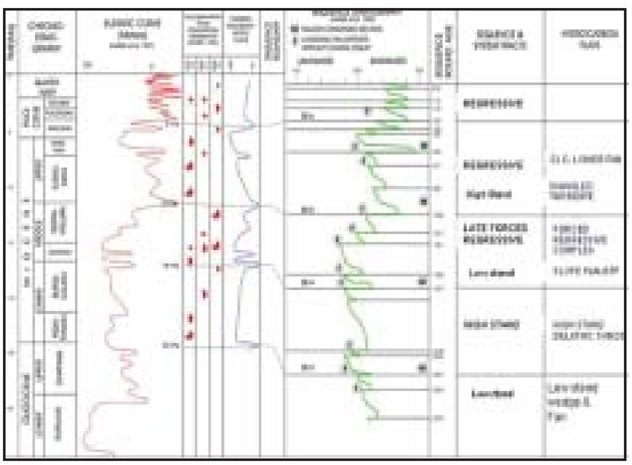

Fig.7. Hydrocarbon plays in Mahanadi offshore in Sequence stratigraphic framework.

Thick argillaceous section deposited in high stand system tract of Sequence-IV has fair-good source rock potential, as indicated by the drilled well data. This is considered to be the principal source rock package in the offshore Mahanadi basin.

The identification of the system tracts with associated stacking patterns of the involved strata and their interpreted position in the base level curve has direct bearing on the prediction of the reservoir facies. Based on this analysis the following identified plays are concluded to be the significant targets for exploration in the basin:

- Oligocene low stand deposits in Sequence-III
- Middle Miocene basin-floor fan and forced regressive packages in Sequence-IV
- Upper Miocene- lower Pliocene shingled turbidites and channel-levee complexes in sequence-V.

Conclusions

The post trappean succession of Mahanadi offshore is divisible into six 3rd order depositional sequences, separated by type-I unconformities and their correlative conformities. Identification of system tracts within the sequences based on bounding surfaces, position within sequence, and stacking patterns has facilitated identification of hydrocarbon plays in the basin.

Based on this study several new plays have been identified viz. Oligocene low stand deposits, Middle Miocene basin-floor fans & force regressive packages and Upper Miocene - lower Pliocene shingled turbidites & channel-levee complexes, which promise high potential for further exploration in the basin.

Acknowledgement

The author is grateful to ONGC management for according permission to submit the paper for publication.

The views expressed in the paper are those of the author(s) and need not necessarily be of ONGC.

References

Catuneanu, Octavian, 2002, Sequence stratigraphy of Clastic systems: concepts, merits, and pitfalls: Journal of African Earth Sciences, 35 (2002),p 1-43.

Haq, B.U., Hardenbol, J., Vail, P.R., 1987, Chronology of fluctuating sea levels since the Triassic, Science, 235, p 1156-1166.

Posamentier , H.W., Vail, P.R., 1987, 1988, Eustatic controls on clastic deposition, II, Sequence and system tract models, in SEPM special publication on sea level changes- an integrated approach, p 125-154.

Raju, D.S.N., Biostratigraphy and Paleoecology of Mahanadi basin, 1986, internal publication ONGC.

Rao, G.N., Mallick, S., Mandal, N.C., Bandopadhay, S., Nayak, A.K., Dutta, S., 2002, Geology and hydrocarbon prospects of Mahanadi basin, proc. 1st conference and exhibition of APG, p 215-221.

Vail. P.R., 1987, Sequence stratigraphy interpretation procedure, in Bally, A.W(Ed), atlas of Seismic stratigraphy, vol.27, AAPG studies in Geology, p 1-10.