Deepwater system of Mahanadi Basin

Abstract

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The deepwater channel-levee systems have come into focus of exploration since a number of giants pools have been discovered from the couple of decodes. The significance of channels are sand conduits has been understood during this period when huge volumes of sandy deposits have been identified to occur down dip of muddy slope systems in number of basins in different parts of the world. The levee overbank areas associated with the channels albeit consists primarily of mud and thinly bedded sands sometime possess excellent porosity and Darcy range permeability to form commercial reservoirs.

In the study area within Mahanadi Offshore a number of channel levee systems have been identified distributed in time and space. Out of them three were Prioritized as immediate exploration targets judging from their volume and distinctive shape. Their age ranges from Early to Late Miocene. The oldest identified channel levee system with larger aspect ratio was possibly active in the middle fan and show more aggradational component than those of the younger channels. The younger systems with less aspect ratio reflect more erosional indicating increase in energy condition in the relatively upper part of fan and expected to have more coarser clastic in them.

Volume visualization of three channel levee systems brought out amplitude distribution pattern in time and space. The high amplitude geo-bodies possibly indicate presence of coarser clastics within an overall mud dominating geological set up.

In Seismic section the younger channel-levee system show the presence of a distinct mass transport complex (MTC) at the base of it. The chaotic and Hammocky reflection pattern on the MTC is representation of slides and inverted blocks generally caused by catastrophic features of the margin.

INTRODUCTION

Mahanadi Offshore basin is a passive margin basin off the east coast of India. It is flanked by Bengal Basin in the northeast and Krishna-Godavari basin in the southwest. The present study area covers 1250 SKM. of 3D volume falling in the eastern part of NELP deep water block MN-DWN-2002/1 block of Mahanadi basin (Fig.1). The bathymetry in the study area varies from 1700 to 1800m. A detailed work was done on the aforesaid volume to bring out the details of the channel levee systems and generation of hydrocarbon prospects.

GEOLOGICAL SETTING

Mahanadi basin along with other passive margin basins off the east coast of India came into existence during Late Jurassic-Early Cretaceous separation of Indian plate from East Gondwana assembly (Australia-Antarctica-India). The initial part of the basin history is recorded in the onland and shallow offshore areas. The pre rift Gondwana sediments are represented in the onland part along NW-SE oriented grabens. During the pre break up and break stage, due to extension, block adjustment in the basement created localized half grabens and grabens, which accumulated continental, fluvial, fluvio-lacustrine and paralic sediments during early Cretaceous.

The rifting is accompanied by volcanic eruptions equivalent to Rajmahal traps along with inter-trappeans. The tensional faults created during rifting are in NE-SW direction and at right angle to former Gondwana trends. The rift stage initiated the separation of continents and creation of oceanic crust. The newly created passive margin formed a huge depocentre from Late Cretaceous to Recent.

The collision of Indian plate and Eurasian plate, consequent uplift and erosion resulted in enormous accumulation of the detrital sediments from Oligocene to Recent time created the Ganga and Brahmaputra delta systems. Interception and funneling of river delivered system and long shore drift by submarine canyons caused turbidite sedimentation in the deep waters forming Bengal submarine fan that presently extends to 7°S latitude.

SEDIMENTATION PATTERN

The present day sediment thickness map of Bengal Fan shows a maximum thickness of 21 Km close to the mouth of Ganga - Brahmaputra delta system (Fig.2). In the study area its thickness varies from 12 to 15 Km. The Bengal Fan, which initiated in Eocene time, consists of stacks of Channel - levee systems and associated geological features. The regional model of channel levee system is shown in Fig. 5.

Out of a number of channel - levee systems identified in different stratigraphic levels in the study area, three of them were prioritized as immediate exploration targets. They are correlated with CLS 1, CLS 2 and CLS 4 depicted earlier in 2D study. The same nomenclature is continued in the present work also. The CLS 1 lies between reflector 3 and 4, CLS 2 between Reflector 7 and 8, whereas, CLS 4 is bounded by reflector 9 and 10 (Fig. 6). To link the identified channel-levee systems in the study area with the regional sediment dispersal pattern, an attempt has been made to trace the channels into regional perspective. The channels in CLS 1, 2 and 4 were correlated beyond the study area with the help of available 2D data to the north and northeast. Correlation of these channels helped in developing a regional geological model indicating the direction of major sediment input. All the three channel-levee systems could be traced towards northeast up to the mouth of the Bengal canyon (Fig. 3). This confirms sediment input from Ganges/ Ganges-Brahmaputra delta existing during Mio-Pliocene time. Those deltaic sediments were possibly redistributed by long shore drift and intercepted and funneled through Bengal canyon in to the deep-sea environment. The coarser sediment brought in to the slope were further transported in to the deeper abyssal plains through the channels by sediment gravity flow.

The channels in the three identified channel levee systems are mixed erosional to aggradational in nature. The aspect ratio of channel in CLS I is 38:1, whereas, that of CLS 2 and 4 are of the order of 14:1 and 3:1 respectively. The oldest identified channel levee system (CLS 1) possibly was active in the mid fan and show more aggradational component than those of the younger channels. The younger CLS 2 and 4 with less aspect ratio reflect more erosion and are inferred to have operated in upper fan. This indicates an increase in energy conditions as well as erosion in the younger channel-levee systems. It can be correlated with a series of significant geological events in Mio-Pliocene time which saw uplift of Tibetan Plateau and strengthening of the monsoon at 7-8 Ma.

In seismic section the youngest channel-levee system (CLS 4) show the presence of a distinct mass transport complex (MTC) at the base of it. The chaotic and Hummocky reflection pattern in the MTC is representation of slides and inverted blocks generally caused by catastrophic failure of the margins. Fig. 15 shows the conceptualized geological models for the early Miocene (CLS 1) and Late Miocene (CLS 4) channel-Levee systems.

DESCRIPTION OF MAPS.

The maps pertaining to the primary and secondary objectives are described below

TWT STRUCTURE CONTOUR MAPS

Reflectors 3 and 4: Reflectors 3 and 4 lie within Early Miocene and follow a regional dip towards southeast (Fig.7). The low in the western part of the area widens in the north with opening up of the earlier adjoined oppositely dipping faults. Few faults with limited lateral extension present in the eastern and western part of the area. The reflectors 3 and 4 form the base and top of CLS-1. A number of small four way closures seen on top of reflector 4 are probably manifestation of relief generated by the levees on the flanks of the channel.

Reflectors 7 and 8: These reflectors lie within Middle Miocene. TWT structure maps of reflectors 7 & 8 (Fig. 7**)** show more or less similar structural configuration, dipping towards southeast direction. Reflectors 7 and 8 form the base and top of CLS-2. The structural configuration on top of reflector 8 (Plate-6) changes due to the relief created by the channel and levees. A subdued low trend, seen passing through the middle of the area is due to presence of the channel in CLS-2. Some of the faults in the eastern part of the volume disappear at the level of reflector 7.

Reflectors 9 and 10: The reflectors 9 and 10 belong to Late Miocene and form the base and top of CLS-4. Reflector 9 is also the top of a mass transport complex. The TWT structure map of reflector 9 (Fig.7) shows a NE-SW trending low, which broadens in the southern part of the area. This represents erosion of a part of the mass transport complex by the overlying channel.

The TWT structure map of reflector 10 (Fig. 7) shows dipping of the reflector towards southeast and represents the inclination of the levee top. Presence of a high in form of a four-way closure in the southwestern part of the area is of importance. No fault in the area continues to the top of reflector10.

TWT THICKNESS MAPS

Between reflectors 3 and 4: This interval represents a major channel - levee system, the CLS-1.The general thickness of this interval increases from NW to SE (fig. 8**).** It varies from 83 to 242 msec. However, this trend is punctuated by NE-SW high thickness trend. Within this trend a sinusoidal pattern of low thickness contour (150 msec) indicates the presence of a channel crisscrossing the area. The surrounding high thickness values represent the proximal levee deposits. The thickness of the levee reduces towards NE and SW in its distal part.

Between reflectors 7 & 8: This interval represents the major channel - levee system CLS -2. The map shows a NNE-SSW high thickness trend with in between low thicknesses (fig.8). The low thickness trend indicates the channel entry direction, which is flanked by high thicknesses in the proximal levee. The thickness on the flanks of this trend gradually diminishes towards NW as well as SE in the outer levee. The thickness of the interval varies from 54 to 357 msec.

Between reflectors 8 & 9: This interval represents a mass transport complex. The thickness of this interval varies from 42 to 550 msec. The maximum thickness is observed in the southeastern part of the area. A low thickness trend in the NNE-SSW direction is observed in the middle of the area (fig.8). This is probably due to erosion in this part of the area by the overlying channel.

Between reflectors 9 & 10: Reflectors 9 and 10 bound the most prominent channel - levee system in the area, the CLS-4. The thickness in the interval varies from 94 to 357 msec. Two parallel NE-SW trending thicks with, in between thin in the same direction is observed in the area (fig.8). The eastern thick trend gradually reduces towards SW. These two high thickness trends are proximal levees of a channel running in NE-SW direction (low thickness trend). The gradual lowering of thickness in the southeastern part of the area reflects the thinning of the levee towards its distal part. As the major part of the western levee lies outside the block, reduction in thickness on the distal part of it is not revealed in the map.

ATTRIBUTE ANALYSIS:

. The entire volume was divided into 72 proportional slices. Different amplitude studies (rms, average absolute amplitude etc.) were carried out along 13 reflectors and 72 proportional slices. Spectral decomposition studies were carried out on 85 levels to understand channel pattern. Out of those studies, attributes, which brought out the targeted features in the proposed locations, are discussed below.

Interval between reflectors 4 and 3: Spectral decomposition studies between the reflectors 4 and 3 shows the presence of a NNE-SSW trending meandering channel at all the levels. One such level is shown in Fig.9.

Interval between reflectors 8 and 7: This interval represents a major channel – levee system, CLS-2. Spectral Decomposition studies show entry of meandering channels from NE (Fig.9).

Interval between reflectors 10 and 9: The interval between reflectors 10 and 9 represents the major channel – levee system in the area, the CLS-4. Spectral decomposition studied on a number of proportional slices shows a NE –SW trend of a sinuous channel (Fig.9).

MAJOR CHANNEL LEVEE SYSTEMS

The deep water channel-levee systems have come into focus of exploration since a number of giant pools have been discovered from them in past couple decades. The significance of channels as sand conduits has been understood during this period when huge volumes of sandy deposits have been to occur down dip of muddy slope systems in number of basins in different parts of the world. The levee overbank areas associated with the channels albeit consists primarily of mud and thinly bedded sands sometime possess excellent porosity and darcy range permeability to form commercial reservoirs.

In the study area within Mahanadi Offshore a number of channel levee systems have been identified distributed in time and space. Out of them three were Prioritized as immediate exploration targets judging from their volume and distinctive shape. They are CLS-1, CLS-2 and CLS-4 in ascending order.

Channel - Levee System 1

This Channel - levee system is the oldest identified geological feature of purport within the studied section. The time thickness map between the reflectors 3 and 4 (Fig. 8) demonstrates the NE - SW trending channel of relatively low thickness, flanked by higher thickness of levee. The E-W seismic section (Fig.14) clearly show the various parts of the channel-levee system. The Average Absolute Amplitude map (Fig.10) as well as spectral decomposition (Fig. 9) also brings out the meandering channel. Avg. Absolute Amplitude extraction with a different colour scheme also shows the amalgamation of a number of channels within master channel of CLS 1. Voxel view of channel is shown in Fig.13. The anticipated lithology as well as seismic pattern of CLS 1 is shown in fig. 15.

Channel - Levee System 2

The CLS-2 is seen in the time thickness map between reflectors 7 and 8 (Figure 8). Trace 5000 seismic section (Fig.14) reveals the major part of the channel - levee system with HAR within the centrally located channel. Very high amplitude along the channel, on extraction of Average Absolute Amplitude (Fig. 13) indicates possible of charged reservoirs. Voxel view of channel is shown in Fig.12. The anticipated lithology as well as seismic pattern of CLS 2 is shown in fig. 15.

Channel - Levee System 4

Time thickness map between reflectors 9 and 10 (Fig. 8) shows a relatively low thickness along a NE - SW trending channel, which is flanked by high thickness contours along the levee. Seismic section trace 3100 (Fig.14) demonstrates the presence of HARP within the channel as well as on the proximal levees.. Extraction of Average Absolute Amplitude (Fig.10) indicates possible presence of charged reservoirs in the northern part of the channel. Voxel view of that part of the channel is shown along with E – W and N – S seismic lines (Fig. 11). Voxel views of through the channel from base to top show relatively higher amplitudes with the channel, with increases in magnitude in the younger levels. This phenomenon points towards possible charging of reservoirs within channel.

The HAR observed on the proximal levees (Fig. 14) seem to be interesting, considering the possibility of presence of quality reservoirs and world wide examples of hydrocarbon pools within them. Extaction of average absolute amplitude (Fig. 10) and Spectral Decomposition (Fig.9) shows distribution of high amplitude along the two parallel levees.

PETROLEUM SYSTEM

Source rock: The source and generating potential in the shallower part of the Mahanadi basin has been dealt elaborately in BICIP report (1989) and also with recent discoveries in Mahandi Block. Based on the works of

Prasad et al, (2004), the sediments below 4500m in the area is envisaged to be within hydrocarbon window. Hydrocarbon expulsion is considered very late i.e., close to 1 Mabp. Hence features of younger generation attain importance for exploration in the area

The likely source area for any thermally generated hydrocarbons lies in ancient bathyl sediments. The nature of organic material in such a setting is not well understood. Further study of analogues is recommended as well as perhaps a geochemical sampling exercise.

It is hard to draw comparisons with other deep water settings, since most of the hydrocarbons found in them have been generated within rifted settings. This is certainly true of Brazil, West Africa, the Gulf of Mexico and the North Sea, where production has been established from deep water sands.

It may be that there is a significant component of biogenic gas within the shallow section, no obvious bottom simulating reflector (BSR) is seen, however it may be that with the extensive amount of tectonic activity at or near the sea bed any gas would have been disseminated.

The presence of an active hydrocarbon generating system is considered to be a significant risk. However the presence of a significant biogenic gas accumulation within deep water channels in the Krishna-Godavari (KG) Basin to the south may give encouragement that a similar supply of biogenic gas may be present in the Bengal/Mahanadi area.

Reservoir and Cap rocks: The Bengal fan, which came in existence in Oligocene time due to collision of Indian plate with Eurasian plate, carries coarser clastics eroded from the Himalayan region into the deep-water environment. The channels identified in CLS 1, 2 & 4 are expected to have good reservoir facies as they lie within Mio-Pliocene because of greater upliftment and erosion leading to increased sediment influx into the offshore area during the period. The coarser component of these influxes is expected to be concentrated in the channels, transporting the relatively finer fractions into the levees by flow stripping. However, thicknesses of reservoir facies within the channels are expected to vary due to variations in amalgamation of individual channels within master channel. High amplitude distribution along the channel indicates the possible presence quality reservoir facies. The seismic reflection patterns and anticipated lihologies within major channel levee systems shown in figure 15.

Entrapment: The reservoirs within sinuous channels are generally in the form of discontinuous mounds / pods. Encased by surrounding shale they can for excellent stratigraphic traps.

Migration: The general fault pattern in the area is shown in Fig.7. These faults with very little throw are right candidates for conduit for vertical hydrocarbon migration. Albeit they are not resolved in deeper sections, their presence at depth cannot be denied. These micro faults / fractures linked with the major faults in the area may provide the migration path for hydrocarbon from source to trap. Fig.15 shows conceptualized geological model indicating possible generation, migration and accumulation of hydrocarbons from source to reservoir in the area.

Conclusions :

- All together 13 reflectors were correlated and mapped. 72 proportional slices were generated within the studied section and attribute analysis was carried out on each of them for dealing the of the different geological features.
- Out of a number of channel-levee systems brought out through attribute analysis, three were prioritized as immediate exploration targets judging from their volume and distinctive shape.
- The sediments below 4500m in the area is envisaged to have reached hydrocarbon maturation window.
- The channels brought out through different studies are expected to have good reservoir facies. The Proximal levee parts are also exected to be sand rich and potential reservoirs.
- The entrapment is generally stratigraphic in nature. The hydrocarbon migration is envisaged to have been taken place through faults/micro-faults from source to reservoir.

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