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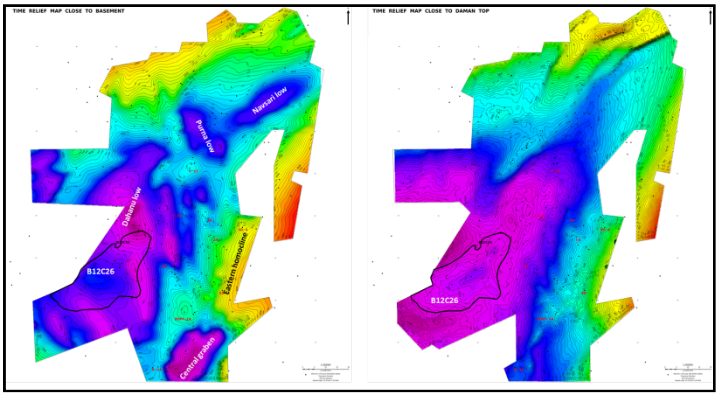
# Understanding Daman Sands through reservoir characterization in B12C26 Area, Surat Depression: A historical Perspective

## Abstract:

The multi-stack sand rich sequence of Daman Formation of Late Oligocene age is very well known for its prolific gas production as well as wide presence in Surat Depression of Mumbai Offshore Basin. The Late Oligocene sequence, bounded by unconformities, is a part of passive margin 1st order Mega Sequence which ranges in age from Early Eocene to Pliocene/Pleistocene. The Daman Formation is deposited in a tide dominated delta within overall regressive conditions and well known for wide network of distributary/tidal channels and bars. The early phase of exploration in the B12C26 area met with mixed success primarily due to an approach, which focused on the structural element in the area and the constraints of available seismic data. However, over the years with more drilled wells and acquisition of multiple seismic 3D, the area showed phenomenal growth. The primary pays in the area are multiple reservoir sands within Daman Formation and these sands demonstrate AVO anomaly well expressed on seismic data. Reservoir geometries of these channel sands were further enhanced on the basis of far stack seismic data analysis. The study not only improved the understanding of the deltaic sands in terms of realistic reservoir geometries, but also brought out a large potential area for exploration. This paper analyzes in detail, the far stack study with a bird's eye view of exploration history over time and the challenges in exploration in the B12/C26 area.

## Introduction:

The Western coast of India is endowed with rich hydrocarbon resource and contributes significantly towards the energy needs of the country. Major production of oil and gas from Mumbai High, Bassein, Neelam-Heera, Mukta and Panna fields are from carbonate reservoirs whereas in the northern part of Basin, the fields of North Tapti, Mid & South Tapti, Laxmi, Gauri, Ambe, C22, C23, C24, C39 & B12C26 are gas producers from clastics reservoirs of Oligo-Miocene age. The B12/C26 field is one such field which lies to the north east of Mumbai High, and south of South Tapti. It has been subjected to mild inversion within the Dahanu low trending in NE-SW direction (Fig.1). B12 and C26 are two separate highs where in total 31 wells were drilled till date with different exploration models, both structural as well as stratigraphic. The exploratory efforts in B12/C26 area started way back in 1978 with drilling of the first well X-1 on B12C26 structure. The initial approach was primarily based on structural interpretation of broad grid 2D seismic data. Initial exploratory efforts didn't yield significant amount of hydrocarbons mainly due to lack of understanding of reservoir facies distribution/dispersal in the area. It was not until 2005, that the first 3D data was used for interpretation of the area which covered part of B12C26 structure and thus a new era of exploration began. Merged data of 5 individual 3D volumes and attribute analysis over that merged volume has helped in accreting a significant in-place reserve in this area. Recently, the attribute study in far stack data of merged volume gave a clearer picture of channel geometry in Daman Formation. Further AVO analysis and cross plots helped to understand the petro-physical behavior of sands in the area.




to Basement and Daman Top

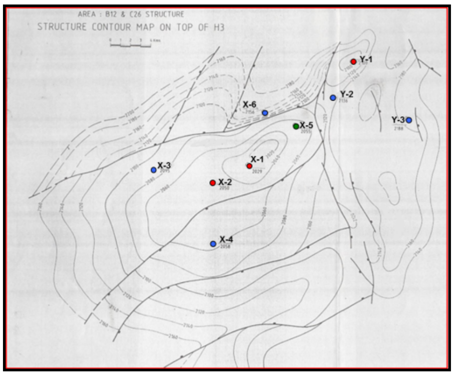



**Fig 2.** Maps depicting wells drilled on the basis of structural interpretation

## Geology of the area:

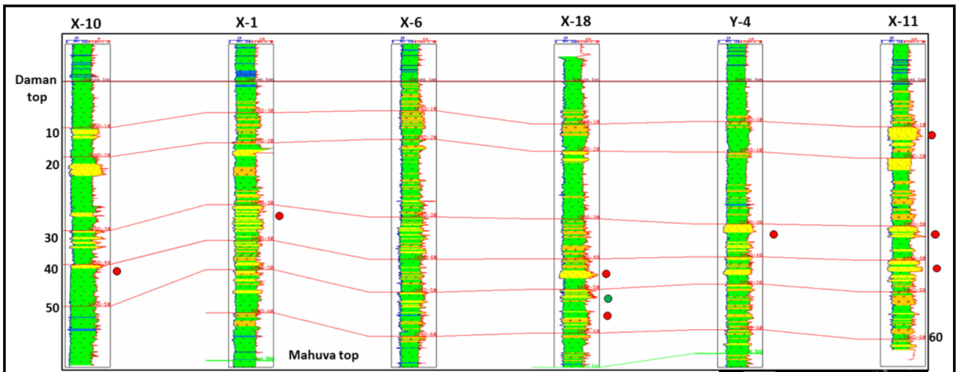
The area falls in the southern part of Daman low which has been marked by several tectonic episodes. The depositional floor for sedimentation consists of paleo highs and many N-S trending half-grabens. Daman

Formation of Late Oligocene age is the main hydrocarbon producer in this area. It was affected mostly by the Miocene tectonics, resulting in numerous traps of 4/3 way closures and up dip shale out traps. Daman has huge potential due to its good porous sands and variety of traps. On the basis of structural interpretation of 2D grids, 9 wells in B12 and 3 wells in C26 structure were drilled. The structural trend is similar in both 2D and 3D data; only the 3D data has more detailed structural elements compared to the former (Fig 1 & 2).

Most of the wells drilled in the area were restricted to Early Oligocene sequences. X-1 is the only well which has penetrated the Panna Formation. The Panna Formation is characterized by poor reservoir facies. The overlying Belapur, Diu and Lower Mahuva formations are represented by argillaceous facies. The Upper Mahuva Formation has thin marine shales and limestone alternations. The limestone thickness increases towards the distal part of B12C26 structure in upper Mahuva unit.

Sedimentation of Daman Formation has taken place in a fluctuating sea level conditions. As a result, during the late Oligocene period, subsequent increase in clastic supply from inland part led to deposition of multi stacks of sands within the Formation. The sands are interpreted to have been deposited in a tide dominated deltaic setting.

The well data indicated multiple sand packs in Daman Formation, identified from top to bottom as Sand 10, 20, 30, 40, 50, 55 and 60 (Other sand units like sand 35, 25 are present in other parts of Tapti Daman area). All the sands are gas producers in this area except Sand 50 which has produced oil from two wells (X-5 and X-18). The sand packs have multiple stacks of sand which are variable in nature. Sand 30 has a wider spread in the as area compared to others, and is overlain by a thick shale with limestone bands developed at some places indicating a marine transgression within Daman Formation. This is used as a regional marker to correlate the sands within Daman Formation. (Fig 3)



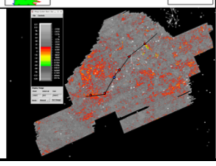



**Fig.3** Log correlation to show the disposition of sands in Daman Formation

## Initial Stages of exploration:

The B-12 structure, in the south-western part of Tapti-Daman sector of Mumbai Offshore Basin (Fig 1) was explored in 1980's. The first well in B12 structure was drilled in 1978 on the crestal part which produced both Gas and Water. Due to the presence of water, no further drilling was carried out till 1992. However, after reviewing the whole set of data, it is found that the water production was due to poor cementation. This led to the drilling of another well X-2 in 1992 which gave hydrocarbon in Daman Formation. Subsequently, X-3 and X-4 wells were drilled to know the areal extent of gas bearing sands in Daman Formation but were found to be dry. Later X-5 was proven to be oil bearing but the result was not encouraging as the reserves were found to be not sizable.

It was in the later part of 2003 the drilling of well X-7 proved the accumulation of commercial hydrocarbons in Daman Formation within a stratigraphic play – a mounded feature, interpreted as sand bar based on broad grid 2D seismic data. Following this, well X-8 was drilled over an inverted structure but it lacked the development of reservoir facies within the Formation. Yet another well X-9 drilled to the SW of B-12 structure on a similar mounded feature, gave commercial accumulation of hydrocarbons from limestone facies of Upper Mahuva Formation. Similarly, the C-26 structure was explored during 1991-1996 based on 2D seismic data. Three wells were drilled based on 2D data, of which the first well (Y-1) in the crestal part of C-26 structure met with success from the Daman Formation but the other two proved to be dry. Electro log evaluation of both these wells during that time suggested marginal saturation. Additionally, in well Y-2, a sand layer towards the bottom part of the Daman Formation was interpreted to have marginal saturation of gas.

## Journey from 2d to 3d interpretation:

The first 3D data of 25,806 lkm was acquired in this area in 2005. The interpretation of 3D seismic data brought out the depositional model for Daman (Channel and bar complex) and Mahuva formations (Carbonate in basal and middle part of Upper Mahuva Formation) as well as a new play – a channel and associated bar within the Panna Formation.

As per the geological model perceived for Daman channel sands; deposition took place primarily in restricted condition under marginal marine/coastal to shallow inner shelf conditions with bathymetry ranging from 5-10m. The general environment was fresh to brackish in nature suggesting a broad inter-tidal regime. The study brought out three major pulses of regression which resulted in progradation of channels – one each during Lower, Middle and Upper part of Daman. (Fig. 4)

One well X-10 was first drilled based on this study for the sand present in upper Daman which was later named as Sand 20. It proved to be dry from this level although it has reservoir facies present. However, this well produced gas from level sand 40 which is present in Middle Daman as well as from Mahuva Formation.

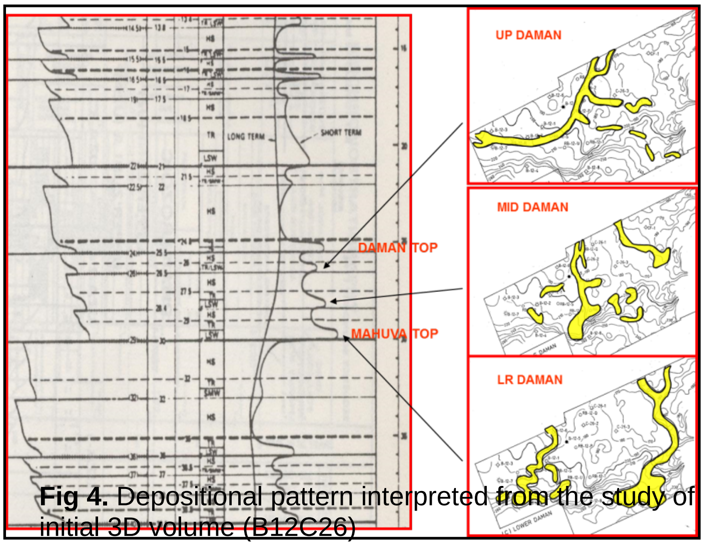


**Fig 4.** Depositional pattern interpreted from the study of initial 3D volume (B12C26)

In 2006, two seismic volumes, C26 and NWB12 were used to analyze the prospectively of the area. The prospects and channel patterns were identified by dividing Daman into 3 units with surfaces D1, D2, D3 and D4 by analyzing different attributes (Fig 5), This resulted in bringing out a complex of channel sands. The study led to drilling of well X-11 (Fig 5) after which B12/C26 field emerged as a major gas producing asset. Subsequently, the merging of five individual volumes (NWB12, C26, B12C26, and EB12 and B12L) provided a better understanding of the B12 area. The study brought out the continuity of various Daman sands in the field and led to generation of multiple exploration targets in the area (X-12, X-17, Y-4 etc.).

Getting lead from this success in 2014-15, the data was PSDM re-processed. Study of this merged volume led to a more refined understanding of the area and also identification of drillable prospects for exploration. Recently, drilling of well X-22 identified, based on the same data, produced hydrocarbon from four different sands within Daman Formation (Sand -30, 40, 55, 60).

Post success of well X-11, seismic amplitude anomaly was consistently used as a tool for identification of drillable prospects using the same study, which led to the drilling of 9 gas wells (X-12,13,14,15,16,17,18,20,22) and resulted in substantial exploratory success. Only three wells (X -19, 21, & 23) proved to be dry. Recently, the angle stack data of merged volume were studied in the whole area to bring out the hydrocarbon distribution and to generate new prospects, the details of study and analysis are explained below.

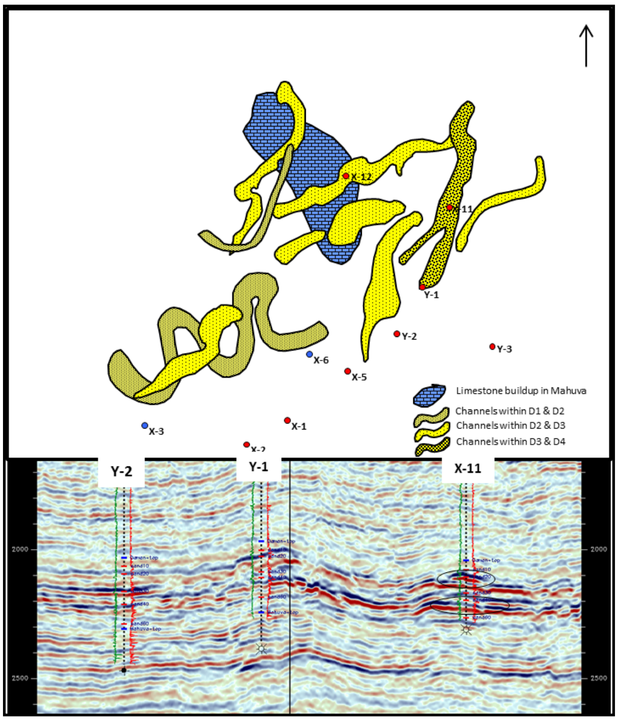


**Fig 5.** Daman channel complex and seismic section showing well X-11

## Analysis of elastic properties using petrophysical data:

To understand the elastic properties of Daman pay sands, an analysis was carried out from the drilled well data. Wells used for the study were X-7, X-11, X-13, X-15, X-18, X-22, X-25 and X-27. Cross plot of Vp/Vs and P-Impedance were attempted to understand the character of sands. The sands in B12/C26 area show class III AVO anomaly in a broad sense. The impedance value for the gas bearing sands varies from 4000-7000 and in deeper sands it goes up to 9000. The Vp/Vs value varies from 1.5 to 1.8 in case of gas bearing sands (Fig 6). The wide range in P-Impedance values render it not to be called classical class III AVO anomaly. From the analysis of cross-plots, the reservoir and non-reservoir facies are separated out clearly. Some of the water bearing sands shows moderate P-Impedance and low Vp/Vs which is the reason why at some places the water bearing sands were not clearly separated from the gas bearing sands. Some gas bearing sands also demonstrate higher P-Impedance and moderate Vp/Vs values. This makes discrimination of gas bearing sands from those of water bearing a challenging task. Fitting of a trend line has been attempted to discriminate gas and water bearing sands with more certainty.

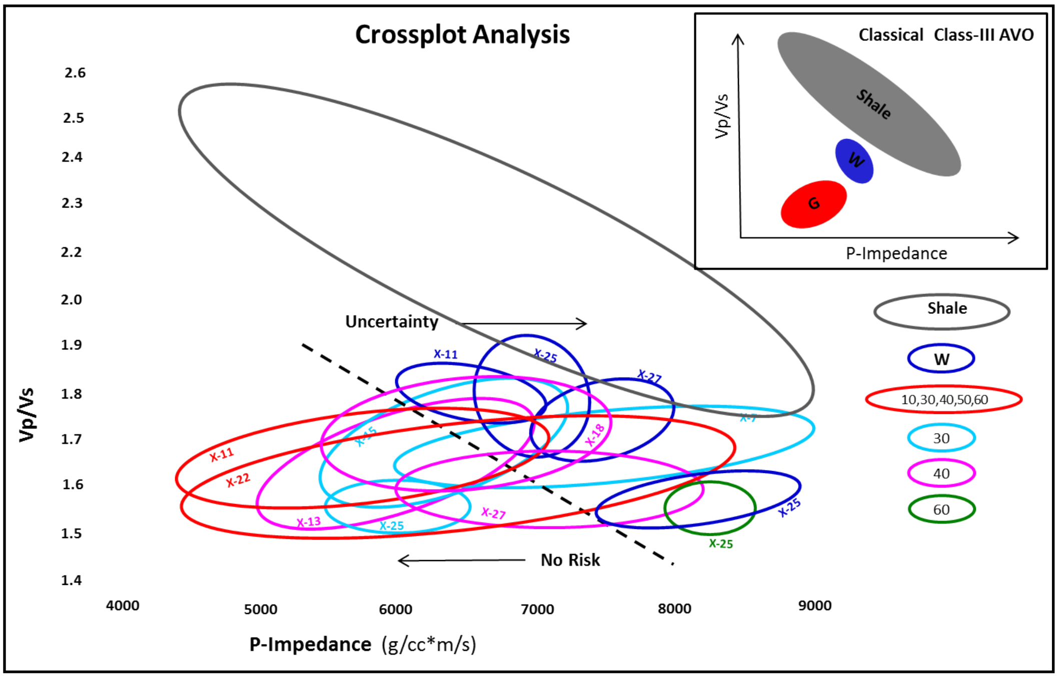



**Fig 6.** Cross plot of Vp/Vs versus P-Impedance for different wells with a trend line

## Demonstration of class-III AVO sands using seismic data:

Having understood the elastic properties of reservoir sands in the area a merged data set was taken up for re-interpretation, with special emphasis on partial angle stack data set in order to capture class III AVO effect of these reservoir sands on seismic. Four prominent markers were correlated (sand 10, 20, 30 and 40) where other sands (sand 50, 55 and 60) towards the deeper part are not mappable in seismic data within Daman Formation. To better visualize the depositional pattern, various seismic attributes were extracted by using the horizons correlated on far stack volume. Pattern emerging on studying these attributes were generally indicative of channel and bar sands. It was observed that not only reservoir sands belonging to level 30 and 40 were better visualized as far as continuity and clarity was concerned, it also brought out another set of shallower sands called 10 which were not seen and analyzed in previous studies carried out so far.

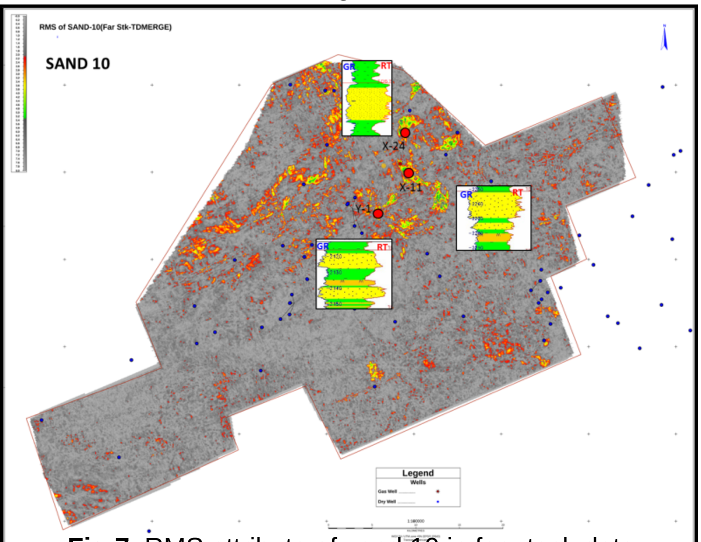


**Fig 7.** RMS attribute of sand 10 in far stack data

**Sand 10:** The attribute studies carried out earlier in sand 10 was very sporadic and didn't have a clear channel geometry, only a patch was seen around the well X-11 but in attribute analysis using far stack data, a perfect meandering channel was seen passing through X-11 and Y-1 where the well X-11 have mid channel facies interpreted from well log character (box sand) (Fig 7). One exploratory well X-24 was drilled in one of the meandering lobe based on this study, which gave hydrocarbon and proved the prospectivity of the channel.

**Sand 20:** Sand 20 showed a well-defined channel feature which was not clearly defined in previous interpretation, where X-10 was the first well to be drilled but it got dry from that level, although the reservoir facies was well developed. Similar case happened with X-11 but lack of effective seal above sand 20 might have been the reason for its dryness as the thickness of intervening shale between sand 10 and sand 20 is very less where sand 10 is a gas producer. Recently one well was drilled to test the sand 20, it encountered 22m of sand, but it was water bearing (Fig 8). This sand highlights the uncertainties pertaining to AVO analysis. The Vp/Vs and P-impedance values for water bearing sand of sand 20 have a range similar to gas bearing sand of other well (Fig 6), possibly due to variation in clay content. The behavior of sand 20 in all the drilled wells suggest that the amplitude anomaly is controlled by some other factor, may be the clay content and grain distribution in that particular level, so it is safer to avoid sand 20 till the reason was not clear.

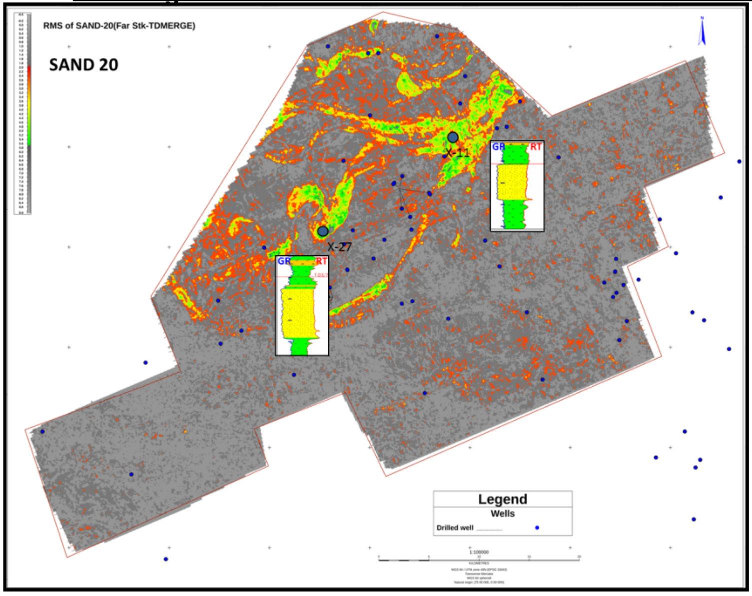
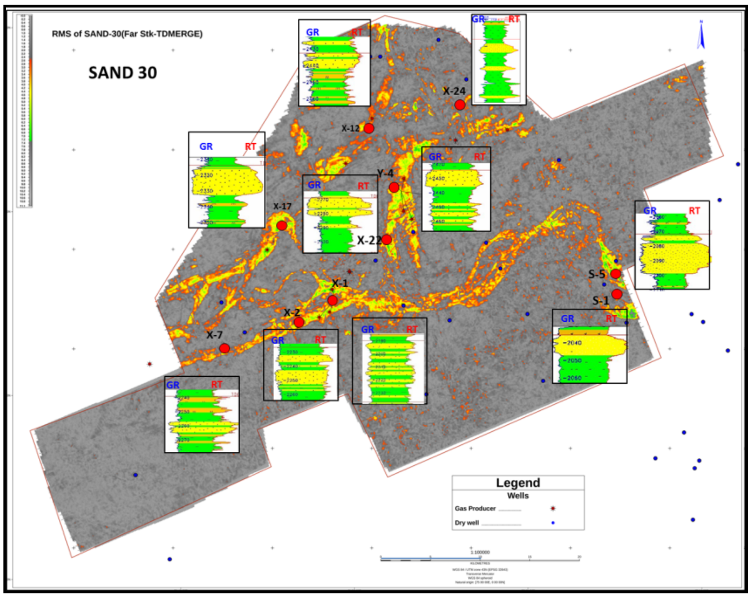


**Fig 8.** RMS attribute of sand 20 in far stack data



**Sand 30:** Sand 30 is the most prolific producer in this area and widely spread. The far stack attribute analysis gave a clear picture of channel pattern in sand 30. Three main channel patterns came out from far stack study, the N-S trending channel, the E-W trending channel, the NE-SW trending channel system (Fig 9).

The channel geometry is more prominent in far stack data and the E-W trending channel was come out for the first time (Fig 9). Two wells were drilled in sand 30 based on this study and out of which one well was hydrocarbon bearing and another was dry. The reason for dry well is attributed to absence of structural component for the entrapment. The attribute around the well can be explained through marginal gas saturation in the sand; however the strength of the anomaly is less as compared to other hydrocarbon bearing wells in the area. This would need quantitative interpretation of these amplitudes to mitigate the risk. Another recently drilled well X-24, with primary objective as Sand10, encountered sand 30 although it didn't have amplitude anomaly at the well position. The reason is nature of sand encountered in the well where four thin sands interlayer with shale bands produced hydrocarbon (Fig 9). Therefore, the far stack data was not able to resolve the sand.

**Fig 9**. RMS attribute map of sand 30 in far stack data

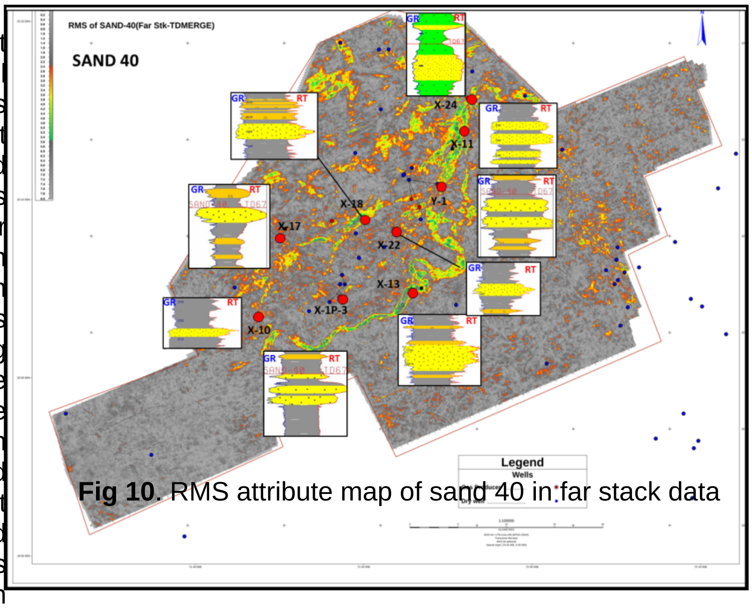



**Fig 10**. RMS attribute map of sand 40 in far stack data

**Sand 40:** Sand 40 is also a prolific producer in the area. Earlier the channel configuration was not well defined in case of attributes extracted from the full stack data of merged volume whereas the far stack data of merged volume enhanced the channel configuration as well as the channel continuity (Fig 10). Recently one well was drilled for the sand 40 based on far stack data analysis and got hydrocarbon.

## Conclusion:

- B12/C26 field witnessed multiple phases of exploration and proved to be a major gas producing area in Tapti-Daman Sector
- The attributes derived from far stack volumes linked conclusively the various channels brought out by previous attribute studies of sand 30 and sand 40, as well as two shallow sands; sand 10 and sand 20 also emerged out clearly.
- After analyzing the results of drilled wells it is established that majority of these reservoir are expressed through amplitude anomaly in far stack data. However strength of amplitude is related to thickness of reservoir sands, clay content and clean sand /alternation of sand & shale.
- Presently this field is producing gas from Daman Formation from 9 wells using two platforms and four more platform are planned/established to exploit gas from this field.

## Acknowledgements

Authors are indebted to Shri M Ayyadurai ED Basin Manager WOB for continued guidance and motivation to write the paper. Acknowledgements are also due to ONGC Management for permitting the authors to publish the paper at APG platform.

## References

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