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Mapping Incised Valley Fill Systems: Application of Sequence Stratigraphy and 3-D Seismic Attributes

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Summary

The 3-D seismic and well data of B-12/C-26 area of Tapti-Daman sub-basin of Mumbai Offshore Basin, India, have been evaluated for mapping of reservoir facies and entrapments within Daman Formation of Upper Oligocene age. The seismic data have been interpreted with application of sequence stratigraphy, 3-D visualization, seismic attribute analysis, coherency, and AVO analysis methods. The basic framework for analysis was defined by correlating bottom and top reflectors of Daman Formation and four internal reflectors. Application of concepts of sequence stratigraphy on logs and seismic data revealed formation of incised valleys in the upper part of Daman Formation. These valleys were filled by fluvial/ estuarine channels which are oriented in east-west direction. In the middle and lower part of Daman Formation, channels are oriented in northeast-southwest direction and are distributary-fills in nature. Depositional geometry and internal facies variations of channels were inferred from seismic attribute maps, coherency and AVO attribute slices. Thick sandstones are inferred in fluvial/estuarine and distributary channels. Stratigraphic entrapments are envisaged for lower and middle channel sandstone reservoirs.

Introduction

Incised valleys are most landward part of uppermost lowstand system tracts formed across type 1 sequence boundary (Mitchum et al., 1993) and are attractive target of exploration because of excellent reservoir quality of associated channel sandstones. Late lowstand to early transgression periods are favourable for formation of incised valleys on emergent shelf and their filling by fluvial/estuarine channel deposits. Three main problems are encountered in incised valley exploration, i.e locating the valley, ii. delineation of reservoir sandstones within valley and iii. finding trap for reservoir (David W. Bowen et al., 1993). Incised valleys often generate discontinuous reflections of varying amplitude which are difficult to interpret laterally (Peyton et al., 1998). Identification and mapping of fluvial channels is possible by integrated interpretation of 3-D seismic data with application of concepts of sequence stratigraphy by which depositional environments and possibility of formation of valley can be predicted. 3-D seismic attributes map the geometry and facies variation within channels.

The area of study is situated in western part of the Tapti-Daman tectonic block of Mumbai Offshore Basin on the Western Continental margin of India (Figure 1). It comprises the shallow shelf region with water depth ranging from 25 to 30 m. In Tapti-Daman block, huge thickness of sedimentary rocks ranging from Paleocene to Recent is present. The general stratigraphy based on well information in the area is shown in Figure 2. Using concepts of sequence stratigraphy seven mega sequences have been identified. Age relationships, lithostratigraphy, along with seismic markers and depositional environments are also shown in the Figure 2. The Paleocene to Lower Eocene Panna Formation unconformably overlies on Basalt/Basement. It was deposited under fluvial to shallow marine conditions and is main source rock in the area. Middle Eocene Belapur Formation consists of mainly calcareous shale and

Middle to Upper Eocene Diu Formation comprises silty shales. The overlying Lower Oligocene Mahuva Formation contains predominantly shales with thin streaks of carbonates deposited in estuarine to shallow open marine environments. The Upper Oligocene Daman Formation unconformably overlies the Mahuva Formation and contains sandstone reservoir rocks deposited in fluvial/estuarine regime with tidal influence. The overlying Middle Miocene Mahim Formation is mainly shaly. This paper is mainly focused on Upper Oligocene Daman Formation. The area is affected by Late Miocene Wrench Tectonics associated with northward movement of Indian plate (Pangtey, 1996).

In the Tapti-Daman area, 3-D data were acquired under different vintages for delineation of pay zones proved by exploratory wells drilled mainly over structural prospects. The 3-D data for present study comes from single 3-D volume of Pre-stack merged and pre-stack time migrated (PSTM) multi-vintages 3-D data volumes, I, II, III and IV (Figure 1). A subset of PSTM data covering B-12 and C-26 structures and spread over 1000 km_2 area with bin size 25.0 X 12.5 has been used in the present study. Twelve drilled wells (A to L) fall in the study area.

The objective of present study is mapping of reservoir sandstones and assessment of hydrocarbon entrapment potential within Daman Formation. The data has been interpreted by applying sequence stratigraphy, 3-D visualization and seismic attributes. Channel sandstones and stratigraphic trapping conditions are envisaged.

Sequence architecture

The horizon and fault correlation within area is shown on a northwest southeast transect passing through well J (Figure 3). The Mahuva Top and Daman Top unconformities bound the Upper Oligocene Daman Mega sequence at bottom and top respectively. Mahuva Top reflector being sandstone-shale interface (high to low impedance) produces low amplitude peak (Figure 4). Within Mahuva Formation thin carbonate streaks produce composite reflections consisting high amplitude parallel events due to strong impedance contrast between carbonate and marine shales. The Daman Top reflector being shale-sandstone interface (low to high impedance) produces troughs. In Daman Formation reflections are discontinuous and varying high amplitudes occur in patches. Intense faulting and folding caused discontinuity and lowering of amplitude. The small extent polygonal faults (Figure 5, 3), further complicate the correlation of seismic events.

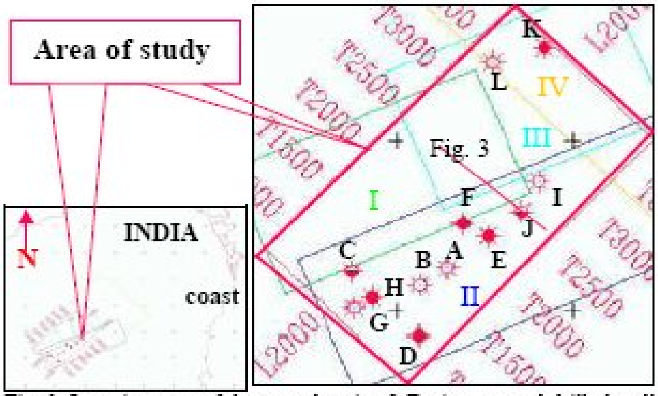

Fig. 1. Location map of the area showing 3-D vintages and drilled wells

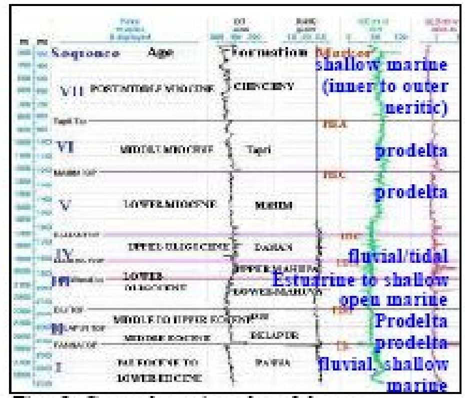

Fig . 2. General stratigraphy of the area

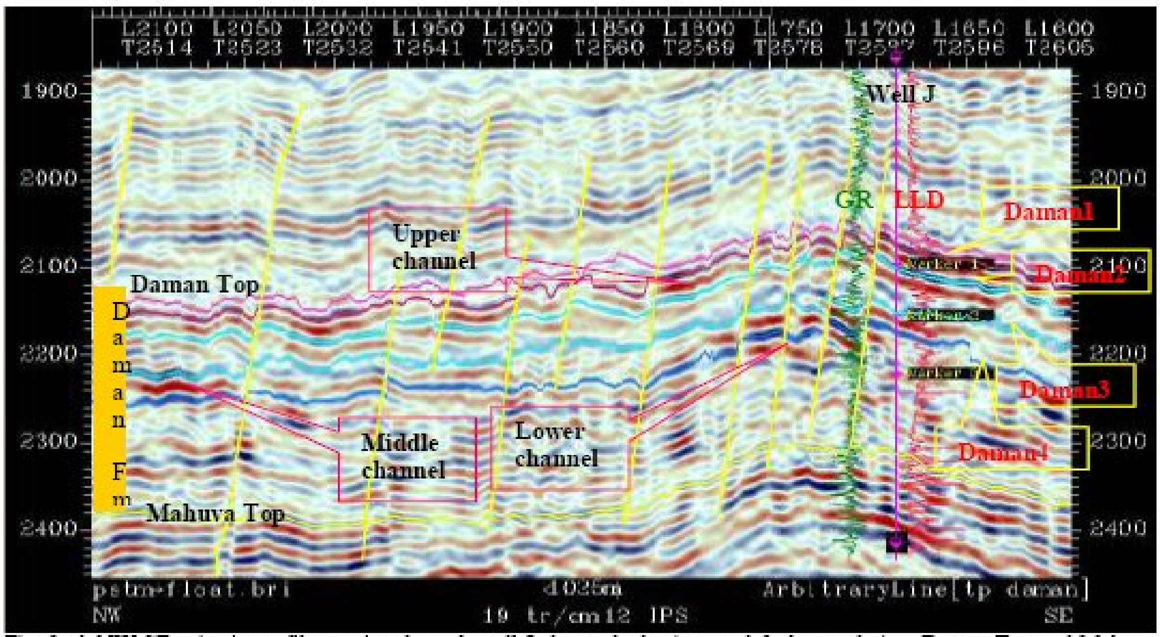

Fig. 3. A NW-SE seismic profile passing through well J shows the horizon and fault correlation. Daman Top and Mahuva Top reflectors bound the Daman Formation. Daman1, Daman2, Daman3 and Daman4 reflectors are within Daman Formation. Gamma ray and resistivity logs are overlaid and channels are marked on the seismic section.

Within Daman Mega sequence, four sequences each consisting of lowstand, transgressive and highstand system tracts are identified on the basis of gamma ray and resistivity logs (Figure 4). The gamma ray values are lowest at bottom (lowstand), highest (flooding surface) in middle and moderate (highstand) on top. The global eustatic curve (Figure 6) shows high frequency relative rise and fall of sea level within Upper Oligocene and inferred high frequency sequences may be caused in response of eustatic changes. On seismic sections such discrimination is difficult because of low frequency and interferences from adjacent thin beds (Figure 4). The seismic signatures of Type1 sequence boundary and lower and middle part of lowstand system tract (basin floor fan, slope fan and delta front etc.) are not visible within area but incised valleys which are uppermost part of lowstand system tract are inferred on logs of few wells (e.g., log profile through wells C, H, and D, Figure 7) and seismic section passing through wells C and H (Figure 8) specially in the upper part of Daman Formation. The synthetic seismogram of well J (Figure 4) generated by using wavelet extracted from seismic shows that depositional sequences interpreted on logs do not generate one to one correlatable seismic events on synthetic or real data, however reflection characters (amplitude, frequency) significantly differ from sequence to sequence. Depending upon standout and correlatability of seismic events within Daman Formation, four reflectors named as Daman1, Daman2, Daman3 and Daman4, from top to bottom are correlated across the area (Figure 3). The reflection configurations and seismic sequence attributes are analyzed with reference to these reflectors.

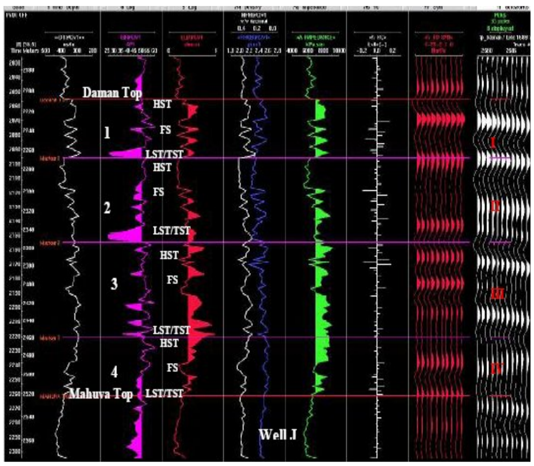

Fig.4. Well to seismic tie, log signatures and depositional sequences (1 to 4) within Daman mega sequence. Seismic sections can be subdivided into four equivalent sub-units (I to IV).

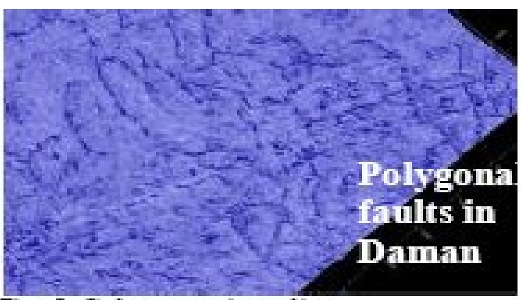

Fig. 5. Coherency time slice

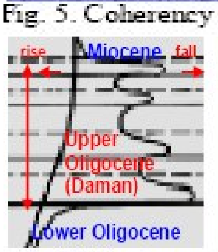

Fig. 6. Global eustasy curve

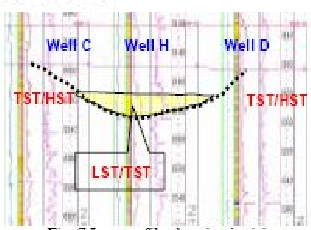

Fig. 7 Log profile showing incision

Inferring geomorphology and sand dispersal

The channels are identified on vertical sections (**Figure 9**) by isolated high amplitude reflection packages. The obvious channel signatures, concave upward erosional surface at base that down cut underlying bed rocks and high amplitude planar surface at top that separates the channel from overlying shales, are occasionally visualized on sections (Figure 8, 9).Horizon slices of real amplitude and attributes, 3-D visualization of flattened volumes and attribute extraction within narrow windows along correlated horizons mapped prominent channels at three stratigrahic levels. Opacity controlled 3-D visualization of flattened reflection strength volume depicts all three channels simultaneously (Figure 10). The spatial position and other attributes of the individual channels are presented in the following sections:

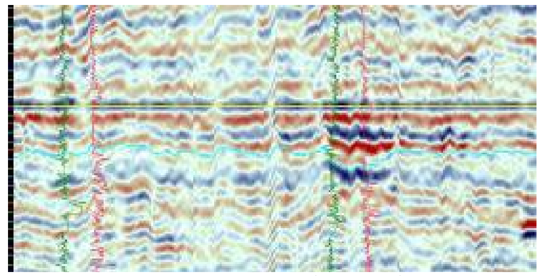

Fig. 8. Section showing signature of channel fills

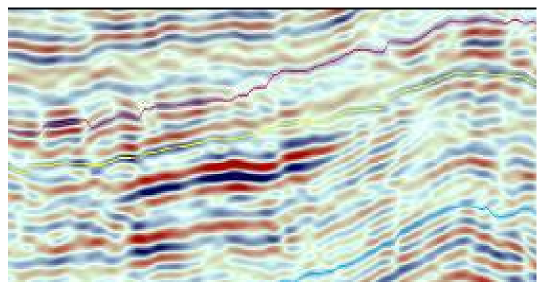

Fig. 9. Section showing signature of channel fills

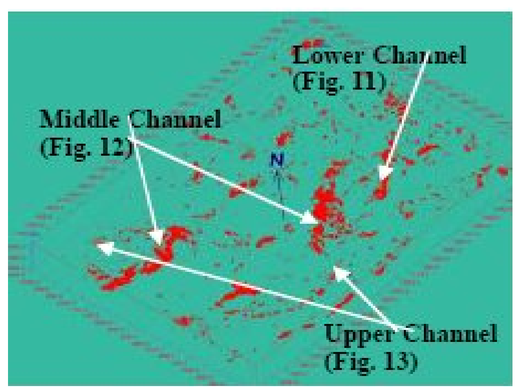

Fig. 10. Opacity cube of flattened volume showing channels at different levels

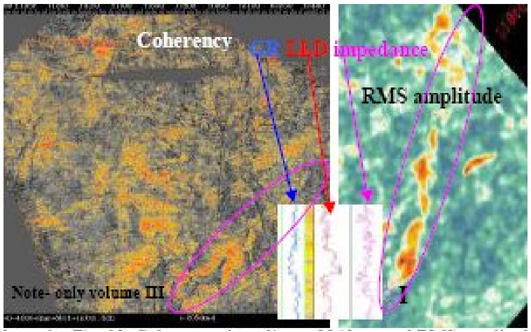

Fig. 11. Coherency time slice at 2240 ms and RMS amplitude map showing lower channel

1. Lower Channel: This is a northeast southwest oriented channel in the middle part of area (Figure 11). The channel is distinctly visible on coherency time slices in volume III. It is best mapped by RMS amplitude extracted within 0 to +40 ms window with reference to Daman4 reflector. It is relatively straight with length 14 km., width 800 m and estimated depth 40 m. The amplitude anomaly does not suggest extension of channel through well I but fining upward log motifs within equivalent time interval show thin channel sandstones which is also gas bearing. The thin gas sands have very low impedance contrast with respect to enclosing shales (Figure 11) and do not generate recognizable amplitude anomaly.

2. Middle channels: The RMS amplitude within 0 to +30 ms window with reference to Daman3 reflector shows very extensive channel systems within middle and northwestern portion of area (Figure 12). The northwestern channel has two preserved segments, western and eastern and in-between segment appears to have been eroded and reworked along its length. The channel in the middle part is flanking the structure but does not extend up to drilled well J. Water bearing sandstones of 11 m thickness with fining upward log motifs are encountered in the well J. The water bearing sands in the well J have insignificant impedance contrast and do not produce amplitude anomaly. The spatial position of middle channel situated in middle portion is visualized by volume detection and rendering. The detected voxels within a given amplitude range are highlighted by opacity control (Figure 12).

3. Upper channel system: It is very extensive channel system mapped in northwestern and southern part of the area showing meandering of varying sinuosity (Figure 13). It is best mapped by reflection strength horizon slice at +40 ms with reference to Daman1 reflector. Northwestern channel is relatively small and has very high sinuosity. Seismic section along the meander channel shows isolated bands of high amplitude reflections. Its origin appeared towards northeast of study area. The southern east-west channel is relatively straight and extends beyond the limit of the study area. Two drilled wells H and J penetrated the southern channel and encountered water bearing thick sands of very high impedance and good porosity. Gamma ray and resistivity logs show fining upward motifs. The amplitude anomaly is generated by high impedance contrast between gas-sands and enclosing shales.

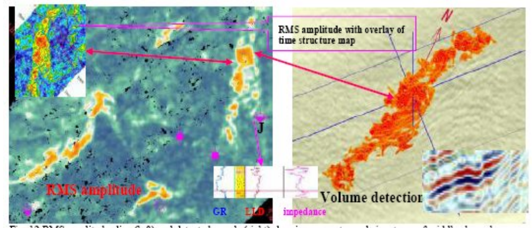

Fig. 12 RMS amplitude slice (left) and detected voxels (right) showing geometry and signatures of middle channels.

Reservoir characteristics

Mapping of channels and inferring sandstone deposits within channels are based on high amplitude reflection packages. Generally, sandstones have varying impedance contrasts with respect to enclosing shales. The cross-plot between gamma ray and impedance in the upper channel sandstones in well H shows relatively higher impedance for water-sands (Figure 14). The cross-plot between net sand thicknesses and RMS amplitude within Daman1-Daman2 interval shows proportionate relationship (Figure 15). Gas bearing well I does not fit in this trend because it has low amplitude and high sand thickness. The cross-plot between gamma ray and impedance for well I (Figure 16) shows that gas-sands of lower channel may have relatively low impedance. Water bearing sands in middle channel may have low impedance and may not generate amplitude anomaly (Figure 12). The AVO analysis for lower and middle channel sandstones give positive P*G AVO anomaly. The P*G slice and PSTM gathers corresponding to middle channel show Class II type sands (Figure 17). Thus high amplitude reflections with positive intercept*gradient anomaly may be gas charged.

Trap characteristics

The middle and lower channel systems are found to be enclosed within shales (Figure 11, 12). Within identified channels vertical and lateral continuity is expected. Since channels are surrounded by shales they may form good stratigraphic trap. None of the drilled wells have penetrated lower and middle channels in the area of study. The Upper meandering channels extend beyond the area (Figure 13), so stratigraphic trapping conditions can not be predicted. Two drilled wells (H and J) penetrated the southern channel but went dry due to lack of trapping conditions though thick sandstones are encountered.

These channels are very risky targets in absence of structural entrapment conditions.

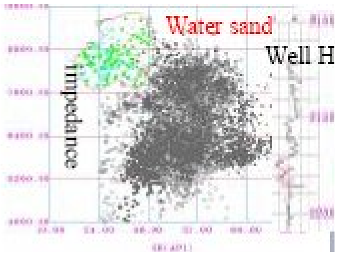

Fig. 14. GR-impedance X-plot

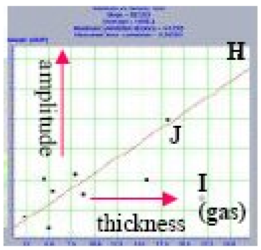

Fig. 15. amplitude-thickness X-plot

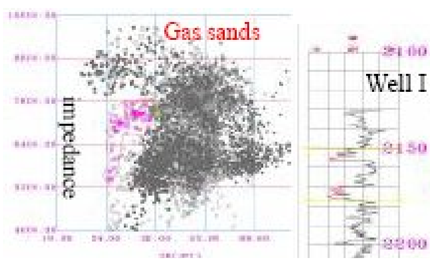

Fig. 16. GR-impedance X-plot

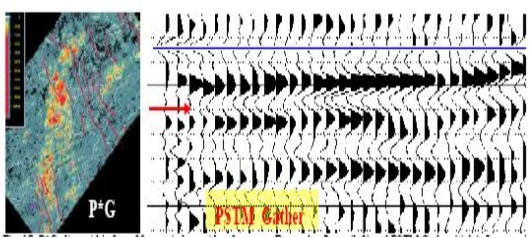

Fig. 17. P*G slice within 0 to -30 ms window with reference to Daman4 reflector(left) and PSTM Gather (right). Increase in amplitude with offset is distinctly seen on gathers.

Discussion and results

In the lower part of Daman Formation (sequence-4), log and seismic amplitude signatures indicate shale dominant section (Figure 3, 4). High amplitude reflection packages in upper sequences generated channel geometries when mapped by amplitude extraction in time windows with reference to correlated horizons (Figure 11, 12 and 13). The incision and fill signatures are obvious in upper and middle channels (Figure 7 and Figure 9). The older channels were deposited most probably in Lower Delta Plain environment by distributory channel-fills. Continued erosion and redistribution of sands is indicted by missing segment in middle channel (Figure 12). The upper channel is significantly different in depositional process, orientation, geometry and petrophysical property. It was deposited most probably by formation of incised valley and subsequent filling by fluvial-estuarine channels during relative fall and rise of sea level. Channels incised the existing delta plain deposits. The sandstones deposited in incised valleys are easily mapped by high amplitude seismic signature (Figure 13 and 14). Sandstones deposited by distributory-fills are thin and have low impedance contrast and do not generate the enough amplitude for mapping (Figure 16). The progressively varying geometry, location and increase in sinuosity of channels (Figure 11, 12, 13) from older to younger levels show progressive decrease in gradient.

Conclusions

Concept of sequence stratigrahy, 3-D visualization and seismic attributes has been applied for interpretation of 3-D data.Channels with sandstones have been mapped at three stratigrahic levels with help of 3-D visualization, coherency and analysis of flattened attribute volumes. The depositional geometry, impedance property and amplitude response of these channels are varying and do not guaranty the hydrocarbon (gas) accumulation. The AVO analysis within channels suggests possibility of gas saturation with class II/III type anomaly. Lower and middle channels have good potential for exploration.

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