Enhanced reservoir characterisation of a channel-levee-complex by mapping reservoir internal architecture in conjunction with local geology: Eastern deep offshore of India

Vallabhareddy Venugopala Reddy[1], Arup Sadhu[2] & Raksha Motiwala[3]

Geophysicist[1], Geologist[2] & Reservoir Engineer[3] in Reliance Industries LTD

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Reservoir characterisation, Channel internal architecture, Dynamic model

Abstract

In deep water turbidite channel-levee system reservoir characterisation is always a challenging job to match the seismic scale to reservoir scale due to reservoir heterogeneity especially when producing field. To address this issue of seismic scale reservoir heterogeneity, multiple datasets were incorporated and an integrated approach has been adopted to map the internal architecture of reservoir facilitating the water movement in the simulation model.

Inadequate water movement in four wells completed in the channel attributed to poor brine sand characterisation.

The issue was addressed by team of geologists, geophysicist and reservoir engineers. It was observed that the three deeper water sands of the channel were not adequately captured in the model and detailed sand characterisation of sand draw was necessary.

Consequently, the master channel surface was revised and deepened to accommodate the missing aquifer sands. Individual channel elements were mapped to model preferential lateral movement of water.

Before revising entire model, the missing brine sands were incorporated as a pseudo region assigned average sand properties. This effort improved water movement in dynamic model and understanding of water movement mechanisms. This demonstrates the importance of reservoir internal architecture mapping for a successful reservoir characterisation of turbidite-channel-levee-complex.

Introduction

Pliocene deep-water turbidite channel-levee sediments of the study area were deposited in the upper part of a regional sediment apron extending from the east coast of south India into the deep Bay of Bengal. Locally, sediment in this system was sourced by the Krishna and Godavari Rivers, likely augmented at times by longshore drift cells. The sediment was transported across a narrow continental shelf and spilled onto the slope, perhaps within a submarine channel or canyon.

Channel development, evolution, and shifting within the block were probably controlled by internal auto cyclic processes of channel avulsion, build-up, and abandonment. As the channel evolved, it has switched course and migrated, eroding a larger valley representing the outline of the entire meander belt. This larger valley or master cut appears to be a larger container or channel within which the main but smaller channels are situated. Vertical connectivity among this individual channel sands within the larger container is variable from excellent in areas, where erosion was effective in removing mud barriers between flow units, to poor at parts where muddy turbidite divisions are preserved between individual channel sand layers.

Successive episodes of cut-and-fill yield complex topography within the channel belt and their details are difficult to characterize in precise detail. Some fine-scale elements and internal channel elements are near the limit of seismic resolution and an effort has been made to do high resolution seismic interpretation through combined used of 2- D sections, RMS slices and 3D-geobody mapping. Intra-channel complexity is manifest in seismic lines cut perpendicular to channels, but lines cut down-slope across successive channels are extremely difficult to interpret in vertical seismic sections (Figs. 4 and 5). RMS amplitude slices are the optimum vehicle for interpreting meandering channels in the subsurface (Fig. 2 and 3).

The current work was carried out in two stages.

In the 1st stage, re-interpretation of the seismic data was done for major modifications / refinement of the master channel surfaces. .On the basis of major seismic discontinuities existing interpretation was refined and incorporated in the framework of the new geocellular model.

In the 2nd stage, were studied issues related to sand connectivity across the fluid contact and intra-well connectivity in the brine leg. An integrated approach has been adopted to map the sand bodies from gas to brine leg within the larger channel, smaller channel elements were mapped to model preferential lateral movement of water through individual channel elements.

Challenges

The gas filled channel sand bodies commonly appear on acoustic impedance inversion (RTI) maps as linear features deposited along the thalwegs of the channels, along their sides, and probably on small point bars. But, since the elastic property of water bearing sand completely overlaps with the overlying and underlying shale, it was really challenging to discriminate shale and brine sand through any particular acoustic attribute and to map sand continuity across the fluid contact.

Methodology

In the current study, internal sand bodies were mapped within the channel, based on the seismic, well log analysis, Gradient Impedance (G.I) attribute and stratal slice of RMS amplitude. These channel top and base were mapped in closely spaced seismic lines while simultaneously keeping track on stratal slices and 3D geobody disposition along with well log correlation. Sufficient care had to be taken at the fluid interface where polarity reversal of seismic events are expected. While incorporating these mapped sand units associated with individual channelised event with in the earlier interpreted Master channel interpretation, it was observed that the mapped channel base is shapped shallower at many places due to interpretation difficulty in the brine leg and at certain places revised it cut across the interpreted surfaces (especially towards the base and margins). Earlier interpretation was mostly guided by bright seismic amplitude against gas bearing sand. The methodology adopted for the study is shown below.

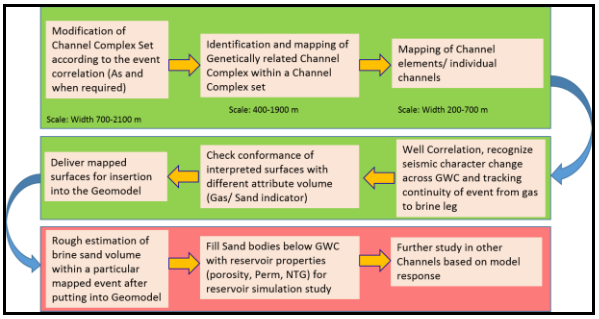

Figure 1: Methodology for brine sand characterization of study channel

Seismic event correlation and mapping of channel elements

Individual channel elements were identified from seismic amplitude and stratal slices made at every 20 m interval. Inferences and understandings developed during analysis of these stratal slices, were implemented while interpreting individual channel elements. Inferring the depositional history solely through RMS amplitude map for the entire channel complex together was very difficult. Entire channel complex seems to be connected in the combined map. However, detailed stratal slices of 20 m interval brings out continuity and point of disconnect for individual channel elements and subsequently the depositional history of the entire channel complex.

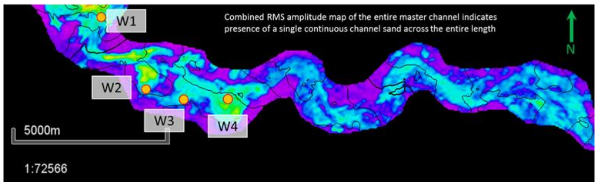

Figure 2: Sand connectivity and continuity all along the channel is deceptive while seeing the entire 100 m section together

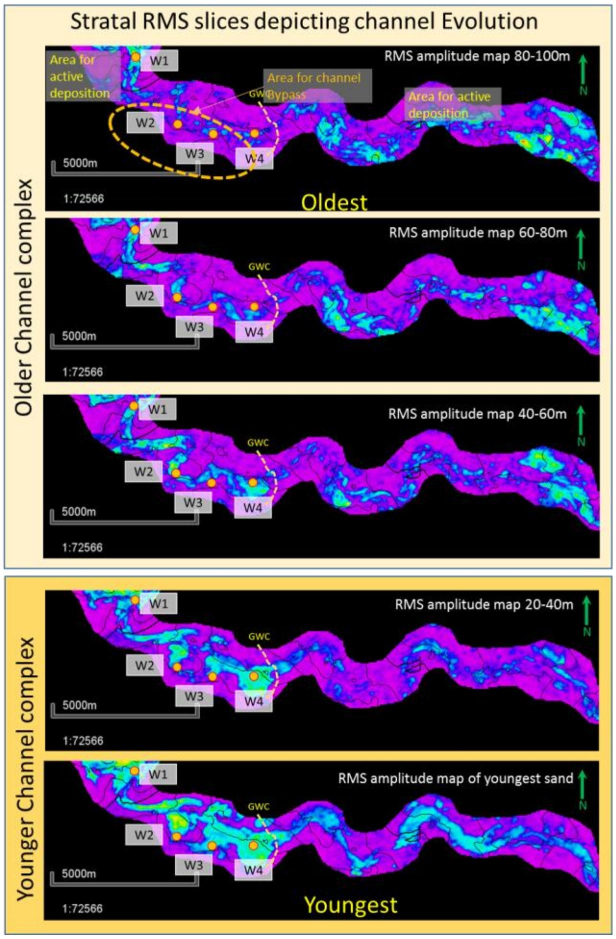

Figure 3: RMS amplitude map of the master channel complex at every 20 m interval

Figure 3 exhibits older channel events (E-C) actively depositing towards the updip portion of the channel mouth and it bypasses the middle part of the channel and carries rest of the sediment loads to the down-dip extent of the channel and deposits after losing energy. Whereas, the younger channel event re-incises at the Up-dip segment and breaches through steeper bends of older channel events. It is relatively straighter and continues down the channel length.

Five Channel sands have been mapped within master channel, three of which are gas sands with down-dip continuity into the brine leg. Two sands are completely water bearing and may have lateral communication with the up-dip gas sands. After QC, based on continuity, interrelationship and nearby well response against these five sands, it has finally been clubbed into three different sand bodies. The continuity of sands at the gas/brine interface was confirmed through GI attribute.

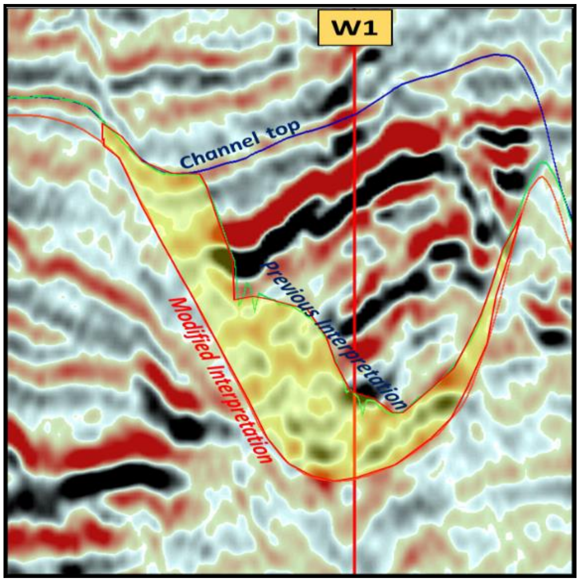

Figure 4: seismic section perpendicular to channel axis showing refinement in interpretation to maintain event continuity. Additionally incorporated gross rock demarcated in yellow color

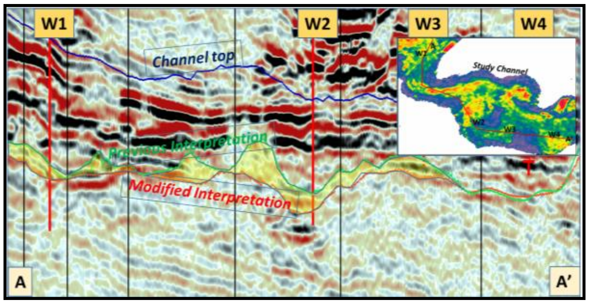

Figure 5: Seismic line along the channel passing through six wells, shows refined channel base interpretation

Polarity reversal of Seismic event against Gas-Brine interface

Multiple elastic attributes were analysed and it was found that brine sands are stiffer than overlying shale or gas sands. This phenomenon is likely to produce a polarity reversal at the brine sand interface and it is supported by well log information and GI attribute too. The reversal of amplitude response at the fluid interface is considered relevant in depicting continuity of event and implemented rigorously during interpretation. Seismic interpretation solely based on the GI attribute was not possible because of it's non-uniqueness across the field and depth dependency. GI attribute was used for QC of the interpretation only.

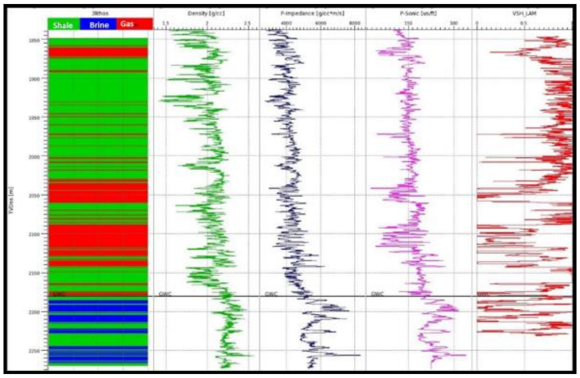

Figure 6: Well log panel of W1 showing elastic log response against gas/brine sand

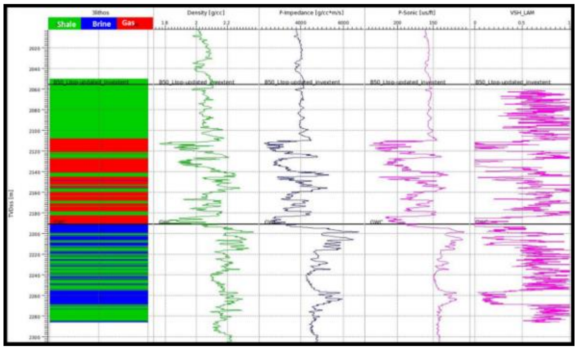

Figure 7: Well log panel of W2 showing elastic log response against gas/brine sand

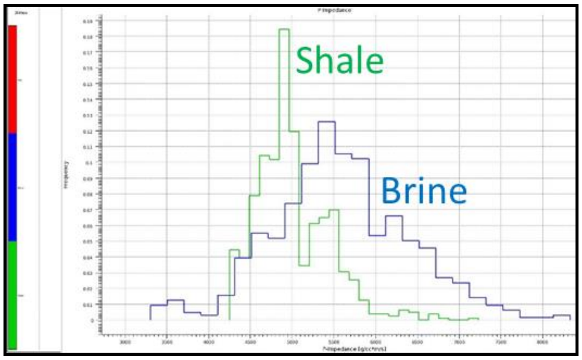

Figure 8: P- impedance histogram of shale and brine sand showing brine sand is relatively stiffer than shale. Well input W1 and W2.

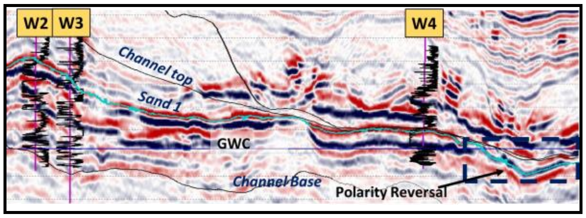

Figure 9: Polarity reversal in seismic across GWC

Final mapped sand bodies along with relevant cross sections are given in the following sections.

These mapped sands were incorporated as a pseudo region into the simulation model and tested. The region was assigned average sand properties encountered at wells. This effort improved match in the four wells in the working model.

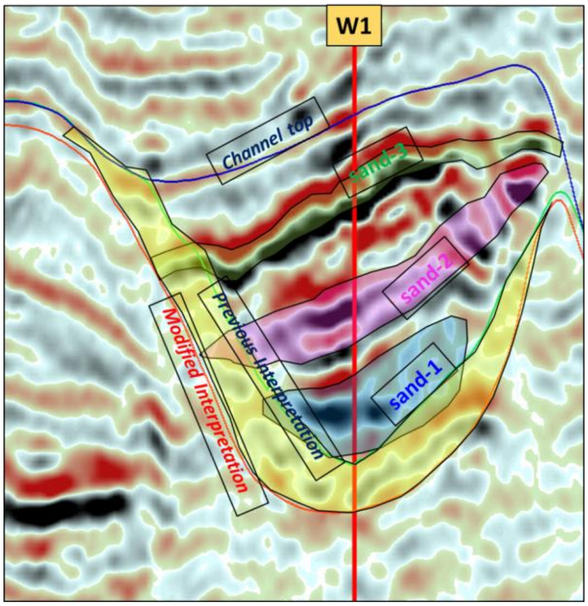

Figure 10: Seismic section passing through W1 well showing different internal channel elements.

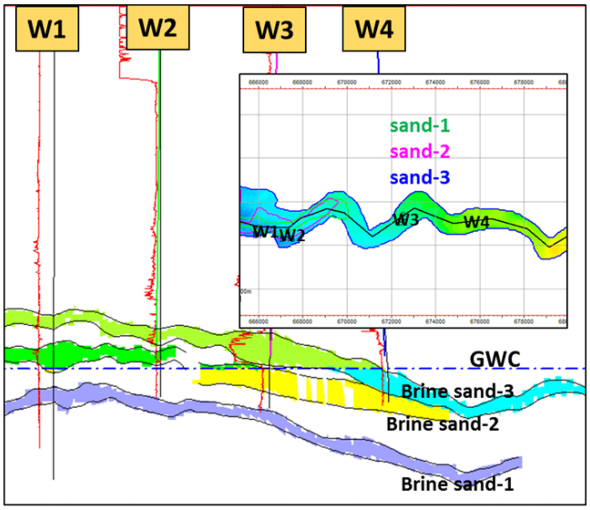

Figure 11: showing cross section view of three final sands in the master channel passing through wells

Results and Discussion:

Water moment in four wells was not observed in model. The issue was addressed by team of reservoir engineer, geologists and geophysicist. It was observed that the two deeper water sands of the channel were not adequately captured in the model.

Detailed brine sand characterisation of this channel was necessary to improve the channel architecture. The channel surface was revised and deepened to map the missing aquifer sands. Individual channel elements were mapped to model preferential lateral movement of water.

Before revising the entire model, the missing brine sands were incorporated as a pseudo region and tested. The region was assigned average sand properties. This effort successfully improved water movement at the well level.

Limitation:

Mapping internal elements within the seismic resolution has been attempted in this study but almost certainly, such features exist at sub-seismic scale too and well performance issues related to them can’t be addressed through this study.

Conclusions:

Based on the Seismic response, well log analysis and Gradient Impedance (G.I) attribute, a reasonable brine sand mapping has been carried out and delivered for simulation studies. Through implementation of these mapped sand bodies into the model, positive response is observed in simulation studies for most of the wells in terms of break-through timing and water match. Brine sand units in the model are more geologically explainable now.

Four wells completed in the Channel struggled to produce water in model even after 6 years of production. Through implementation of these mapped sand bodies into the model, the water movement improved in the 4 wells, hence improving the understanding of the water movement mechanisms in the channel. Brine sand units in the model are more geologically explainable now. Same interpretations will be integrated in the next revision of the geological model. The study demonstrates that complex reservoir characterization problems can be successfully addressed through integrated effort by subsurface team.

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