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Uncertainties in Hydrocarbon Exploration in Deepwater areas: a few case studies

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Summary

The era of easy to find hydrocarbon from conventional traps are gone and thus the present thrust of hydrocarbon exploration are mainly in the frontier areas, specifically in the deep waters. But the uncertainties involved for various components of petroleum system (e.g. reservoir, charge, trap, source rock etc) makes it difficult to assess because of wide variability of these components especially in rank exploratory deepwater areas. This paper presents a few case studies for assessing the petroleum system components in deepwater areas. Out of the seven cases, three case studies will discuss the reservoir uncertainty, two will highlight the generation/charging uncertainty of deep water reservoirs and one is on seismic imaging uncertainty for structural definition. The last case study will discuss about a DHI signature.

Keywords: *volcanics, Marl, Tight reservoir*

Introduction

The exploration in deepwater and ultra-deepwater areas bears a high financial risk mainly due to huge rig cost. Moreover the size of the findings vis-à-vis their commerciality is another major concern. The petroleum system components of the hydrocarbon reservoir become very difficult to assess in the complex geological situation present in some of the deepwater basins of India.

In this paper, seven case studies are presented dealing on the issues of petroleum system uncertainty in deepwater basins viz. three case studies on reservoir uncertainty, two on charging uncertainty, one on structural imaging uncertainty whereas the last one we will discuss a DHI case study.

The study areas for these case studies are from island arc and passive margin settings where sediment thickness varies from 5Km in passive margin and more than 3Km in *forearc* part of the island arc system of the basin.

The *forearc* sub-basin forms a part of Andaman island arc system which extends from Myanmar towards north to Sumatra in south with thick sedimentary sequences from Oligocene to Recent. The basin came into existence as a result of the northward movement and anticlockwise rotation of the Indian plate and it's under thrusting below Asian plate from Late Cretaceous onward. As subduction progressed, the '*Outer High Arc complex*' started rising steeply, thereby creating a depression or a '*Fore Arc*' sub-basin between '*Volcanic Arc*' and the '*Outer High Arc'*. The Western part of the sub -basin forms mainly from sediments derived from '*accretionery prism*' whereas the eastern margin is bounded by the outer arc of the main volcanic arc system. The sediment thickness towards eastern and western margin is much thinner and the in-between ponded low is having much greater sedimentary thickness (~3Km). The Fig.1 shows the schematic cross-section with study area in the forearc sub-basin.

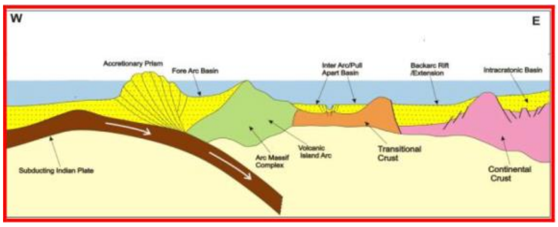

Fig.1. Cross-section of Island arc Basin with Fore-arc sub-basin & Accretionery Prism

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The second study area is from a pericratonic basin in East-coast of India which is having a thick sedimentary sequence from Cretaceous to Recent. In the deepwater part, the Mio-Pliocene sedimentary thickness increases because of collision of Indian plate and upliftment of Himalayas. The huge Mio-Pliocene sediments forms numerous channels and levee complexes (CLC) and are apparent in seismic sections. Number of wells have been drilled in the basin mostly targeting these Mio-Pliocene CLC complexes. Fig.2 shows a schematic cross-section of the basin.

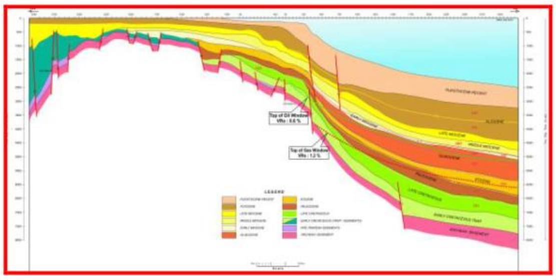

Fig.2. Cross-section of Passive Margin Basin of East-Coast of India

Uncertainties associated with Different components of Petroleum System

Reservoir Uncertainties

With the advancement of geophysical technology identification of probable reservoir zones become easier.

But still it is a challenge to predict the reservoir zones in exploratory areas with few or no well control. Following case studies show some of the variables which make the reservoir identification difficult, mainly because of the reservoir like seismic signatures of the non-reservoir units.

1. Reservoir Uncertainty -Presence of volcanic rocks

The area falls in the *forearc* sub-basin of the island arc system. Presence of thick sedimentary sequence along with structural closure in the area and presence of a *flat reflector* (F) in the shallower section was thought to be an attractive exploratory drilling target in the deepwater part of the basin where no well was drilled at that time (Fig.3).

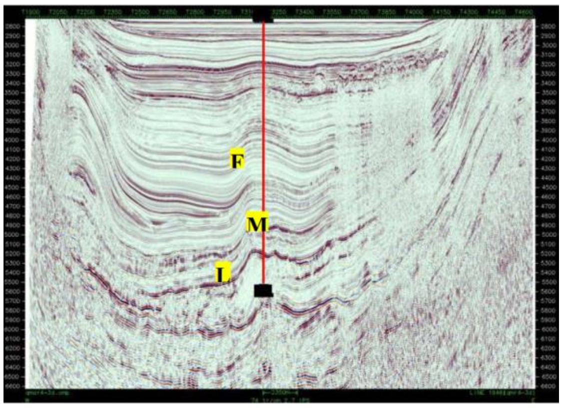

Fig.3. Seismic Section of Case Study-I – Reservoir Uncertainty

Before drilling, multilayered structural closure in both time and depth domain along with clastic and non-clastic *(deeper targret)* reservoir was envisaged as the hydrocarbon accumulation model.

After drilling, zones within structural closure above the *flat reflector(F)* found tight, though hydrocarbon bearing thin arenaceous reservoirs (~2m) was found above and below the anomalous zone (F). Conventional clastic reservoirs in the deeper Miocene section was absent. Drilled lithology shows presence of marlstone with volcanic rocks, thin silty layers and claystone within structural closures at different levels.

Fig.4 shows representative wireline log signature and thin section of side wall core of the Mio-Pliocene section of the well.

MTC (*mass transport complex*) zone(M) above the carbonate unconformity were having low V_p/V_s ratio generated due to high V_s value of volcanics admixtured with marlstone in the zone. Presence of tuff and volcanic glass within almost the entire section makes permeability of the envisaged reservoir zones within structural clossure close to zero.

Non-clastic carbonate (L) of Mid–Early Miocene deposited in *innner to outer shelf* was found having poor porosity. Overlying uncompacted clyastones might have affected the reservoir porosity of these carbonates.

Overall presence of volcanic rocks and marlstone resulted in poor permeability and porosity of the envisaged reservoir.

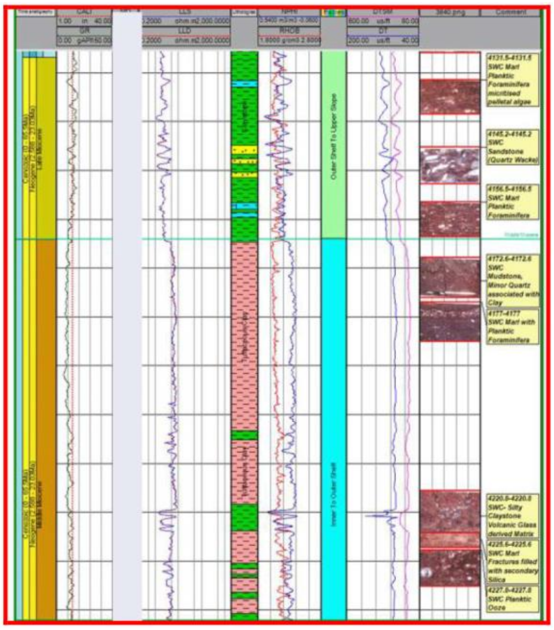

Fig.4. Typical log Signature & SWC of the well

2. Reservoir Uncertainty -Tight Non-Clastic Reservoir

The area also falls in the *fore-arc* sub-basin of the Island arc system. Regional correlation and presence of high amplitude in the Oligocene section indicates presence of carbonate rocks in the zone. The seismic correlation indicates the top of Oligocene also forms a structural closure. Fig.5 shows the seismic section of the well.

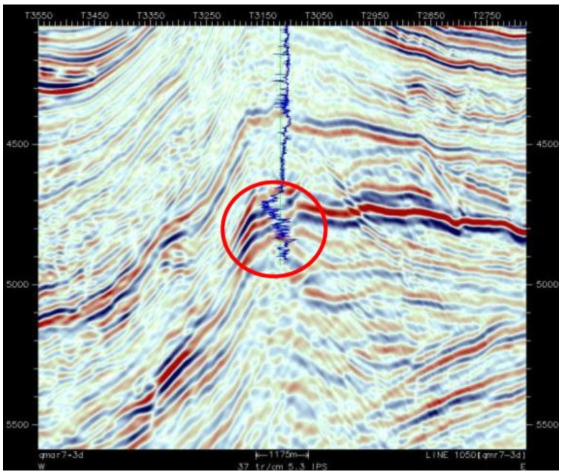

Fig.5. Seismic Section of Case Study-II

After drilling, the reefal limestone in the targeted zone was encountered but with almost no effective porosity and the zone was devoid of hydrocarbon. Fig.6 shows the log signatures and the side wall core of the encircled zone.

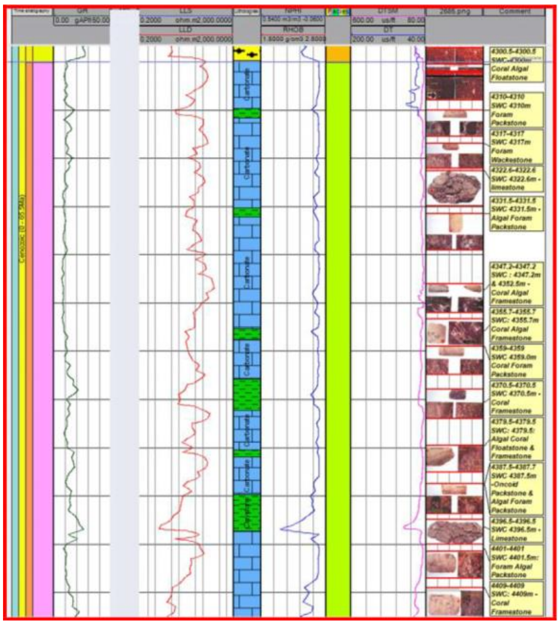

Fig.6. Carbonate Log signature of the encircled zone

In this case the age and lithology prediction was found correct. But before drilling, the reservoir zone could not be envisaged as tight, which resulted a dry hole.

3. Reservoir Uncertainty -Deepwater Limestone

The area falls in the Passive margin setting in east coast of India. Fig.7 shows the well location in N-S and E-W direction along with Average Absolute amlitude (AAA) and inst. Frequency of the high amplitude event (yellow reflector). Before drilling, a clastic high amplitude event terminating against the clay filled channel cut with fan shapped geometry and AVO anomalies was envisaged as a gas filled clastic reservoir.

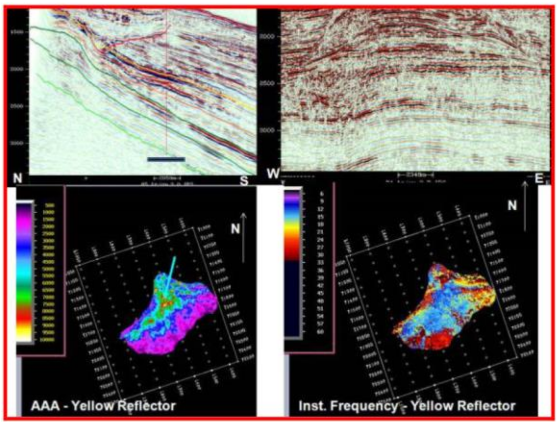

Fig.7. N-S & E-W seismic line with attributes of high Amplitude event (yellow reflector)

After drilling, the high amplitude event was found to be of carbonate with very thin (~1-2m) vertical zones and high amplitudes are originating because of carbonate presence rather than gas filled clastic reservoir. Fig.8 shows the detail log signature of the high amplitude zone along with seismic.

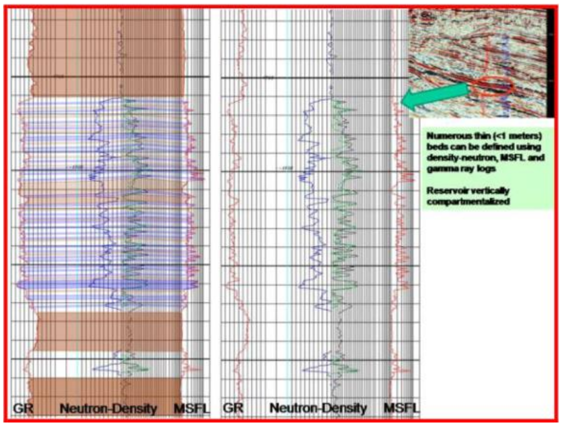

Fig.8. Detail log signature of High amplitude zone

Fan shapped amplitude distribution and downdip dimming of the amplitude was generated due to presence of very thin vertically compartmilazation of the envisaged reservoir.

Charging Uncertainties

Among all the components of petroleum system the most difficult areas of acessment is the '*charging and migration of hydrocarbon*'. Geophysical tools like AVO may indicate presesence/absence of hydrocarbon but the quantitative estimate for a drilling decission is difficult to asscertain. Whatever techno-economic parameters may be used for estimation of commercial viability, it is difficult to deal with the issues of fizz gas/ undersaturated reservoirs. In these two case studies one clastic and one non-clastic reservoir will be discussed where these problems had been encountered.

4. Charging Uncertainty -Deepwater Clastic Reservoir

The study area lies in the pericratonic setting in east-coast of India where prominent channel system has been interpreted from the seismic data. AVO and other anomalies also indicate the presence of gaseous hydrocarbon in the zone. Fig.9 shows the seismic section and average absolute amplitude map (AAA) of the high amplitude zone which clearly brings out the channel morphology.

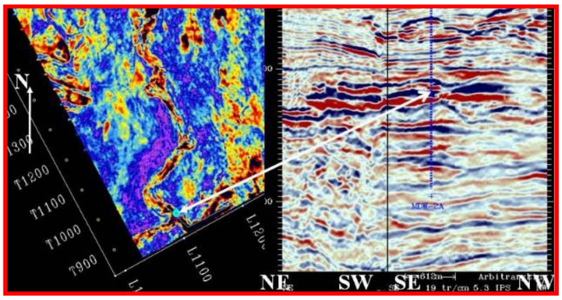

Fig.9. AAA of the channel zone & the seismic section through the channel amplitude

As predicted, gas was found in the high amplitude zone of the chaneel consists of sand bodies of 1-5m thickness seperated by shale/silty sand. Elan log signature of the gas bearing zone are given in Fig.10.

Since the sand bodies are not spatially continous, even after drilling a well, it is difficult to estimate the potential of these hydrocabon bearing zones with the best available technology. Moreover all sands within the zone are not hydrocarbon bearing. Since AVO and other geophysical tools are sensetive to presence of hydrocarbon, but not the saturation, it is almost impossible to acess the no of sands that will be charged within the sequece and to estimate the required no of wells for its delineation.

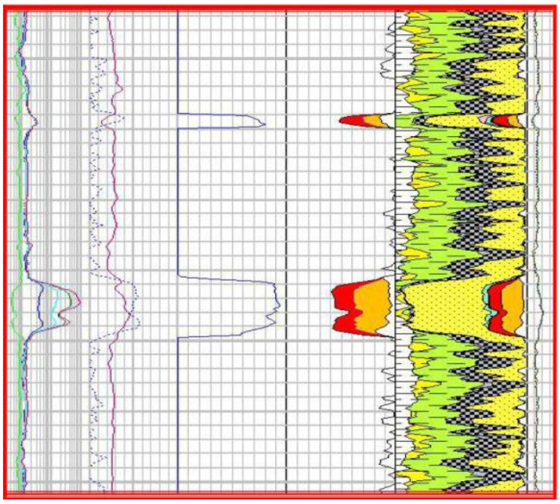

Fig.10. ELAN analysis of some zones within channel

5. Charging Uncertainty-Deepwater Limestone Reservoir

The study area lies in the *fore-arc* subbasin in island arc system. Here a carbonate body was targetted for hydrocarbon exploration. A graben was identified close to the target. Before drilling it was envisaged that the graben may act as a source pod to charge this body with the help of the associated fault seen in the seismic section. Similar results were also obtained from charge modelling studies with the available heat flow data. The structural entrapment as well as the good porosity was expected. The Fig.11 shows the seismic section of this target.

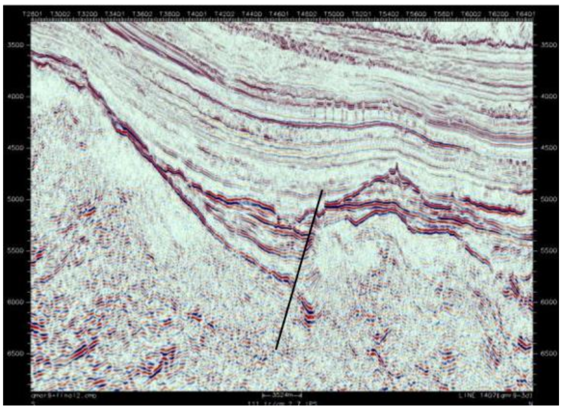

Fig.11. Seismic Section of carbonate body

After drilling, the heat flow was found lower than expected. The effective porosity log was analyzed within the carbonate body (Fig.12), which shows good porosioty development in the upper part which gradually decreases towards bottom

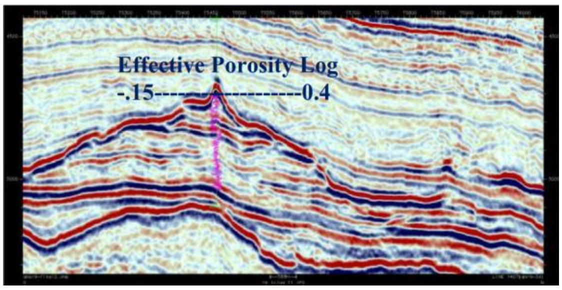

Fig.12. Seismic Section of carbonate with effective porosity log (zoom)

Uncertaniny for hydrocarbon generation due to lower heat flow and charging was not correctly envisaged from seismic and geological data as no well was drilled in the grabenal part. The other components of the petroleum system though present in the area *(viz. structural closure, effective porosity, close vicinity of a envisaged source pod etc.)* but generation/migration was the main factor for absence of hydrocarbon.

However, in the earlier case study, though hydrocarbon was present, the quantification of these hydrocarbon bearing sands are difficult to acess in pre-drill situation.

Processing Related Structural Uncertainties

In the rank exploratory areas with no well data, the seismic imaging is maily dependent on the computation algorithim and skill of the seismic data processor. This case study shows a PSTM and PSDM imaging of an area from island arc basin where structural defination may be a major issue for the interpreter.

6. *Structural Imaging uncertainties*

As mentioned earlier, the example is from a *forearc* sub-basin of island arc basin. The large structure in *fore-arc* sub-basin forms due to compresseional forces generated from '*Back-arc*' spreading in the east. The seismic data was primarily PSTM processed from a vendor. Fig.13 shows the PSTM processed seismic data.

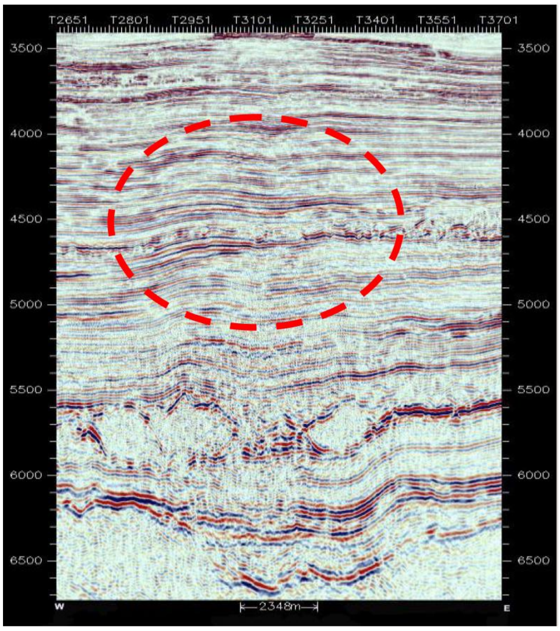

Fig.13. PSTM Processed Seismic Section

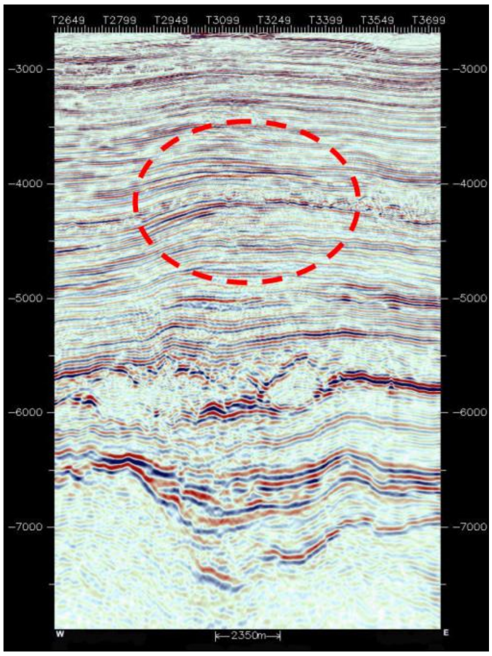

Fig.14. PSDM Processed Seismic Section

The data shows presence of a NW-SE trending structure with a low separating the two culminations. The western culmination is prominent in the lower section whereas some discrete high amplitude develops in the western culmination. Subsequently the area was PSDM processed. The Fig.14 shows the PSDM processed seismic line of the same area where structural amplitude of the low in-between the culminations almost diminishes in the upper part, but still the saddle shaped low exist in the deeper section. The structural definition was also highly altered in the lower section. Confusion further increases as PSDM processing from another vendor shows different configuration of the structure (Fig.15) with no low in-between. The definition in the lower section is also altered. The interpretation for structural genesis may be highly different for these three styles and affect the investment decisions.

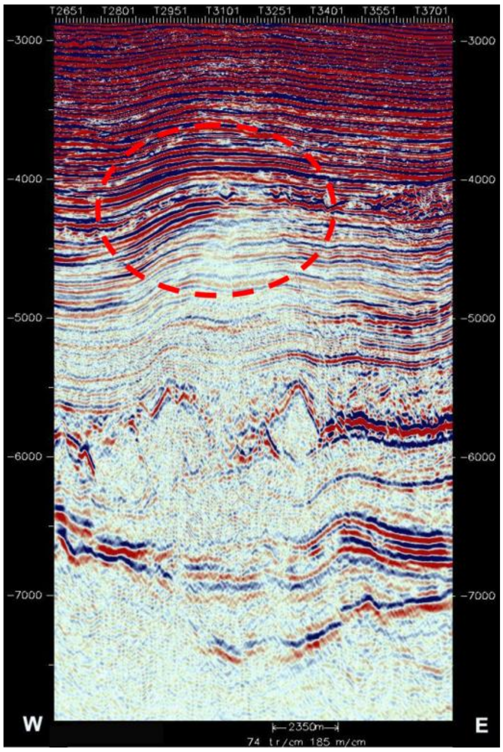

Fig.15. PSDM Processed Seismic Section of the same area

7. *Direct Hydrocarbon Indicators -DHI Intricacies*

This example is from again from the *forearc* sub-basin of Island arc basin and it is for a shallow target. The seismic section zone of interest has been shown in Fig.16. The RMS amplitude map over this high amplitude feature indicates a '*fan shaped morphology'.*

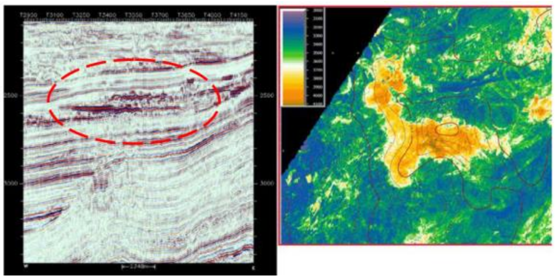

Fig.16: High amplitude seismic event in vertical section and it RMS amplitude distribution

The distribution of RMS amplitude prompts us for looking further into the anomaly by AVO analysis. Since anomaly was at shallow depth, it was expected to be sensitive for the hydrocarbon presence/absence. Fig.17 shows the AVO anomaly within high amplitude zone. High Positive P*G was observed in the zone indicating class –III type of anomaly.

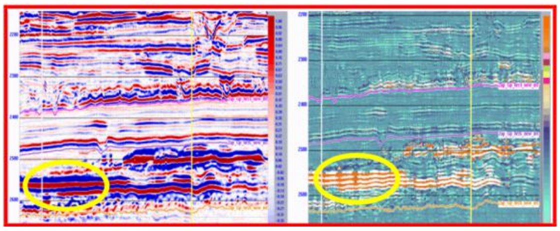

Fig.17. Seismic (left) & P&G Signature of the anomaly

After drilling, the high amplitude zone was found to be a false one, and the lithology obtained was mainly silty clay and there was no anomaly in the log signature. The envisaged sand in the upper section (fan like distribution of amplitude along with the standard logs superimposed on it (Fig.18) shows presence of minor silty layer within encased in dominantly argillaceous section. The high amplitudes generated in seismic is probably due to compaction difference within shale or due to tuning effects of silty layers

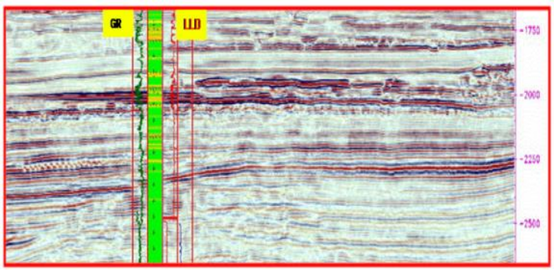

Fig.18. Depth converted Seismic section with logs & Lithology encountered in the zone

Conclusions

Seven case studies have been discussed form different basins dealing with the uncertainties of deepwater exploration. In deepwater exploratory areas the number of wells are less, so the sensitivity of seismic attributes with geological objects are often difficult to calibrate. Morphology of high amplitude zones may only be indicative of coarser clastics / hydrocarbon presence, which is one of the possibilities only. Even in best possible scenario, the uncertainties associated with different components of petroleum system cannot be nullified. Exploration risk can only be minimized with integration of geology of the area with proper use of geophysical tools and experience and skill of the interpreter.

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