Identification of residual oil zones in a part of Gandhar field using multicomponent seismic data

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Summary

Interpretation of Multicomponent Seismic data, as compared to traditional 3D Seismic studies, requires integration of PP & PS seismic data. In the last few years Multicomponent Seismic Interpretation studies have contributed to exploratory success and reservoir characterization in a few fields of Cambay Basin, as well as in a few other basins in India. An integrated approach based on reservoir performance analysis, observed fluid contacts in wells, local area contacts from well performance data and joint inversion data along with seismic driven petrophysical models was followed to identify zones of residual oil in the GS-9 pay in the area around well G#DD. Inversion output attributes were correlated with well sand thickness, and a relationship was established between the two. This relationship was used to populate the well property in the study area to generate sand isolith maps. Likewise, other petrophysical parameter maps (H_{eff}, S_w, V_{clay}) were prepared to characterise the reservoir. Common areas were identified satisfying the range of each attribute. The areas were further reduced by excluding zones having high cumulative water production. Three different zones for residual oil were identified.

Introduction

The Middle Eocene Hazad Member of Gandhar field (Fig. 1) in the Jambusar-Broach tectonic block of South Cambay Basin has been interpreted as a prograding constructive deltaic depositional systems with sediment input from east and northeast, and with development of tidal flats near its top[1,2]. A sequence stratigraphic study[3] of Hazad member suggests that the successive sandstone units (GS-0 to GS-9) exhibit a coarsening-up trend constituting a 3rd order highstand systems tract (HST), with the top of GS-9 representing a maximum regressive surface (MRS, [4]). The Hazad member consists of 13 different sand units, which

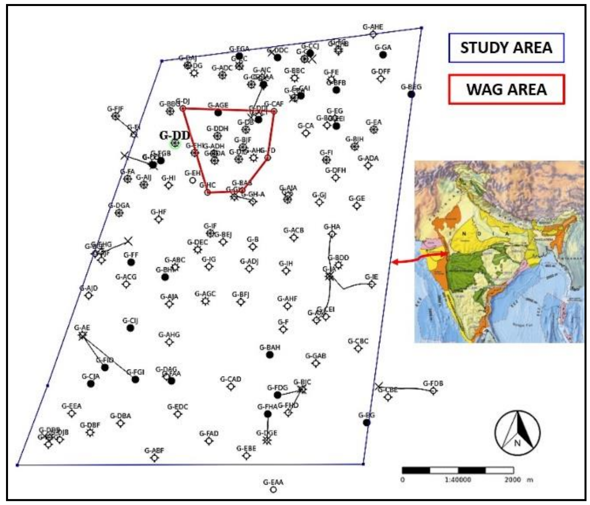

Fig. 1 Location map of the study area within Gandhar field

shows a westward progradation separated by events of marine flooding[5]. The degree of progradation is maximum in the middle part of the Hazad sequence. These sands are the major hydrocarbon contributors for Gandhar field, which is in production since 1986. The field has undergone various stages of development involving drilling of infill locations, water injection and optimization of water flood. Suitable EOR methods targeted towards recovery of some part of the remaining oil gives a tremendous incentive towards the field development, and ONGC has been actively exploring various advanced technologies including CO_2 injection etc., for EOR in Gandhar field.

In the present study area, water injection through designated wells in GS-9 sand in an area around well G#DD did not lead to the desired enhancement of hydrocarbon production from the targeted wells. The possible reservoir heterogeneity being not clear from existing well data, the problem was attempted to be addressed in the present study. Pre-stack joint inversion of PP & PS data yielded P-impedance, Shear impedance, Density and Vp/Vs ratio volumes. These

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volumes show good match at well locations and are consistent with the seismic data. Sand isolith as well as petrophysical parameter maps (effective porosity, water saturation and V-clay) of GS-9 were prepared to characterise the GS-9 reservoir in the area. Various reconstructed lines passing through different injector and producer wells were generated that explained the continuity/ discontinuity of GS-9 Geobody which, in turn, helped to understand the efficacy of EOR process.

Methodology

One of the objectives was to analyse the connectivity of reservoir facies between the injector wells and the producing wells within the WAG area. It was considered prudent to analyse for the presence of hydrocarbons around the producing wells.

PP and PS seismic data of 40 SKM around the well G#DD were taken up for joint inversion. Of the total 124 wells in the area, only 31 wells were considered for study. Out of these, just four wells were having shear wave logs and G#EAA, G#FHA and G#FHD were found to be suitable to run inversion.

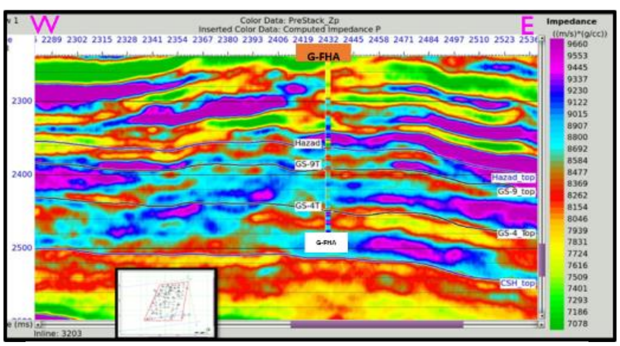

Fig.2: P-impedance section through well G#FHA

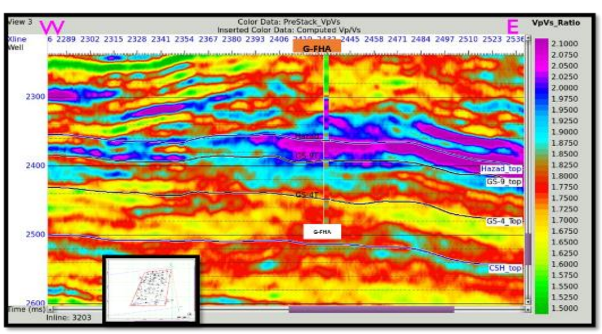

Fig.3: Vp/Vs section through wells G#FHA

Another well G#FDB at which only P-sonic was available, was also considered by estimating the S-sonic through Castagna's equation. A model based PP- S Joint inversion, optimized at the well locations yielded P-impedance, Shear impedance, Density and Vp/Vs ratio volumes. Sections passing through the well G#FHA overlain with P-impedance and VpVs attributes are shown in Figs.2-3. Colour coding suggests that the inversion outputs are quite matching at the well locations.

A. Generation of maps of petrophysical parameters at GS-9 pay level

An important application of inversion outputs is to generate sand isolith map and from the trend of it (considering as seismic), to generate petrophysical parameters maps. Initially, the best suitable attribute out of inversion outputs and a few on-the-fly generated PP seismic attributes were selected in terms of highest correlation factor. The Vp/Vs as well as P-impedance (Zp) attributes from inversion showed highest correlation factors of more than 22% with the sand thickness at the well locations, compared to the other attributes (Fig. 4). Out of these two attributes, Vp/Vs was selected as it is

	Well Log Data	Seismic Data	Correlation
164	GS9-ISOLITH	Zp GS9 GS9+14	-0.229553
165	GS9-ISOLITH	VpVs GS9 GS9+14	-0.224035
166	GS9-ISOLITH	Inst Freq GS9 GS9	-0.195406
167	GS9-ISOLITH	Dn GS9 GS9+14	-0.150477
168	GS9-ISOLITH	Zs GS9 GS9+14	-0.0958896
169	GS9-ISOLITH	Inst phase GS9 G!	0.000984793
170	GS9-ISOLITH	Deriv GS9 GS9+14	-0.128021
171	GS9-ISOLITH	Integ GS9 GS9+14	0.0405686
172	GS9-ISOLITH	Amp Envl GS9 GS!	-0.0592252

Fig. 4 : Correlation factor between well data (sand thickness) and seismic data.

very sensitive to presence of hydrocarbon. Hence, a relationship between the selected attribute and the well data (sand thickness) is established. This relationship is used to populate the well property in whole of the study area to generate sand isolith map. Kriging and then collocated co-kriging were run using the trend of Vp/Vs, by applying well-to-well variogram and seismic-to-seismic variogram respectively. Similarly, other petrophysical parameter maps such as effective porosity map, water saturation map as on 2017, cumulative water productions upto 2013 and 2017, cumulative oil production map upto 2013 and at 2017 were also generated for GS-9 pay using the trend of sand isolith in each case. Effective porosity follows the trend of sand isolith. It seems that the WAG area is divided into two parts in terms of sand count as well as effective porosity. The sand isolith and effective porosity maps of GS-9 are shown in Figs. 5A & 5B. Various reconstructed lines passing through different injector and producer wells

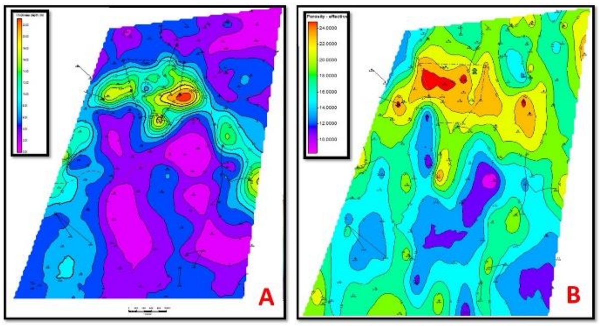

Fig. 5: A) Sand Isolith map and B) Effective Porosity map of GS-9 sand

were generated which explained the continuity/ discontinuity of the reservoir sand, and in turn, helped to understand the efficacy of EOR process. Water saturation map in the present scenario is very much required to find out the residual oil zones. Cumulative water production maps up to two different years lead us to quantify the

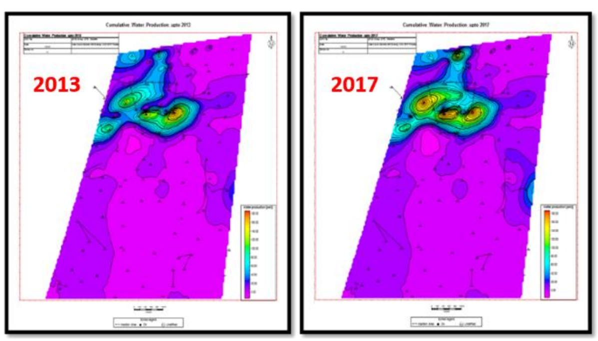

Fig. 6: Cumulative water production map at GS-9 pay at the end of 2013 and 2017.

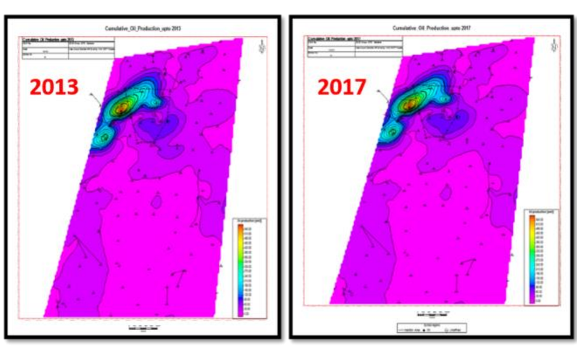

Fig. 7: Cumulative oil production map at GS-9 pay at the end of 2013 and 2017.

water flow and its direction of flow (Fig. 6). Cumulative oil production maps at two different years (Fig. 7) suggest that there is hardly any enhancement in oil production at the producing wells.

B. Connectivity among injectors and producing wells - enhancement of recoverable hydrocarbon in the producing wells

Various reconstructed lines passing through different injector and producer wells were generated which explained the continuity/discontinuity of the reservoir sand, and in turn, helped to understand the efficacy of EOR process.

i) RC line passing through injector well G#BAB and producing well G#DID

Effective porosity, water saturation and Vp/Vs sections along the RC line passing through well G#BAB & G#DID are shown in Figs. 8 to 10 respectively. The reservoir geobody that exists at these two locations in GS-9 pay seems to be narrow in between but the bodies are connected. Due to this

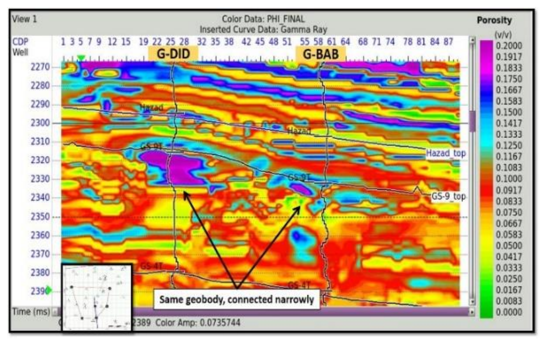

Fig.8: Effective porosity section along an RC line passing through wells G#DID & G#BAB.

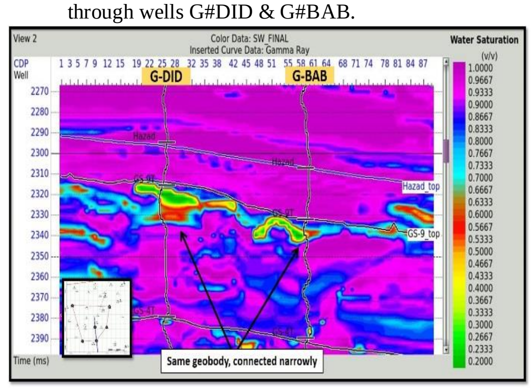

Fig.9: Water Saturation section along an RC line passing through wells G#DID & G#BAB.

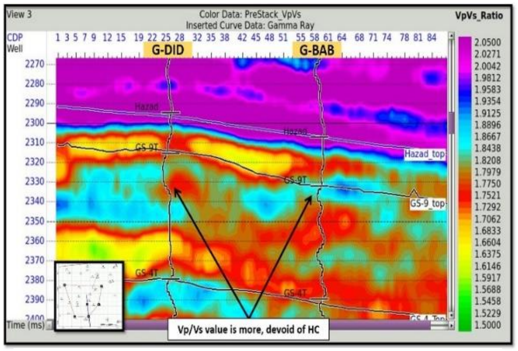

Fig. 10: Vp/Vs section along an RC line passing through wells G#DID & G#BAB.

while injecting through G#BAB, the pressure level at G#DID may not reach to that level as expected. Water saturation level also became high at G#DID. There is high Vp/Vs at both well locations which shows that the reservoir is not much interesting from hydrocarbon point of view.

ii) RC line passing through injector well G#CAF and producing well G#DB

Effective porosity, water saturation and Vp/Vs sections are shown in Figs. 11 to 13 respectively. The

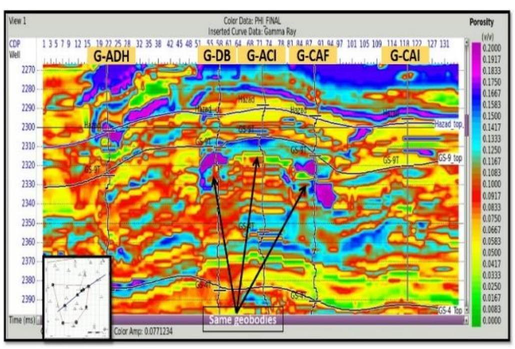

Fig.11: Effective porosity section along an RC line passing through wells G#ADH, G#DB, G#CAF & G#CAI.

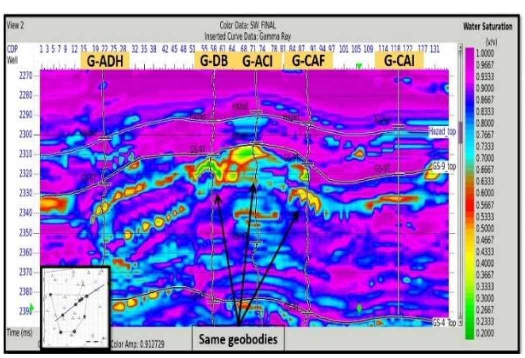

Fig.12: Water saturation section along an RC line passing through wells G#ADH, G#DB, G#CAF & G#CAI.

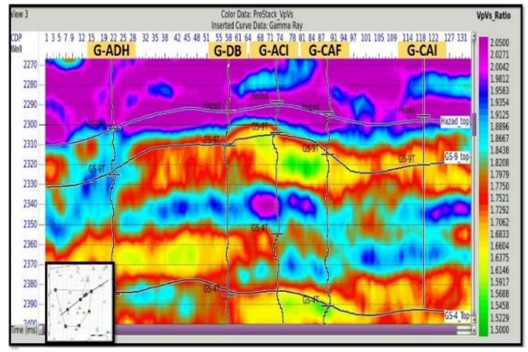

Fig.13: Vp/Vs section along an RC line passing through wells G#ADH, G#DB, G#CAF & G#CAI.

effective porosity section suggests that a single geobody connects the wells G#DB, G#ACI & G#CAF, while there is no reservoir facies encountered at well location G#ADH. A small geobody is seen at the well location G#CAI which has produced oil from GS-9. No hydrocarbon occurrence at G#ADH is due to lack of reservoir facies, and Vp/Vs is also very high. GS-9 pay at G#ACI seems to be oil bearing as suggested by the low value of water saturation as well as Vp/Vs value. There may be recoverable hydrocarbon present at G#DB as suggested by the Vp/Vs section. But injection through G#CAI is not going to help in enhancing the oil production at G#DB because the wells G#CAI & G#DB are not well connected.

Similarly, several other sections through different RC lines passing through different combination of wells have been extracted and analysed. Lateral discontinuity of the sand bodies are in consonance with the observations made by Jaiswal et.al.[5] about rapid fluctuation in the depositional conditions in a subtidal to intertidal depositional system. Vp/Vs is one of the most important parameters which is directly affected by the presence of hydrocarbon. The lowering of Vp/Vs is found to be a very good tool as an indicator of hydrocarbon in the present field. Within the WAG area it has been observed that the presence of recoverable hydrocarbon is not much. Further, the injection plan is not going to help to increase the productivity of hydrocarbon with respect to water.

Identification of residual oil zones within the study area

Identification of zones of residual oil is a quite difficult job, since there can be several reservoir parameters within a specific pay zone contributing to a particular seismic attribute value. Fluid replacement modelling theories for clastic reservoirs suggests that the Vp/Vs ratio is considerably reduced in case of gas/oil compared to water. Many attributes with respect to reservoir filled with hydrocarbon have specific range of values within a specific pay zone. Therefore, on map those areas are considered which fall within that particular range. Range is extracted by cross-plotting between the attributes at the nearby producing wells. None of the wells having shear wave logs within the study area are found to be producing from GS-9 pay. Therefore, two nearby wells in Gandhar field, G#EGG and G#EFI, having shear wave logs and producing from this pay were considered and cross-plots between GR and Vp/Vs was carried out (Fig. 14). The Vp/Vs range is quite low (1.55 to 1.62) at well location G#EGG whereas it varies from 1.67 to 1.86 at G#EFI. A Vp/Vs cut-off range from 1.55 to 1.86 is considered to exclude the area beyond this range. The included area was further restricted or reduced by applying some more cut-offs of other attributes. This is important because there might be other facies which may show the value of Vp/Vs in above mentioned range. An attempt was also made to study the cross plot of Vp/Vs ratio with Water Saturation for the above wells; however, it did not show any significant trend (Fig. 15). The following cut-off values were considered for the corresponding attributes to finalise the zones of residual oil:

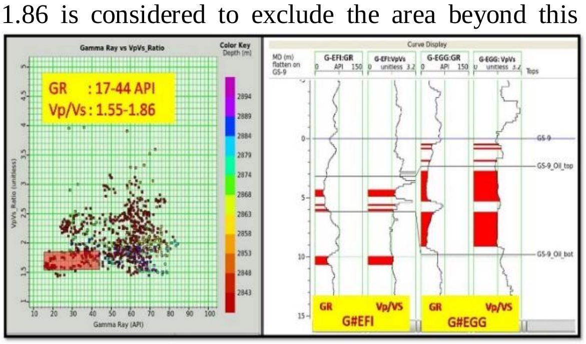

Fig.14: Crossplot of GR and Vp/Vs logs for wells G#EGG and G#EFI

1. Sand isolith map – less than 4m (to minimize the risk, but it does not mean that sands less than 4m thickness are non-producing.)
2. Effective porosity – less than 14%, supported by cross plot of GR & effective porosity at well G#DID.
3. Water saturation (initial testing) – more than 65%, also supported by crossplot of GR & water saturation at G#DID.

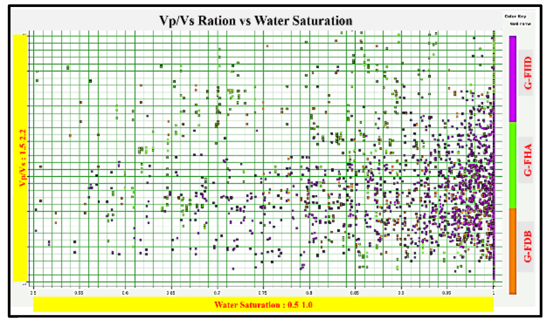

Figure 15: Cross Plot of Vp/Vs with Water Saturation for wells G-FDB, FHA & FHD

Common areas were identified satisfying the range of each attribute. So far as cumulative oil & water productions are concerned, there is hardly any comprehensive increment in oil production between 2013 & 2017 even after applying injection plan; however, movement of water flow is well established. The areas were further reduced by excluding the zones which have high cumulative water production zone (by excluding the zones coming within approximately 200m of radius at well location) and considering zones above OWC (1870m) for GS-9 pay. Identified residual oil zones are falling within the favourable area after applying the corresponding cut-off ranges on different attributes taken into consideration (Figs. 16, 17). After applying the above criteria, three different zones of residual oil were identified. The residual oil zones are overlain on the depth structure contour map on top of GS-9 sand (Fig.18).

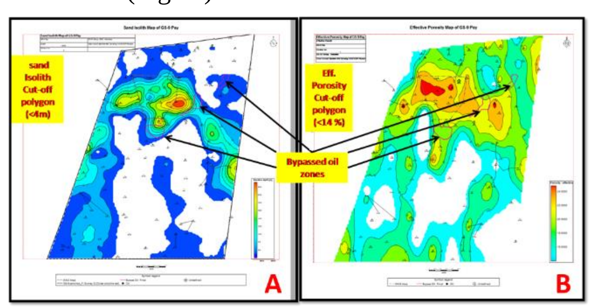

Fig. 16: Residual oil zones overlaid on cut-off maps of A) sand isolith and B) effective porosity

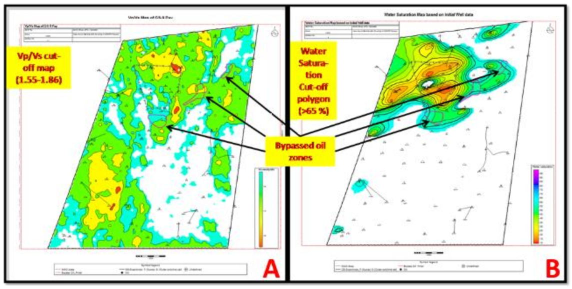

Fig.17: Residual oil zones overlaid on cut-off maps of A) Vp/Vs and B) water saturation (initial well data)

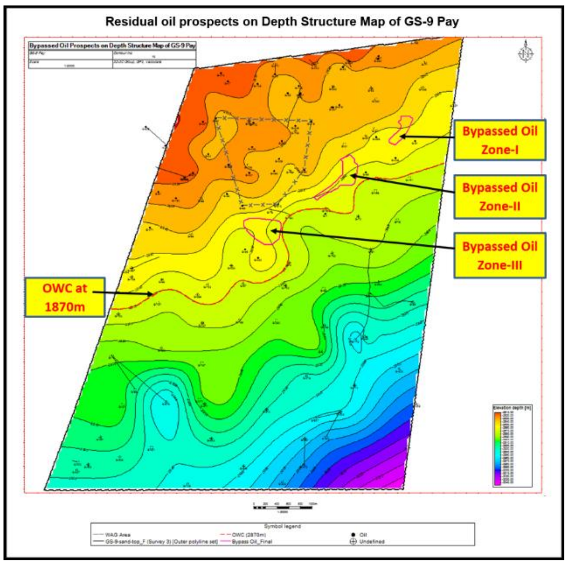

Fig. 18: Residual oil zones (pink coloured polygons) overlain on depth structure contour map on top of GS-9 sand.

Conclusion

Multicomponent seismic data interpretation is an essential tool in reducing exploration risks and enhancing reservoir management. While well data alone leaves a certain margin of imagination for reservoir continuity between the wells, these attribute volumes provide a better approximation of the actual picture subsurface. Pre-stack Joint inversion of PP and PS data around well G#DD yielded P impedance, Shear impedance, density and Vp/Vs ratio volumes. These volumes show good match at well locations and are consistent with the seismic data. The joint inversion outputs were found to be fruitful in deriving the petrophysical parameters in the area of interest. These outputs, along with production performance data and observed fluid contacts in wells drilled, helped in identification of three zones of residual oil in GS-9 sand.

Thus, pre-stack joint inversion, coupled with petrophysical analysis has proved to be an effective tool for reservoir characterization, effective WAG injection planning and shall help in placement of development wells. This type of study can also be carried out in and around other watered-out pools where seismic multicomponent data and shear wave logs are available.

N.B.: The views expressed in this paper are those of the authors only, and not necessarily of the organization they represent.

Reference

[1] Pande, A.N., Bhattacharya, S.K., Chaudhury, C.L., Upadhyay, H. and Sharma, D.C., 1989, Environmental Reconstruction and Depositional Modelling of the Hazad Pay Sand in Gandhar Field Part II; unpublished ONGC Report.

[2] Parakh, A.K., Sinha, D.K., Ahmed, A., Brahma, K.C., Prusty, S.K., Hussaini, S. and Shridhar, K.N., 2013; Depositional Model and Facies Distribution of Hazad Sands, Narmada Block and Integration with Broach Block, Cambay Basin. Unpublished ONGC Report, pp. 58.

[3] Jaiswal, S, Bhattacharya, B. and Chakrabarty, S, 2018; High resolution sequence stratigraphy of Middle Eocene Hazad Member, Jambusar-Broach Block, Cambay Basin, India; Journal of Marine and Petroleum Geology (Elsevier), vol. 93, 79-94.

[4] Catuneanu, O., 2006. Principles of Sequence Stratigraphy. Elsevier, Amsterdam, pp. 386.

[5] Jaiswal, S, and Bhattacharya, B., 2018; Characterization of middle Eocene tide-influenced delta: A study from core samples of Hazad Member, Ankleshwar Formation, South Cambay Basin, India; Journal of Earth System Science, 127(65).

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