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SEISMIC SIGNATURE-LITHOFACIES RELATIONSHIP AND ITS APPLICATION IN RESERVOIR CHARACTARISATION OF SYNRIFT SEQUENCE: A CASE STUDY FROM NARMADA BLOCK OF SOUTH CAMBAY BASIN, INDIA

Abstract

Synrift plays of alluvial fan complex regime are the focus of exploration in southern part of Cambay Basin. Inherent heterogeneity of reservoir with variable fluid dynamics pose challenges in delineation of such plays and optimization of recovery. Attempt has been made to address the issues by integrating seismic attributes and lithofacies to evolve a viable geological model for synrift exploration. Calibration of well lithofacies to that of seismic signature/pattern is the effort put forward. Maximum ~900m of synrift section in a half graben set up and ~50m thickness on most of the highs have been evaluated. Studies have brought out development of three lithofacies subunits with corresponding chaotic, transparent and stratified seismic pattern. The mid or distal part of an alluvial fan may coalesce to the proximal part of another fan thus bringing a mid fan interlayered with a distal fan making a total alluvial fan complex. Seismic pattern with truncation events along the graben bounding walls on top of Basement/trap surface indicate coalescing fan complex. High P-impedance value was seen at Paleocene pay (LS-1) level within synrift top at wells with those with good reservoir facies (sandstone, siltstone, conglomerate). In the late stage of synrift sedimentation deposition of LS-1 took place as final phase on top of filled half graben/lows. Study has brought the lithofacies-seismic pattern relationship. Areas have been identified on the flanks of lows to target better reservoir thickness and to look for coarse porous reservoir along narrow depositional low to delineate the Paleocene pay equivalent beyond the known limit.

Introduction

In the southern part of Cambay Basin, India, the Paleogene sequence of deposit is well developed on top of Basaltic Technical basement within Narmada Block. The study area is bounded by Narmada River in north and Tapti River in south,which represents two fault zones parallel to Satpura trend. Cambay shale of Paleocene/early Eocene age unconformably overlay the Olpad section of Paleocene age. The lowest unit of established pay (LS-1) in the area lies within the top of Olpad. Cambay shale is overlain by Ankleswar formation. Major pays are within Hazad Member of Ankleswar Formation of Middle Eocene age in the area under study. Miocene sands are oil and gas bearing within Tarkeswar and Babaguru Formations. Structural set up of the area under study includes east-west trending Ankleswar and Kosamba highs separated by Sisodra low. Reverse faults bound these Miocene inverted structural highs aligning the Satpura trend. The syn-rift fault system have extensively affected the study area, with the NNW-SSE oriented older faults parallel to the basin margin dissected by younger transverse broadly EW trending faults leading rise to a number of fault blocks with half-grabens and localised highs & lows. In the post rift phase, major E-W trending reverse faults responsible for the genesis of the inverted structures were activated in post-Babaguru time (Fig-1).

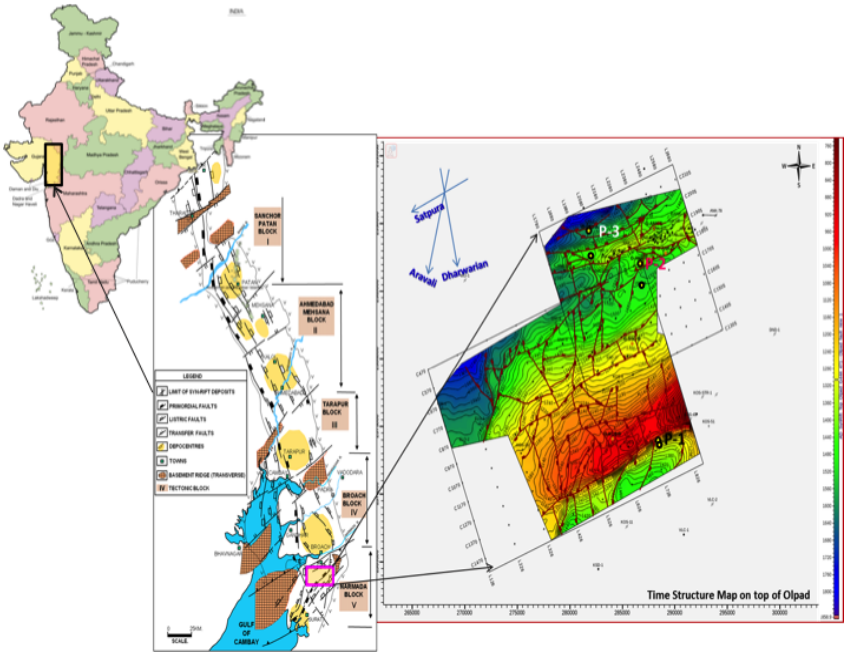
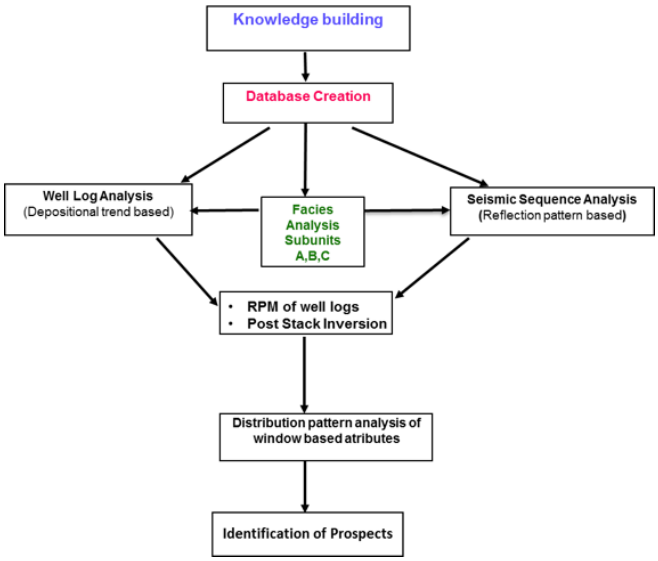


Fig. 1: Tectonic Map of Cambay Basin & Study Area

Workflow



In order to delineate existing leads and chase for new locales of interest within synrift, it is imperative to develop better geological understanding with seismic data of enhanced quality. The following workflow was adopted to integrate the available geoscientific data and analyse the synrift sedimentation pattern in the area to identify prospective locales.

Litho Facies Demarcation

The synrift sequence is represented by Olpad formation of Paleocene age. Deposition of Olpad Formation took place in response to opening of Cambay rift (synrift fill). Sediments brought by streams flowing from the highlands dumped along narrow elongated channels and subsequently dispersing over low gradients to evolve into an alluvial fan. Later it was overlain by Cambay shale during basin wide marine transgression. Olpad Formation top is determined on the basis of first appearance of basalt fragments below shales of Cambay Formation or transition from grey fissile shale/claystone in overlying Cambay Formation to red/reddish brown/greenish grey claystone of Olpad Formation corroborating with standard logs. Demarcation of subunits on the basis of litho facies association are - **Facies A**: The unit is made up Trap derivatives, which are mostly gravity driven and comprise of sub rounded basalt grains in an argillaceous matrix of claystone. **Facies B**: The unit consists of argillaceous matrix of dominant claystone with medium to coarse-grained altered/weathered, moderately sorted angular to sub angular basalt derivatives. **Facies C**: The unit consists of sandstone/siltstone streaks with mainly red ferruginous claystone, green chloritic claystone or variegated claystone distinguished clearly from overlying grey, fissile to moderately fissile shale of Cambay shale. The drainage is better developed with finer clastics over a low gradient dispersal.

In general, the entire Olpad Formation wherever preserved, has a pattern with coarser A-facies at the bottom, medium B-facies in middle and C-facies having the fine sediments as shale/siltstone at the top. The resistivity and density log responses indicate gradual increase in grain size from C to A subunits in most of the wells. Deviation of such pattern of superposition is observed in the wells of study area indicating amalgamation of deposition. In the wells of study area maximum thickness of Olpad Formation (~900m) is observed on a graben and minimum thickness of ~50m on the highs/flank.

Seismic Pattern Identification

PSTM seismic data used in the study, is the re-processed output using 5D Interpolation with matching pursuit algorithm. This enabled creating the structural framework to integrate well data with greater confidence. On the basis of seismic reflection pattern of surfaces corresponding to well markers unit boundaries are demarcated. On top of Basement/Trap an unconformable signature is deciphered in the wells with shift of baseline of logs. The same is confirmed from seismic with truncation events along the graben bounding walls on top of surface corresponding to Basement/trap.Several sequences are identifiable on seismic within the grabens. Facies A, B and C within the synrift sequence was calibrated by overlaying well lithology on time section. Facies-A having distinct chaotic signature, Facies B to that of transparent and Facies-C with stratified seis pattern is observed within synrift section.

Reservoir characterization with respect to LS-1 pay, at the top of Olpad is a challenge due to the heterogeneity of wide lithological variations viz. trap conglomerate, sandstone, siltstone, claystone, shale, carbonaceous shale/coal. Moreover, designing an attribute for understanding facies distribution was difficult as the pools are discontinuous, sporadic with lack of strctural control. Most Positive Amplitude (MPA) attribute extracted within a window of ~20ms against the LS-1 could largely explain the drilled well status. It was observed that wells with good reservoir facies was generally fell in the moderate amplitude zones, while wells with poor facies mostly lie in the low and high amplitude zones. Rock Physics Modeling (RPM) was carried out to quantify the feasibility of lithology discrimination with P-impedance. Profound rise in P-imp values (> 8000 m/s * g/m3) was seen at LS-1 level at wells with good reservoir facies (sandstone, siltstone, conglomerate). Further, Post Stack Inversion (Model Based Inversion with input seismic, multi-well wavelet & LFM) reveals the hydrocarbon bearing zones to be associated with high P-imp (> 7500 m/s * g/m3) and moderate amplitudes of pay sands within LS-1 unit (top of Olpad). To decipher their distribution on the basis of this study, geo-bodies were extracted applying a cut-off of ≥ 7500 m/s * g/m3, with a reasonable confidence to infer that such geo-bodies would have a high probability of prospective locales with respect to LS-1 pay (Fig-2).

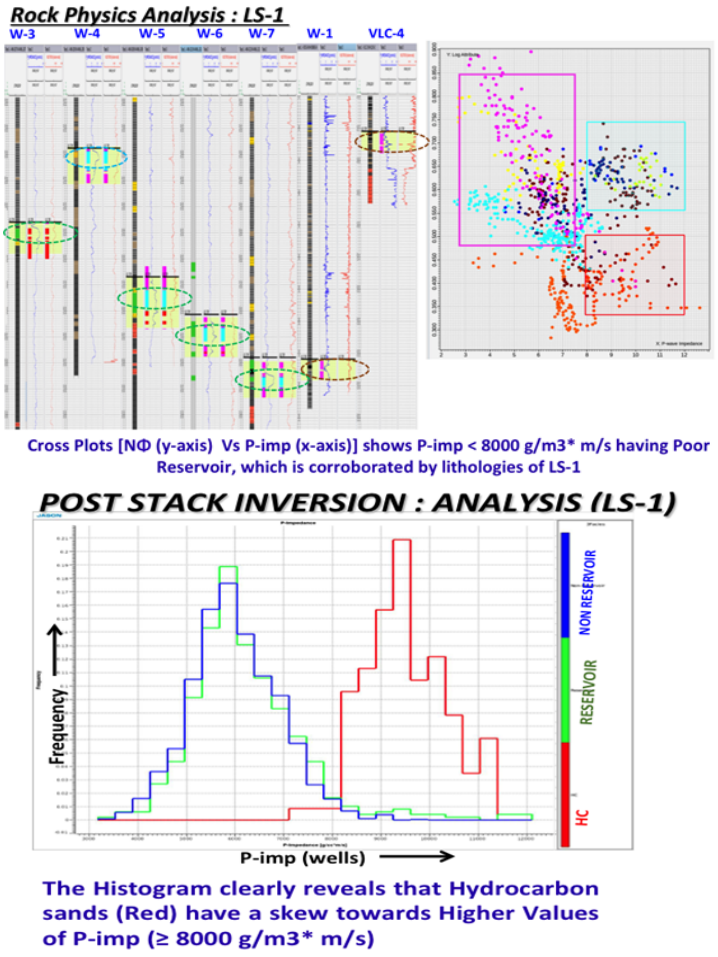
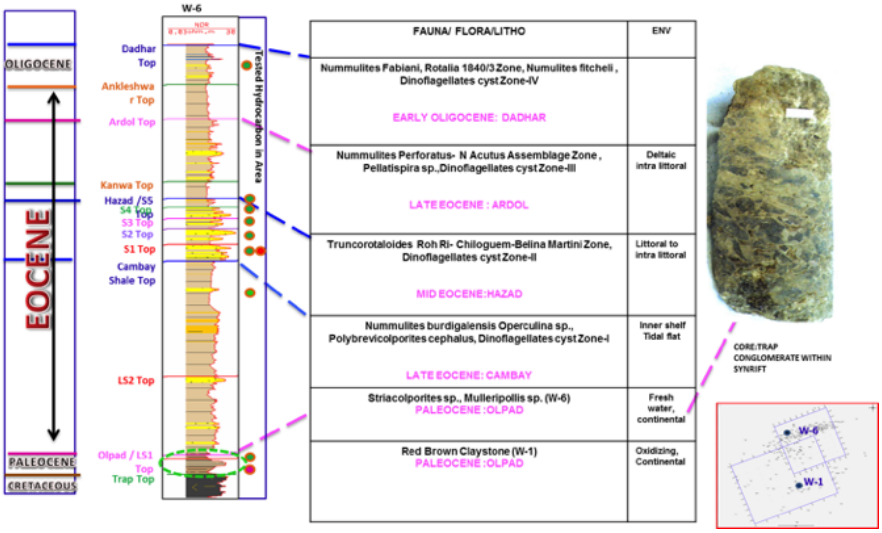


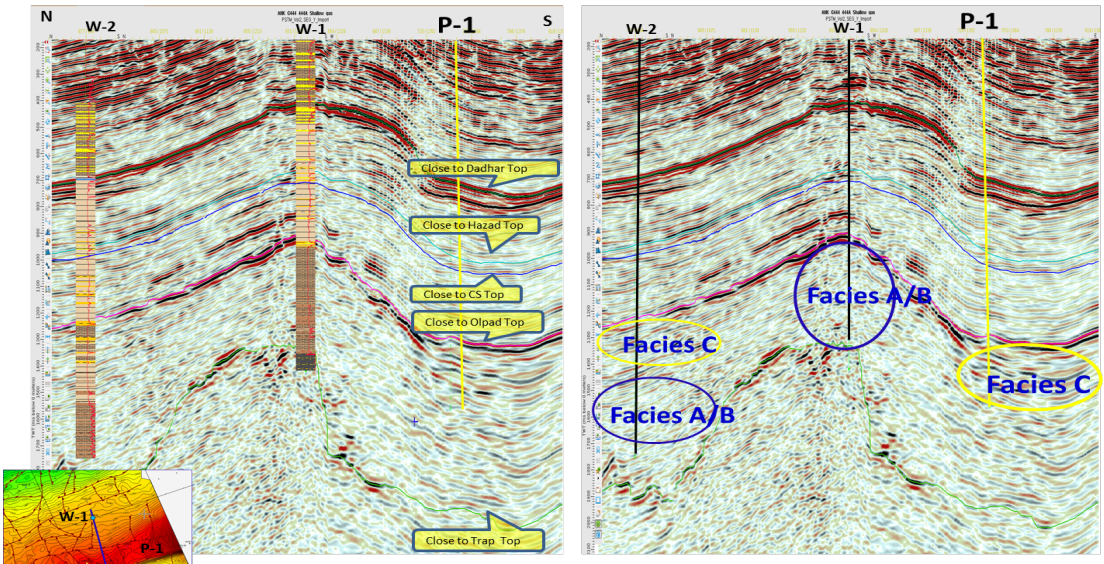
Fig. 2: Rock Physics Modelling & Post-Stack Inversion Analysis

Geological Model

Facies analysis has been done integrating biostratigraphy, sedimentology and other subsurface data (Fig-3). Palynological studies indicate synrift deposits to be marked by first downhole appearance of *Rhombipollis geniculatus, Peninsulapollis gillii* and *Yegupollis prolatus* and other associated taxa including *Polycolporopollenities calvus, Crassivestibulitis karii and Spinizonocolpites adamanteus* which is suggestive of Middle to Late Paleocene age of Synrift section in the area. Presence of thin walled micro gastropods and bivalves in wells suggests that Olpad Formation was laid in fresh to brackish water condition.



The lithological association of proximal, mid and distal facies of Alluvial fan complex is found in synrift section of the area. Olpad is mainly represented by epiclastic volcanic sediments,red clay stones and altered trap fragments. Highly altered chloritic clay balls, secondary silica (chert) and occasional red clays are the main constituent framework grains representing lithic wacke/arenite microfacies. Proximity to provenance, poor sorting, immature composition of volcanoclastics, poor organic content and stratification, presence of highly oxidising facies are suggestive of deposition in an alluvial fan complex with progressive variation in grain size from mid to distal part of fan regime. Observed coarsening up sequence within alluvial fan regime may be indicative of active fan progradation and out building while fining up sequence may indicate fan retrogradation.The conglomerate, sandstone assemblage define the limits of proximal fan near to highlands, fine sand/ siltstone with claystone that of mid fan extent while the claystone, shale predominance mark the outer limit of distal fan to the basinal side. The distal/mid part of a fan may coalesce to the mid/ proximal part of another thus bringing a mid fan interlayered with a distal fan making a total alluvial fan complex. The same is confirmed from seismic with truncation events along the graben bounding walls on top of surface corresponding to trap. Within the synrift deposits several sequences are identifiable on seismic section in the grabens that may indicate coalescing of fans. Facies A of dominant trap derivatives with claystone gives a chaotic seis pattern of gravity driven dumps on top of Trap Basement along the lows. Facies B of predominant claystone is associated with transparent seis signature of very low amplitude. Facies C of interlayered silt/sand to clay/shale clastics generally associated with high amplitude bands on upper part of the synrift sequence(Fig-4).



A: gravity driven Trap derivatives of sub rounded basalt grains in an argillaceous matrix of claystone
B: argillaceous matrix of dominant claystone.
C: sandstone/siltstone streaks with mainly red ferruginous claystone, green chloritic claystone or

Fig. 4: Seis-signature correlation with Litho-facies

Deposition of LS-1 took place in the late stage of synrift sedimentation as subunit C in the final phase of filling up of half graben/lows. Channel system was active that brought sandstone, siltstone with shale whereas presence of trap derivatives encased in claystone is associated from nearby highland at places and carbonaceous facies also found in localised brackish environment. The synrift deposit is topped by LS-1 sand under LST.

Prospectivity Analysis

Three major prospective areas have been identified based on present study. **Area-1**: To the south of the main EW fault bounding the Kosamba Structure a moderately high amplitude stratified upper unit of synrift deposits, within a wedge-shaped body limited by two near parallel N-S trending faults is identified in Kosamba area. Significant frequency dilation is seen associated with these events, which may be suggestive of likely reservoir. The geobody extracted against this amplitude anomaly shows a fan like morphology with a NE entry.

Nearby deep well W-1 drilled upto Basement (-1515m) on Kosamba high basically encountered ~500m of trap derivatives embedded in claystone of the synrift deposits. The zone encountered in W-1 is devoid of strong seismic signature whereas another well W-2 terminated within Olpad has given moderately high amplitude signature against reservoir facies (siltstone streaks). Therefore, calibration of reservoir facies with moderately high amplitude can be inferred (Fig-5). No other nearby deep wells has encountered this seismic event in the area. Similar event was observed in well W-3 of north, wherein silty sand layers developed within high amplitude zone gave indication of hydrocarbon on testing. P-1 lies in the rising northeastern flank of Sayan Low. Wells drilled in western flank of Sayan Low has given hydrocarbon indication against core having lithology of carbonaceous shale& siltstone. TOC (Av. 3.8%) and S2

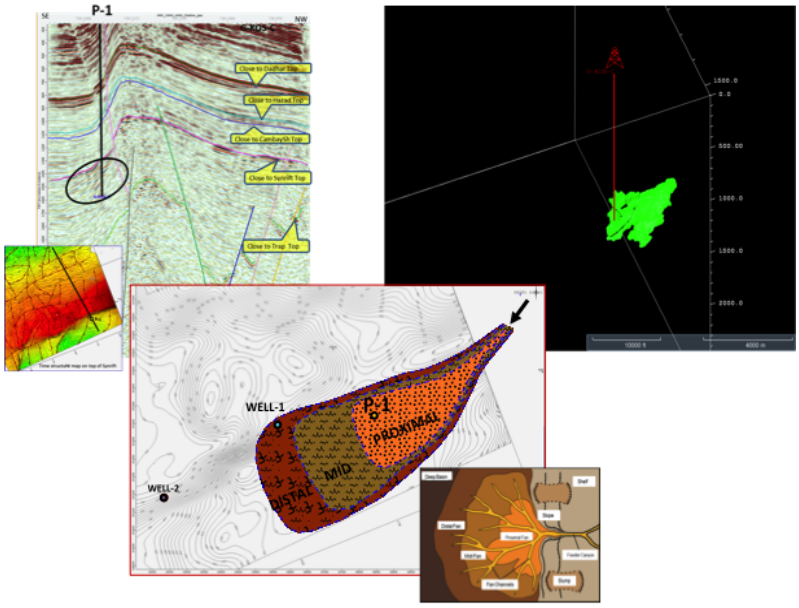


Fig. 5 : Seismic Profile through Area-1 (left), shows high amplitude bands within syn-rift, which have a fan shaped morphology (right).

(Av. 6.42 mg HC/gm rock) suggest organic richness and HC generation potential of

synrift section.

Area-2: A synrift section of 120ms thickness is envisaged to be deposited as derived fragments of nearby highland consisting of basalclastic which is likely to have coarser porous sediments encased in a wedge shaped localised low along a narrow e-w corridor under continental regime during Paleocene in Sajod area. The small width/depth ratio of the seismic geobody implies a set up of coarser porous clastic deposits. Siltstone facies in W-3 as found in synrift section may be a part of the mid fan facies of main alluvial fan of Ankleswar field where wells of conglomeratic assemblage form the proximal part to the east. As evidenced by palynological association of fresh and brackish water deposit of Olpad unit carbonaceous shale/coal deposits are also found in Ankleswar wells showing lateral lithofacies variation. The proximal part of a fan may coalesce to the mid or distal part of another thus bringing a mid fan interlayered with a distal fan giving stratified layered seismic character (Fig-6). Location lies up dip of nearest well, W-6 (siltstone in LS-1, but not charged), separated by a conspicuous EW fault.

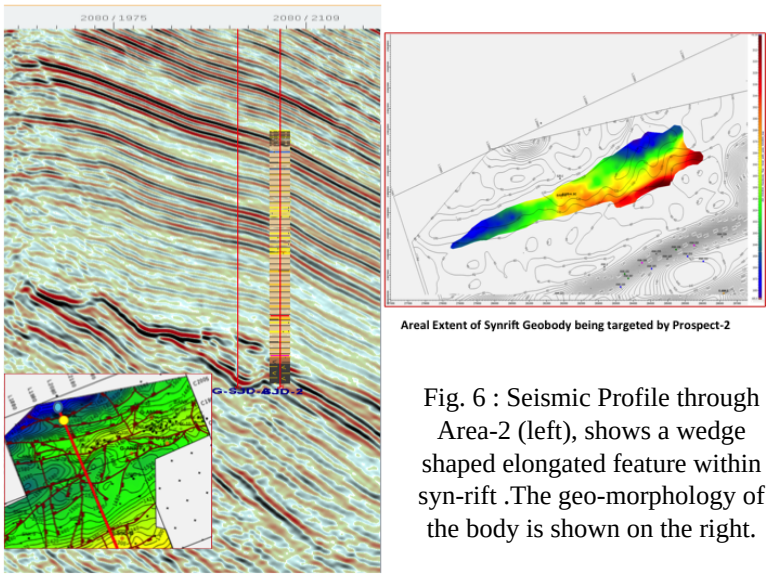


Fig. 6 : Seismic Profile through Area-2 (left), shows a wedge shaped elongated feature within syn-rift .The geo-morphology of the body is shown on the right.

Area- 3: The active channel system of late rift fill deposits over low gradient has full spread as LS-1 deposit in the study area. The reservoir facies of sand-silt has a vertico-lateral variation to that of non-reservoir shale, clay and carbonaceous shale/coal. Multiple pools coexist within a structural high separated by litho heterogeneity with distinct hydrodynamics. To look for reservoir facies under a possible entrapment beyond the known hydrocarbon limit geo-bodies were extracted applying a cut-off of ≥ 7500 m/s * g/m3. Stratistuctural control with litho heterogeneity of the area left the scope of existence of another pools in the vicinity of producing area of LS-1. Prospect-3 falls within moderate amplitude zone with high P-imp, inferred as good reservoir facies equivalent of LS-1 (Fig-7) in Ankleswar area.

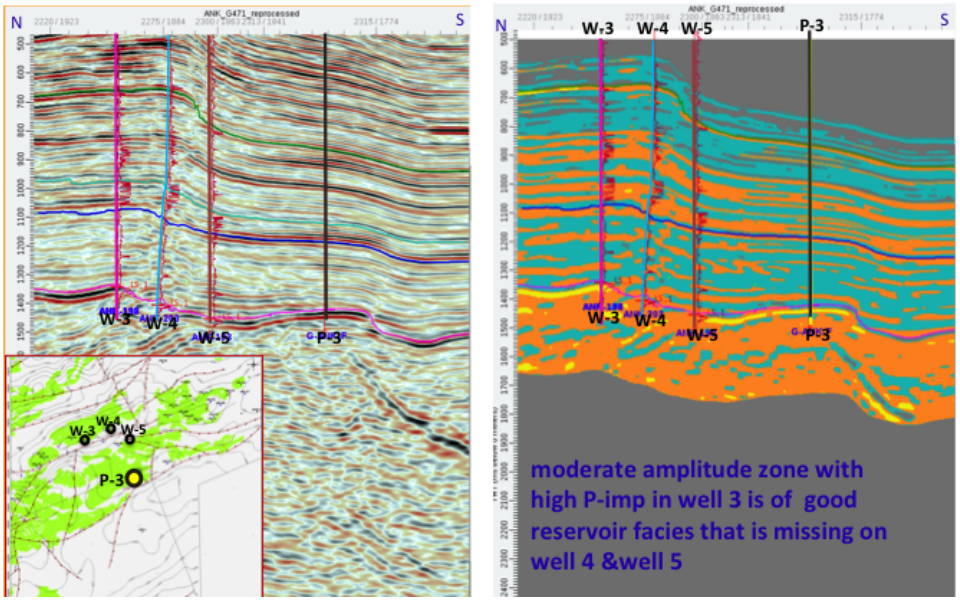


Fig. 7: Arbitrary Seismic Profile through P-3 in area-3, shows a high P-imp feature at the top of LS-1, which is calibrated with reservoir facies in W-3 and contrasted with non-reservoir facies in W-4 & 5. Geobody map with P-imp cut off > 7500 m/s * g/cm3 as inset.

Conclusion

Exploration for synrift prospectivity has been sporadic in the area and hasn't met with much success. Hydrocarbon shows in rocks of syn-rift sequence in a few wells in and around the study area along with evidence of mature source have rendered attention for prospectivity. Relatively shallow depths of synrift section in the area, present a compelling case for probing them, equipped with better understanding. The 5D interpolation with matching pursuit algorithm reprocessed PSTM seismic data used in this study enabled a better analyses. Within the synrift deposits several sequences are identifiable on seismic in the grabens indicate likely coalescing of alluvial fans. Lithofcies with seismic signature classified the depositional pattern of synrift. Areas within moderate amplitude zones with high P-impedance are inferred as good reservoir facies. Low frequency – high amplitude bands within the wedge are calibrated with reservoir facies of deep wells which have penetrated Olpad Formation in the area. Lowest known hydrocarbon pay in the area is LS-1 (top of Olpad). The active channel system of this late rift fill deposits over low gradient has full spread in the study area. As an outcome of the study, locales were identified in Sajod, Ankleswar and Kosamba area for establishing the synrift prospectivity in South Cambay Basin, India. Success of identified prospects lead to new areas for exploration.

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