Delineating hydrocarbons by PP-PS processing and joint inversion in Gandhar field of Cambay Basin, India.

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Summary

Elastic rock properties carries important information and link with subsurface lithology and pore fluid content. It is highly valued by the seismic exploration industry. In traditional seismic, only the P-wave was considered to provide useful information, and the other waves were considered to be noise. However the different vibrational modes of these waves mean that they respond differently to changes in subsurface rock properties. The P-wave is sensitive to both, the fabric of the rock and also to the fluid content of the pore spaces. On the other hand, the shear wave is largely insensitive to the fluid content. Thus the two wave types carry different information about the subsurface. This is the prime motivation for the joint recording, processing and analysis of both compressional and shear waves. Presently converted seismic waves (P-to-S on reflection at seismic interface) are being increasingly used to explore for subsurface desired targets. Rapid advancements in multicomponent data acquisition methods and processing techniques have led to numerous applications for P&S images. Uses that have arisen include sand/shale differentiation, carbonate facies identification, definition of interfaces with low P-wave contrast, anisotropy analysis, imaging through gas zones, shallow high resolution imaging, and reservoir imaging. The present study presents the application of multicomponent data in Gandhar field of Cambay basin, which aims to delineate different sand reservoir of Hazad members of Ankleshwar formation.

Directly extracting density, Vp/Vs, Zp, Zs, Poisson's ratio and other elastic parameters from the inversion of pre-stk 3D3C data provides a more accurate and straightforward way to delineate the characteristics of the sands reservoirs. However the complicated overburden, geological conditions including heterogeneity of the fluvial deposits associated with larger scale of stratigraphic variability in the area of study impose serious challenges for multicomponent data processing. The strategies and key processing steps utilized in the PP and PS data processing to overcome the challenges are also described. The high quality PP and PS pre-stack data have been used for joint PP-PS inversion to extract seismic attributes. The inversion results for different attributes highly correlate with the wells data in the area and provide strategy for future exploratory location's in the area.

Introduction

Multifold stacking technology (Mayne,1962), has become a routine practice in current seismic exploration with the objective to enhance S/N ratio by stacking one CDP or CMP gather in one trace. However if all the previous processing is accurate & reliable, stacked data are not strictly equal to actual pure P wave information. Traditional stacking always tends to mix AVO effects together and thus leads to wrongly restored amplitudes as well as reduced resolution. So far the stacked data are regarded as the P-wave data in traditional thinking.

However, even pure P-wave can hardly address issues of lithology and fluid prediction in most cases. Instead integration of P-wave & S-wave information is highly advocated, as S-wave information is sensitive to variation in subsurface lithology & fluids. Therefore development of 3D3C is driven largely by the needs for S-wave information that is highly valued for reservoir prediction. A successful application of the technology to distinguish true and false flat points by the joint PP/PS inversion was reported (Dang el. At. 2009 & Stewart R, 2002). It provided more information for reservoir characterization and fluid prediction.

In this article, a concept was proposed, aimed at maximizing the availability and values of elastic information from pre-stack P-P & P-S data by incorporating three important aspects, amplitude preserved processing, rock- physics, and inversion algorithms for pre-stack elastic extraction. The rock physics largely solves velocity issues for different type of reservoir rocks, the results of which provide evaluation standards for amplitude preserved processing which works to recover true-amplitude responses induced by lithology and fluids. At the last stage, inversion algorithms make efficient use of pre-stack amplitude relationships and finally extract reasonable elastic information. Rock physics build an indirect function between velocity and geologic variable such as lithology, porosity, density,pore geometry and pressure, fluid saturation, pressure, and so on. It is not only an important bridge between geologic variables and seismic responses but also a powerful tool for quantitative analysis of reservoir characteristics.

Geology:

The evolution of Cambay basin began following the extensive outpour of Deccan trap Basalts during the late Cretaceous and development of tensional faults along its margins. The basin is tectonically divided into five blocks and is characterized by thick sedimentary section of Tertiary – Quaternary age, which is underlain by Deccan trap Basalt. During Paleocene, the Basin continued to remain as a shallow depression, receiving deposition of Trap wash/conglomerate/clay-stone exclusively derived from basaltic trap showing diagenetic alterations under the fluvial environment named as Olpad formation. After this, there was a conspicuous and wide spread marine transgression, and a thick, fissile, pyritiferous shale sequence known as Cambay shale was deposited during upper Paleocene to early Eocene. The sandy facies of Hazad & Ardol Members (Ankleshwar Formation), Dadhar, Tarkeshwar, Babaguru (Mid Eocene to Miocene) were deposited in various regressive phases interspersed with minor transgressive cycles of deposition of the shaly facies of Kanwa, Telwa and intervening shales of Tarkeshwar and Babaguru formations. The petroleum system in the study area consists of Cambay shale as source rock, Hazad members as reservoir rock and Kanwa shale as cap rock. The established twelve sequences of sandy facies separated by thin shaly facies of Hazad member deposited in fluviatile deltaic environment. The generalized stratigraphy of the Cambay basin is given in **fig:1**

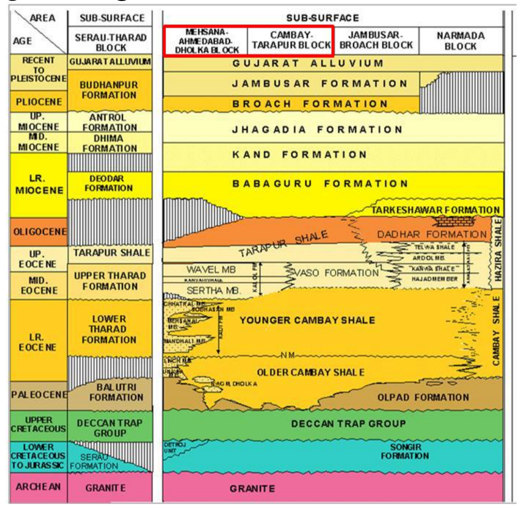

Fig:1 Generalized Sratigraphy of the Cambay basin

Joint Inversion-Theory and Method:

Conventional inversion with a single mode P-waves tries to invert three unknowns, Vp, Vs and density from two seismic attributes P wave gradient and intercept time. This causes uncertainties in the inversion. The joint PP and PS inversion has stabilized the problem by introducing the PS gradients. However, in practice, the noise in both PP and PS gathers also causes some difficulties in the inversion. Stewart et.al. (2002) proposed a dual inversion scheme, which uses the vertical Vp/Vs ratio from PP and PS travel time registration combined with PP and PS AVO attributes in the elastic inversion. The method involves has been successfully used in OBN data from Mumbai High area of Western offshore Basin, as well as in land data of Kalol, Padra & Jambusar area of Cambay Basin. Before performing inversion, the conditioned gathers amplitudes were studied over an aperture of angles (offsets) extending from 0 to 45^0. Assuming linear isotropic half space, plane wave reflectivity given by the equation-(Aki & Richards,1980)

$Rp(\theta) = R_0 + R_2 \sin^2\theta + R_4 \sin^2\theta \tan^2\theta$

Where….

$R_0 = \Delta Zp / 2\mathbf{Z}p$

$R_2 = 1/2 ((\Delta Vp/\mathbf{Vp}) - (2\mathbf{Vs}/Vp)^2 \Delta\mu/\boldsymbol{\mu})$

$R_4 = 1/2(\Delta Vp/\mathbf{Vp})$

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Vp, **Vs, Z**p **& μ** are velocities, impedance and rigidity for first media
ΔZp, ΔVp are p wave impedance & velocity contrast at interface and Δμ rigidity contrast at interface.
The inversion involves mainly two steps, The first step is to extract AVO attribute section (Rpp intercept section and gradient section) derived from the migrated and conditioned P-wave gathers, and the PS gradient section from the imaged conditioned PS-seismic gathers. The seismic wavelet is extracted from amplitude preserved data at a well. Then synthetic AVO gathers are generated for both PP and PS and correlated with seismic data for best fit in the objective zone. In the second steps using well data a simulated analysis technique is used during inversion process to find a global minima in this complex optimization and then compute the elastic parameters computation and correlation for the target area.

Data processing:

Although the multi-component data are of good quality due to favourable near surface medium for the explosive source in the area of survey, but due to dense population, metal road and underground oil/gas pipe lines there is strong coherent noise, scattered noise and some random noise. The processing was done following standard practices with utmost care for signal conditioning on the basis of amplitude, frequency, velocity in different domain to enhance signal to noise ratio. For PS data, Shear statics was computed using receiver stacks. The linear coherent noise, ground-roll and scattered noise were removed by transforming the data in X-spread domain. Efforts were made to remove noise without affecting the signal at all stages of noise removal. Difference section of input and output was taken for QC purpose and amplitude spectrum was studied for qualitative and quantitative analysis of S/N ratio. It was seen that after signal conditioning the most of the coherent & incoherent noise, amplitude burst from PP & PS data are removed. Surface consistent amplitude correction and afterword deconvolution was applied with proper parameters in slant time windows. 3D Regularization of PP data was done in offset mode before migration to fill the missing near offsets. The RMS velocity volume was created and anisotropic parameter was computed on migrated gathers and volume was generated. The final RMS velocity, anisotropic parameter and Vp/Vs volume was created after smoothening with proper algorithm for the migration purpose only.

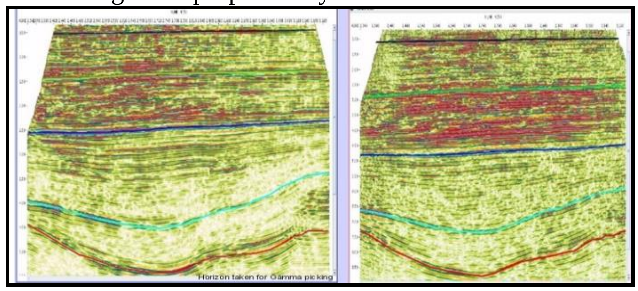

Fig:2 Representative event registration for PP(left) & PS(right) section (PP time) for Vp/Vs (Gamma function) along a inline.

The Vp/Vs is computed at interval of around 500m by event registration taking few seismic horizons on PP section as base and equivalent horizons in PS section as shown in **Fig:2**. Vp/Vs volume is created and smoothen for migration. The final PP and PS prestack time migrated gathers were thoroughly check for any kind of operator noise. The post processing on migrated gathers was done for linear noise, foot print removal, multiple suppression and spectral balancing for better resolution without any artifacts. In the process of footprint removal using FK filter in 3D mode, the input data is converted from the time-space domain to frequency-space domain for filtering. In the process acquisition footprint is treated as an additive noise with spatial periodicity. PS radial component data was used for inversion process and interpretation work. The migrated stack section for PP and PS data along an inline is shown in **Fig:3** justify the quality of imaging at depth 5500 mt (PP TWT 5200 msec.).

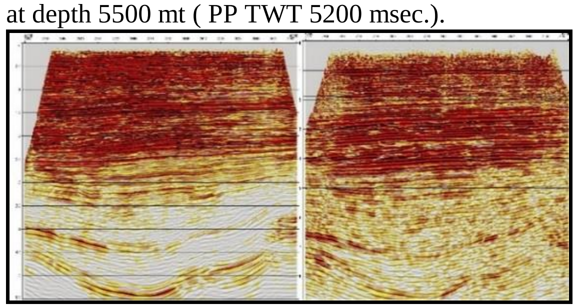

Fig:3 PP (left) & PS(right) migrated stack

In Fig:3 the PP & PS section are showing the similar geometrical subsurface feature but having difference in imaging for PP and PS section. The amplitude build up in PP section does not appear same as in PS section.. This may have useful meaning and needs

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evaluation. There are many images in PS section in synrift area but not seen clearly in PP section. The PS section has better resolution at shallow level. Thus PP & PS data studied together will help in better imaging of the subsurface stratigraphy.

PP and PS data matching & event registration:

Registration of P-wave reflection events for a reflectors with their equivalent reflector on the PS data is very important step. The frequency band width of PP data was up to 70hz while PS data has bandwidth of only up to 30hz . Care was taken to match the prominent horizon near objective zone and only three horizons were taken. In the area four wells were selected having DSI logs and well information were used for inversion process & all type of correlation.

Synthetic seismograms are created using sonic log information and wavelet derived from the imaged stack section of PP&PS data. The wavelet for both PP & PS created from migrated stack and their amplitude spectrum are shown in **fig:4.** Two wells were taken for study. From both wells, it is clear that the synthetic seismograms correlate well with the sections for PP waves as seen in **fig:5 & fig:6.**

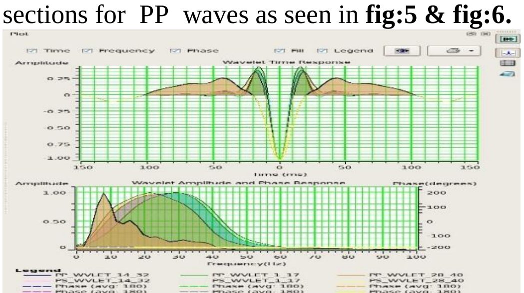

Fig:4 Wavelet for PP&PS (Top) & spectrum (Bottom) extracted from PSTM seismic sections.

The PP&PS event registration is carried out on PP&PS migrated sections for the target zone which is between 2000msec to 2600 msec PP TWT. Three horizons, Hazad top & bottom (top of Cambay shale) and Y-marker within younger Cambay shale were picked on PP & PS section and taken for inversion.

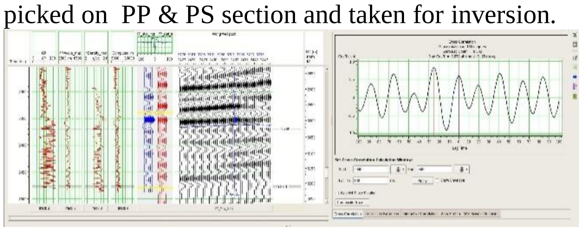

Fig:5 PP Synthetic seismogram at location Well A.

The average Vp/Vs ratio used for events registration on PS section to squeeze it in PP time was taken 2.3. This value of interval Vp/Vs is taken after many iterations to adjust the horizons based on matching of horizons taken on PP and PS sections and this value of Vp/Vs was taken as reference for model building and joint inversion.

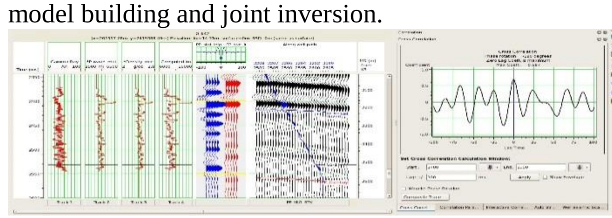

Fig:6 PP Synthetic seismogram at location Well B.

Since all the three horizons chosen are very prominent throughout the area, in both PP and PS sections, except top of the Cambay shale in PS sections on some locations due to low frequency data.

PP & PS joint inversion:

The inputs to the PP & PS joint inversion are AVO attributes, the P-wave gradient & intercept time and PS-wave gradient. The reference Vp/Vs ratio from the events registration is also used as the initial model building process for the joint inversion.

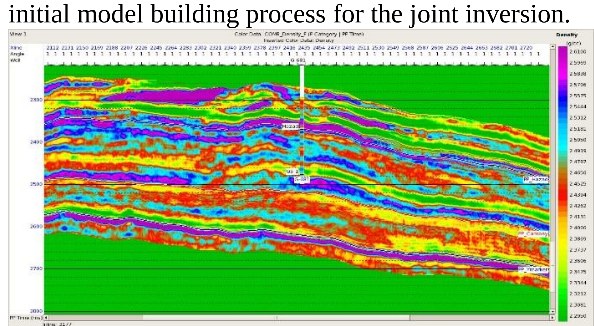

Fig:7 Inverted density section around well A

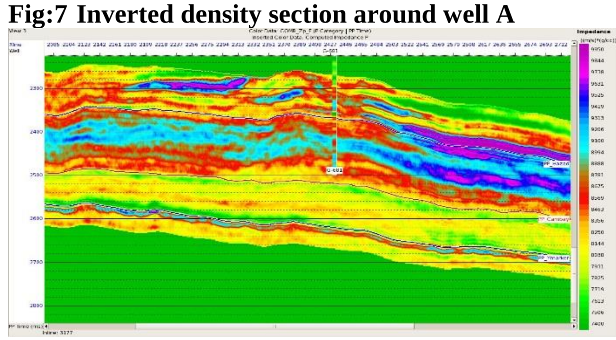

Fig:8 Inverted P-imp.(Zp) section around well A

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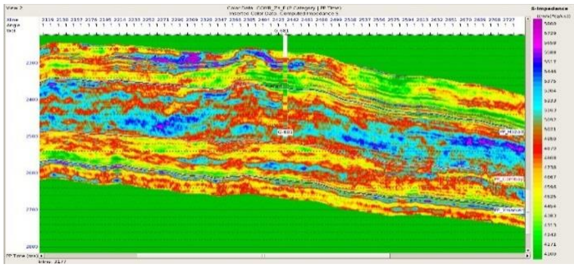

Fig:9 Inverted S-imp. (Zs) section around well A

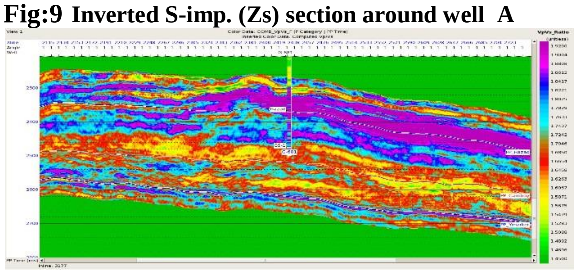

Fig:10 Inverted Vp/Vs section around well A

The joint inversion was run in PROMC software of Hampson-Russel. After the joint inversion, inverted density, Zp, Zs and Vp/Vs section in the objective zone were obtained and well A & Well B were posted on the respective position with the log curve for display. Both are deviated wells. In the area, average range of Vp/Vs value for shale is around 1.9-2.2 displayed as brown to purple, for dry sand it varies in the range of 1.65-1.85 yellow to red color as confirmed from many well's data.

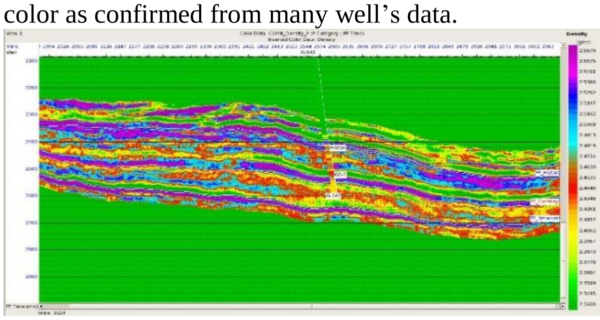

Fig:11 Inverted density section around well B

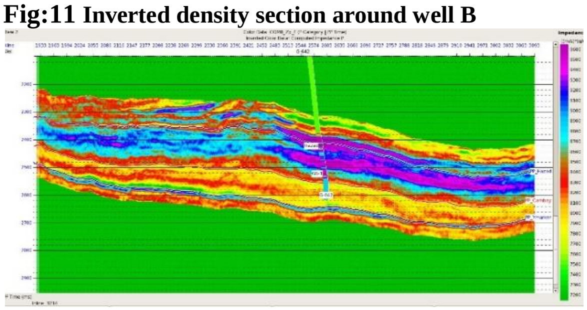

Fig:12 Inverted P-imp. (Zp) section around well B

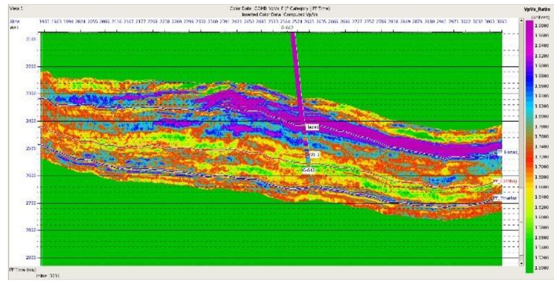

Fig:13 Inverted S-imp. (Zs) Section (Zs) around well B

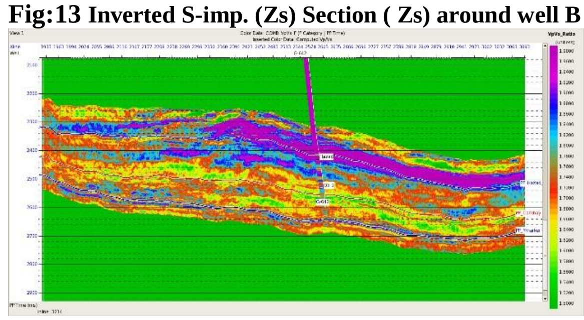

Fig:14 Inverted Vp/Vs section around well B

In well A at target zone, Vp/Vs value show a strong anomaly at GS-1 level, which can be seen in density, Zp section and no anomaly in Zs section**.** This is a oil well **(Fig:7-10).** In well B. although Vp/Vs value at target zone is around 1.6, but no desirable anomaly is seen in Zp and Zs section. In the vicinity of well Vp/Vs section indicate lower value of Vp/Vs in objective zone but absent of shale as cap rock. This is a dry well. (**Fig11-14)**

Discussion:

The results for both the wells show that the addition of PS data to the inversion process, improves the density estimation accuracy spread around the well and all the prominent lithological boundary are clearly visible on density section . With joint PP-PS inversion the objective of sands, shale discrimination was better achieved. The S-impedance section around both the wells shows better lithology discrimination in comparison to P-impedance section. The Zp section for both the well shows different character from the Zs at some places and similar character at other places provide the insight for reservoir characterization and open the door for lithological discrimination study in the objective zone. In the section for well A, there is a remarkable change in the character of Zp, ZS & Vp/Vs in the right side of well at top of cambay shale which needs to be analyses. The inverted Zs and Vp/Vs are better

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resolved and sub layers are also better demarcated in comparison to Zp section.

As per petro-physical analysis in the area, the Vp/Vs value of the hydrocarbon saturated sands in the hazad members ranges from 1.40 to 1.60 and for the shale it is more than 1.95 which is clearly demonstrated in the inverted section. It is found that Vp/Vs values dramatically decreases less than 1.6 within the oil sand reservoir for well A, which is quite consistent with the theoretical assumptions for the area based on the study of the core analysis data. In general, Vs values in sands saturated with fluid increases & Vp decreases slightly but will not change too much and both the waves have different sensitivity to pore fluids in saturated sands. As a result Vp/Vs decreases too much in lower range for hydrocarbon saturated sands overlain by high value of Vp/Vs as seen in inverted Vp/Vs sections for well A . In well B, the value of Vp/Vs is in the range of 1.6 in objective zone but upper limit of reservoir show no remarkable change in Vp/Vs value. Thus the inverted Vp/Vs section can provide a good tool for hydrocarbon exploration.

Conclusions

It is concluded that amplitude preserved processing of Gandhar area 3D3C seismic data has resolve many amplitude related issues on both PP and PS seismic sections and show different amplitude characteristics based on inputs. The PP-PS joint inversion has successfully inverted showing high resolution attributes section. Vp/Vs values from PP-PS joint inversion correlate well with drilling data for the wells in the area, and may prove useful in reducing drilling risk for future wells as it effectively delineate the characteristics of the oil sand and dry sand reservoir. In Gandhar area large no. of wells are there and most of the prominent producing area has been covered by 3D3C data, shear wave data can be incorporated with P-wave data for interpretation. The recent discovery in Jambusar area (2019) based on the Vp/Vs analysis from 3D3C data and side tracking of two wells in Kalol area (2015-17) based on the result of sand map generated using Vp/Vs section from 3D3C data also justify the importance of 3D3C data for development location's for all basin in future. It is ascertained that adding PS data as additional information along with PP data for interpretation add values and reduces risk factor for hydrocarbon exploration & exploitation. In pre-stack joint inversion process, the inverted attributes sections increases the resolution of events and reduces the uncertainty in reservoir characterization. In present studies, result shows a better correlation of estimated density with the observed well data using PP & PS joint inversion. So 3D3C data, integrating with core data and well logs spreads in the area, gives better foresight in reservoir characterization in reducing drilling risk for hydrocarbon exploration and exploitation.

Note: The view expressed by the authors in this paper are their own and not necessarily of the organization they represent.

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