Seismic inversion is an approach to provide a useful connection between observed seismic data and interpretable elastic physical properties of potential reservoirs. For the calculation of reservoir characterization, Post stack seismic inversion plays an important role to estimate the reservoir properties i.e. porosity and acoustic impedance etc. In this paper, we use the post-stack time migrated seismic data (PSTM) and log data to delineate the reservoir properties and also the fundamental properties including acoustic impedance and porosity of target zone. To complete this work, seismic inversion and geostatistical method has been used. The methodology of inverting seismic data into acoustic impedance is pertinent to key information of this study. In addition, suitable wavelet representative of the given conditions is important for encouraging result. In the next stage, geostatistical inversion is applied by using applications of probabilistic neural network (PNN) to estimate the porosity of low impedance sand body of Lower Ranikot using well Mehar-02. By using PNN the impedance volume is transferred into porosity volume while the finally 18% porosity is predicated with the help of the petro physical properties of Mehar-02, and display on the seismic section as high porosity zone with low impedance.

Introduction

The Seismic data inversion including both post and pre-stack inversion that is become a basic tool in the exploration and production industry and is used in different stages from the discovery to development. The exercise immediately after drilling an exploratory well starts with well-to-seismic tie, which is not always a simple task. Frequently, it is observed that the match between seismic and synthetic traces is less than satisfactory, even after considering wavelet and other logging data conditioning. Considering seismic forward-modeling tools are incapable in understanding the problem, the interpretability and reliability of inverted data for reservoir characterization and reservoir property distribution become a cause for concern. This necessitates finding an alternative way to carry out reliable seismic inversion or to go for more advanced pre-stack inversion.

The seismic data and wireline log data were acquired for the development of hydrocarbon resources in the study area and for the discovery of oil and gas well. Based on the type of adopted data, seismic inversion is divided into two broad categories: pre-stack and post-stack inversion. The former is the most commonly used pre-stack and post-stack inversion. The latter relies on model driven from well log, seismic, and geological data (Pyrcz et al., 2014). This work is carried out by using the model-based inversion as external attribute to estimate the porosity of the reservoir zone. In specific, colored inversion, model-based inversion, and sparse spike made use of the derived impedance models as external attributes while the seismic and logging data are used as an internal attribute for the geostatistical analysis (Leuangthong et al., 2011; Pyrcz et al., 2014). This work is carried out by using the model-based inversion as external attribute to estimate the porosity of the reservoir zone. Fig. 1 shows flow chart of the proposed inversion methods. The objective of this work is to extraction of acoustic impedance using Post-Stack seismic inversion and the establishing of relation between impedance and porosity to get the porosity distribution over the reservoir scale. By using the (PNN) technique, the impedance volume is transferred into porosity volume and display on the whole cube and carrying out two dimensional interpretations of the seismic data, establishing a link between the reservoir property and seismic data. It is hoped that this work will provide a new tool for seismic analysis and geological interpretation which enhanced the exploration activity.

Geological Setting of Study Area

The study area Mehar Block is located in north western part of the kirthar Fold belt and partly located in the margin of kirthar Fored deep,
which is dominated both topographically and geologically by the roughly N-S trending Kirthar escarpment covering boundary between the Sindh Province in the east and Balochistan to the west (Malkani, 2015). The Mehar Block mainly covers the eastern part Fig. 2 show the location of the study area and the oldest rocks exposed are Dungan carbonates in the core of the anticline. The main part of the block is covered by sediments younger than Eocene and in fact, large parts of the block are covered by recent deposits. In the region west of the Kirthar escarpment the entire section from Chiltan Formation (Jurassic carbonates) to Nari Formation is exposed (Dettmer et al., 1990).

Based on publications, interpretations, assumptions and suggestions (Dettmer et al., 1990). and tectonic experience in the Kirthar Fold Belt (Kirthar, W Puhlji, Sibi and Bolan Block) the Mehar Block and direct surroundings is located in an overthrust belt which is dominated by roughly eastward directed forward breaking thrusting or foreland breaking thrusting (Kazmi et al., 1997). It seems therefore obvious to explain the three observed Main Fold Systems by thrust fault tectonics. Since the main tectonic transport during the ‘Himalayan Orogeny’ in the Kirthar Fold Belt has been directed towards the foreland, i.e. the Indus Valley, opposite west directed thrusting has to be considered as ‘back-thrusting’ or ‘hinterland-divergent thrusting’.

In Mehar Block most of the stratigraphic formations are thick enough to be mapped properly. Several sequences however are either rather thin, such as Pab Sandstones, Dungan and Laki carbonates or missing at many places or difficult to distinguish. The Ranikot shale cover the Moghulkot formation whereas Pab sandstone is sandwich between them as shown in Fig. 3. (Sultan et al., 1995). In some areas however the Pab Formation is stratigraphically absent which results in a stratigraphic contact between Ranikot shales and overlying Moghul Kot shales. In that case the Moghul Kot Formation and Ranikot Group have been lumped together as Moghul Kot Ranikot Group.

Methodology

In these following sections, the data set for this research was acquired as part of dissertation requirement. The data used for this work was...
obtained from Directorate General of Petroleum Concessions (DGPC) Pakistan, 3D seismic volume (in SEG-Y format) survey data covering an area of approximately 15 km$^2$ and bore-hole logs data of three wells in the area are available for the calculation of petro-physical parameters. The data volume consists of in-lines and cross-lines with line spacing of 25 m for both in-line and cross-lines, and the sample rate is 4 ms. The all kind of wire line logs including gamma ray (GR), resistivity (LLD), sonic (DT), caliper, density (RHOB) and spontaneous potential (SP) log are used in this study. For this work the seismic and well log analysis were carried out by using different existing and partially modified techniques to enhance conventional interpretation and reservoir characterization. Keeping the main objectives in mind first of all the performing of impedance inversion on the data set and gradually applied the other steps as following.

**Post-stack Acoustic Impedance Inversion**

Several approaches can be adopted to perform post-stack seismic inversion. Among these are band limited inversion (BLI), sparse spike inversion (SSI) and model-based inversion (MBI). These inversion algorithms are practiced for p-impedance for detection and delineation of the gas-sand reservoirs (Ali et al., 2018). In this research paper Model-based inversion algorithm has been working to invert 3D processed seismic data into acoustic impedance. The Mehar 3D seismic data and Mehar-01 and Mehar-02 wells data are used in seismic-well tie process. While the seismic wavelet Fig.4 representative of the seismic behavior in given data is extracted at optimal well tie and is utilized in inversion analysis. Thus, the Initial acoustic impedance model is built by integrating low frequencies from well and seismic, which shows higher vertical resolution and lower horizontal resolution shown in Fig. 5. Thus, better control on resolution is brought by inversion and the further steps for the post-stack seismic inversion are as following:

**Wavelet Extraction**

The commonly used approach to estimate a wavelet is established on well-logs information that delivers true reflectivity series. The seismic trace is the outcome of convolutional effect of earth’s reflectivity and the source wavelet, added by the random noise. Mathematically, seismic trace is given in eq (1) (Mallick, 1995; Faivre et al., 2002)

$$S(t) = R(t) * W(t) + N(t)$$  

Where, $S(t)$ is seismic trace, $W(t)$ is seismic wavelet, $R(t)$ is earth reflectivity, $N(t)$ is noise and the earth reflectivity in terms of acoustic impedance, can be determined if noise factor is minimized and wavelet is de-convolved. Wavelet extraction process involves statistical estimation of initial constant wavelet from seismic section. In this process, both the existing wells and the seismic data near well locations are utilized. In Fig. 4 wavelet is extracted by finding the operator which upon convolution with the reflectivity series from the well thus an initial correlation is established between real and synthetic data. Then wavelet is extracted from well to improve the correlation and finally, wavelet is extracted from Mehar-02 well. The extraction time window was set from 1300 to 2000 ms, with a wavelet length of 100 ms and input wavelet is greatly affected by the amount of phase shift. As the phase shift is greater, the error will be higher in the resulting impedance data (Jain, 2013).

**Figure 4. Extracted wavelet from well Mehar-02 and its amplitude spectrum.**
Seismic-Well Tie

After extracting wavelet well log to seismic correlation is the next step which is done for each well individually. The process of correlation is applied as follows showing the display of seismic in-line 1196 and four marked horizons and blue traces (synthetic traces) and red trace (real traces) which a maximum coefficient of 74% are shown in Fig. 5:

1. A synthetic trace is generated using well log data and compared it to the seismic trace nearest to the well location.
2. Time stretching and squeezing is applied to the data to align the seismic and well-log reflectors.
3. Correlation coefficient and Root Mean Square (RMS) error are measured between the seismic and adjusted well-log synthetic traces.

Initial Model Low Frequency Model

The computation of initial impedance model is the next step of the inversion. It was created by incorporating low frequency from well data, seismic data and marked horizon (Russell, 1988; Ali et al., 2018). Thus, the low frequency component (0-15Hz) is used to obtain the absolute acoustic impedance in inversion algorithm (Russell, 1988).

The model based seismic inversion technique uses an initial model on the basis of impedance information (sonic DT and density logs), structural information (horizon data) and the estimated wavelet at well location for suitable correlation Fig. 5. The initial model is established by using Mehar-02 well and the developed model and extracted average wavelet Fig. 4 are used to generate a synthetic seismogram. The comparison between synthetic and observed seismic estimates is evaluated by the misfit function. We try to obtain the initial model by minimizing the misfit. For this purpose, we update the model iteratively until the optimum result is achieved (Russell, 1988; Sen et al., 2013).

Post-stack inversion analysis was performed using the created model shown in Fig. 6. While the sonic P-wave log from well has been superimposed on the section with the display of well tops on it and the color represents acoustic impedance as shown in the Fig. 6 where seismic events are also picked (Sui main Limestone, Ranikot, Pab and Mughal kot) The initial P-impedance model reveals higher vertical resolution and lower lateral resolution; then inversion provides better control on vertical and lateral resolution.

Results

Analysis of the Model-Based Inversion

The analysis is performed in two steps: First, one composite seismic trace is extracted from seismic data and inverted into impedance in which Correlation coefficient (CC) and Root Mean Square (RMS) errors are estimated. Secondly, If CC and RMS errors are in acceptable range then the inversion methods are applied to entire seismic data to invert impedance and density.

The inversion analysis window ranging from 1300 to 2000 ms is performed at Mehar-02 well and results are compared to the original log as shown in Fig. 7. In this process, impedance models derived from the well and those inverted from the seismic data are compared. In Fig. 7, the red trace shows inverted impedance from the seismic trace, the blue trace shows impedance from well log data and the black trace...
shows the initial model. Thus, the results show good correlation and the model is accepted for further analysis.

The synthetic traces are generated and correlated with the seismic traces for all wells and the differences between them are measured. In our analysis, comparison of real with synthetic shows good correlation with coefficient over 0.99 and RMS error is 0.13.
Inversion Results

Inverted Impedance

The seismic data is inverted utilizing initial model Fig. 6, estimated wavelet Fig. 4 at best seismic-well ties Fig. 5, basis on the analysis of model-based inversion Fig. 7 and the final cross-section of the inversion result is given in Fig. 8 the entire seismic section is inverted into impedance, overall inversion analysis holds good for generating acoustic impedance section. The complete 3D seismic is now transformed into acoustic impedance Fig. 6 and the zone of interest Ran-
Ranikot Formation is starting at 1830 to 1870 ms has low impedance and it is clearly visible and highlighted by the green color and its value ranges from (8427–7184 (m/s) (g/cc)) on seismic section is shown in Fig. 8. The inverted results with zones of low and medium impedances (yellow and red) are developed in the Ranikot Formation show the zones with alternate sand-shale units presented in the location. The P-impedance log is superimposed for comparison with the inversion result thus P-wave log shows fair correlation with the inverted section.

**Inverted Density**

The cross section of the inverted density is given in Fig. 9 which shows the low density near 1830 to 1870 ms level are clearly visible and highlighted by yellowish to green color on the seismic section. This low density zone is may be due to the presence of sand channels as it is also seen in inverted acoustic impedance section in Fig. 8. The density log is superimposed for comparison with the inversion result thus Fig. 9, represents the coherency of the inverted section with the density log at the well location. Some of the zones mark least coherency with the data set and Overall inversion analysis holds good for generating inverted density section.

**Petro-Physical Analysis**

We perform the petro-physical analysis of the well Mehar-02 to calculate the required values of porosities. Petro-physical studies have been carried out for Ranikot Formation in which the GR (Gamma Ray log) clearly reveals that its upper portion is a shaly member and lower portion is clean rock. The Steiber equation is been used for calculating the volume of shale \( V_{SH} \) and that result of volume of shale \( V_{SH} \) is further used for the calculating the effective porosity. The other track includes different porosity logs like PHID-2 (Density Porosity and 2 for well 2), PHIT-2 (Total porosity-2) and PHIE-2 (Effective Porosity-2). The volume of shale in lower portion is almost 10% and in upper portion it is more than 30%. While the effective porosity (PHIE) has been calculated from neutron-density and density porosity and its ranges from about 12-20% indicating a better development of porosity. The average effective porosity in the reservoir is 18% as shown in Table 1 and Fig. 10 shows the composite diagram, of raw log curves, porosity and matrix proportion of rock. Therefore, the first log represents

| Table 1. Estimated Petro-physical properties of reservoir zone |
|---------------------------------------------------------------|
| **Rock properties** | **Depth (ft.) (12658-12741)** |
| 1 Average Volume of shale (VSH) | 09% |
| 2 Average density porosity (PHID) | 21% |
| 3 Average Total porosity (PHIT) | 14% |
| 4 Average effective porosity (PHIE) | 18% |
| 5 Average saturation of water (Sw) | 35% |
| 6 Average hydrocarbon saturation (Sh) | 64% |

Figure 10. Composite Log showing Petro-physical properties and marked reservoir zone on well data. First one is lithology track, second is resistivity track, third one is porosity track and remaining are calculated well parameters. SPD (spontaneous Potential log), GR (Gamma Ray log), CALX (Caliper log X), RS (Shallow Resistivity log), RMLL (Microlatero Log Resistivity), RD (Deep Resistivity), NPHI (Neutron Porosity log), ZDEN (Z-Density log), DT (Sonic log). Volume of shale (VSH) which is calculated with the help of Steiber equation. PHID-2 (Density Porosity and 2 for well 2), PHIT-2 (Total porosity-2) and PHIE-2 (Effective Porosity-2). SW-A1 (Water Saturation-A1) and HS-A1 (Hydrocarbon Saturation-A1).
the lithology log which includes SPD (spontaneous Potential log), GR (Gamma Ray log) and CALX (Caliper log X). The second log belongs to depth in feet fo the well while the third log represents the Resistivity log which includes RS (Shallow Resistivity log), RMLL (Microlateral Log Resistivity) and RD (Deep Resistivity). The fourth log represents the density log which includes NPHI (Neutron Porosity log), ZDEN (Z-Density log) and DT (Sonic log). While the SW-A1 (Water Saturation of well-A1) and HS-A1 (Hydrocarbon Saturation of well-A1).

**Geostatistical Method**

The geostatistical method is usually followed to predict many geophysical parameters from well and seismic data. Here we utilize Probabilistic Neural Network to compute porosity volume from seismic data (Pramanik et al., 2004; Pyrcz et al., 2014). The parameter porosity is inverted, which is calculated from the petrophysical analysis Fig. 10. The input data consist of petro-physical logs of Mehar-02 well along with 3D seismic cube and inverted results based on Model-based algorithms. As the model-based inversion is carried out for the inversion analysis therefore that model-based model is used as external attribute in order to estimate the porosity of located reservoir.

The objective in this unit is to apply neural network algorithm to estimate porosity over the whole 3D volume. For this purpose, initial step is to build a relationship between seismic data and measured log through training process. Once the relation is established, we apply this relationship over the whole volume. Fig. 11 shows analysis window for the well being used, with the target porosity log on the left side, the extracted seismic trace and inverted trace on the right side while the two horizontal yellow lines show the analysis window of the well data porosity.

The porosity and inverted impedance cross plot of the Mehar-02 well as shown in Fig. 12. The porosities are display on y-axis while the inverted impedance is placed on x-axis. As the correlation coefficient is obtained by using a linear regression technique, this linear relation is valid within the resolution boundaries of seismic and well log data. Thus, the linear relationship developed between porosity and acoustic impedance by a best fit line in red color can be seen in Fig. 12, which passing through the maximum number of data points. The correlation coefficient between porosities and inverted impedance is 0.738 which is fair result and the variables used in the equation are $y= \text{effective porosity and } x=\text{acoustic impedance}$. As shown in Fig. 12 the porosity and impedance has inversely proportion thus the porosity increases the impedance decreases with a negative slope.

Further a single attribute analysis was done followed by the multi attribute analysis. During this a convolutional set of weights was used with an operator length of five samples. The results of the training analysis for various combinations of attribute sets and it analysis are
Figure 13. (a) Single attribute analysis (b) Multiple attribute analysis whereas modelled log is given in red color and original logs are in red color.

presented in Fig. 13. The training process using one attribute produces a correlation value 0.8066 in Fig. 13a while using series of attributes the correlation has been increased to 0.9446 in Fig. 13b. While the Fig. 14 represent the cross plot established between actual and predicated porosity for the model based using probabilistic networks (PNN). The predicated porosities are display on y-axis while actual porosities derived from well data are placed on x-axis and best match line in red color can be seen on the cross plot which is passing through the maximum number of data points correlation coefficient between actual and predicted is 0.815 which is good result.

In response to Probabilistic Neural Network (PNN) training a comparison between target log (porosity) and original log has been drawn at well location. Fig. 15 shows PNN training has enhanced the coefficient to 92% using five-attribute analysis, which is better and validation step is also performed while leaving the target log out of the training calculations.

Final step in geostatistical inversion is to invert the porosity on whole seismic data. The Fig. 16 shows zoomed view of the line which contains the Mehar-02 well, on which the inverted porosities are applied and derived the multi-attribute relationship between the seismic and target log (porosity). A high porosity values are estimated, which is located between 1830 ms and 1870 ms time interval which is clearly seen in Fig. 16, that higher porosities are trapped in highlighted zone by light blue toward pink. The maximum porosity values are nearly 18% in lower Ranikot which was also estimated in petro-physical analysis and now its distribution is inverted on whole seismic data. We applied this result over the whole volume to obtain the same volume of target porosity log.

Discussion

Inversion results depend greatly on the quality of the seismic-to-well tie and log calibration. However, wavelet estimation is also a crucial step in any inversion procedure. The latter is required in the Forward Modeling required to generate a synthetic model that is used to
drive the inversion process. Although, acoustic impedance alone cannot suggest the lithology, fluid content (sands, shale) and porosity, because even slight variation in one factor can bring extreme variation in impedance value. To have a broader control over the results more data is required and Angle Verse Offset (AVO) analysis is suggested.

The seismic inversion is used here to characterize the reservoir zone, for this purpose first p-impedance model is computed from the well data interpretation data and then it is used for inversion to get the impedance section. The inversion not only provide acoustic impedance model it also provide other reservoir properties such as effective porosity and water saturation of location (Rijks et al., 1991) Thus on impedance section reservoir zone is picked by low value of impedance and this impedance model is used to find the porosity distribution of Ranikot Formation in the seismic section. Now a day geostatistical method is widely used to predict different geophysical quantities with integration of seismic and well data and in this study PNN is used to compute porosity volume from seismic 3D data.

In second stage the inverted impedance surface of the Ranikot Formation which estimated from the model-based post-stack inversion algorithm was converted into porosity Fig. 16. The porosity varies from 14% (light green color) to 18% (dark pink color) and the average porosity of Mehar-02 well is around 18% (light blue to dark pink color). Thus, the average porosity value estimated at the well by petro-physical analysis matches the value estimated from seismic inversion Fig. 16.

**Conclusion**

Integrated Petro physical models, Geostatistical and Model-Based Inversion are widely used to estimate the physical properties of target zone in the exploration of hydrocarbons. In this study we used PNN techniques to identify the hydrocarbon bearing zones within study area of interest which gives us suitable results. While the reservoir characterization and seismic interpretation can be improved by predicted seismic porosity.

We successfully applied our methodology to the integrated inversion seismic derived impedance that shown, the value of low impedance ranges from 8010-8850 m/s/g/cc. and these variations clearly indicate the alternate layers of sand/shale in the study area.

The PNN method was used to predict the porosity values in the study area by using the Model-Based Inversion as an external attribute.
from that attribute the maximum porosity value is 18%. The result suggests that given seismic and well log data for a region, a PNN method can produce a more reliable estimation of the petro-physical properties of Mehar Block.

Acknowledgments

I am highly thankful of Directorate General of Petroleum Concessions (DGPC), Pakistan for providing seismic and well data for research purposes. I would also like to thanks Dr. Aamir Ali Associate professor of Quaid-i-Azam University, Islamabad, Pakistan department of earth sciences. The authors would like to acknowledge the National Natural science foundation of China for substantial support of general projects (41374116) and (41674113).

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