Chapter 4

Research Methodology

The research methodology is described step-wise in the following sections. However, it is appropriate to mention at this stage that due to paucity of well and seismic log data from Indian oil fields and from the regulatory bodies, the study was performed on open access data provided from F-3 Block, the Netherlands and Penobscot region, Canada. The main impetus of formulating the methodology, after obtaining the data, was on obtaining the seismic-well log tie, perform a host of prevalent inversion techniques and finally verify the inversion based results by rigorously using the state-of-art geotechnical techniques to gather the pertinent parameters to delineate the reservoir. The reservoir characterization is largely done by post-stack and pre-stack inversion methods, but by using various geostatistical techniques for characterizing the geophysical parameters is the way forward, which makes the characterization of the reservoir more reliable. Therefore, rigorous scrutiny and implementation of various pre-and post-stack inversion techniques in conjunction with the use of recent geostatistical techniques has brought forth the novelty component in the present research and has made the research findings very trustworthy.

4.1 Seismic Inversion

In the current research, post-stack inversion and pre-stack inversion methods are used for the characterization of reservoirs. For this, seismic and well log data are used as input providers. The research has used the CGG Veritas Hampson Russell Software (HRS) package to estimate the volume of P-impedance from various post-stack inversion methods in the study block of the Netherlands. The pre-stack inversion methods have been used to predict volumes of elastic impedance, P-impedance, S-impedance, P-wave, S-wave, V_P/V_S ratio, and Lambda-mu-rho for Penobscot 3D pre-stack seismic data. Various seismic inversion methods used for post- and pre-stack data are systematically represented in Fig. 4.1.

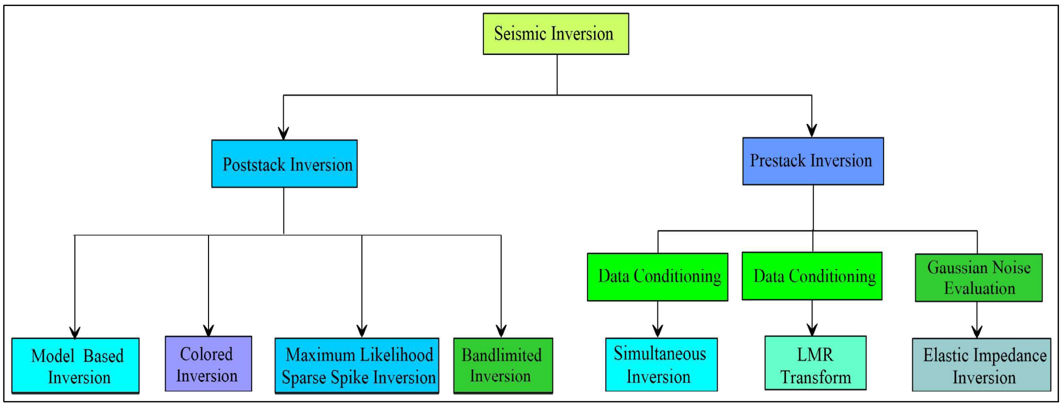


FIGURE 4.1: Flow chart of the seismic inversion methods

4.1.1 Post-stack inversion

Four types of post-stack inversion methods, namely, model based inversion (MBI), colored inversion (CI), maximum likelihood sparse spike inversion (MLSSI) and bandlimited inversion (BLI) have been used to predict P- impedance in inter-well region for post-stack seismic data.

4.1.2 Pre-stack inversion

For pre-stack seismic data, three types of pre-stack inversion methods, namely, simultaneous inversion (SI), LMR transform and elastic impedance inversion (EI) have been rigorously used for the estimation of various petrophysical properties in the inter-well region.

Data conditioning was performed on pre-stack data from Penobscot oil field, Canada, before applying SI. SI was also performed using raw pre-stack seismic data in order to visualize the effect of data conditioning on SI.

Gaussian Noise was manually added in raw pre-stack seismic data and EI was performed to understand the effect of Gaussian noise on EI.

4.2 Geostatistical techniques

The state-of-art geostatistical tools have been used to further predict various petrophysical parameters like porosity, density, P-wave and gamma ray for post-stack seismic data of the F3 block. The P-impedance derived from post-stack inversion methods has been used as an external attribute while attributes extracted directly from seismic data (seismic attributes) were used as internal attributes in the geo-statistical investigation. Four important geostatistical techniques, namely, single attribute analysis, multi-attribute analysis, probabilistic neural network (PNN) and multilayer feed forward network (MLFN) have been used to predict the porosity, density, P-wave and gamma ray volumes. The single and multi attribute are important essential analyses while PNN and MLFN analysis may be used to further understanding of results. However, in the present study, all the four geostatistical techniques have been used to obtain the results as illustrated in Fig. 4.2.

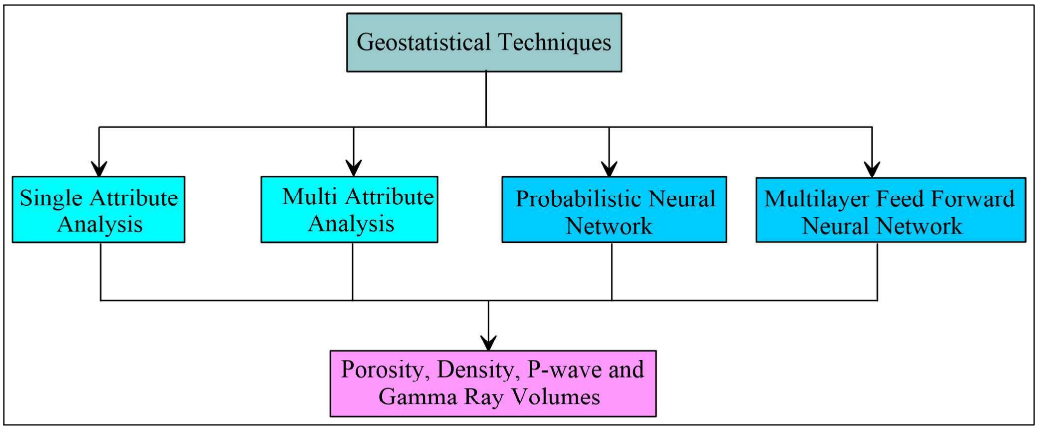


FIGURE 4.2: Geostatistical techniques vis-à-vis outputs

By combining the above, a comprehensive research design is illustrated through the flowchart in Fig. 4.3.

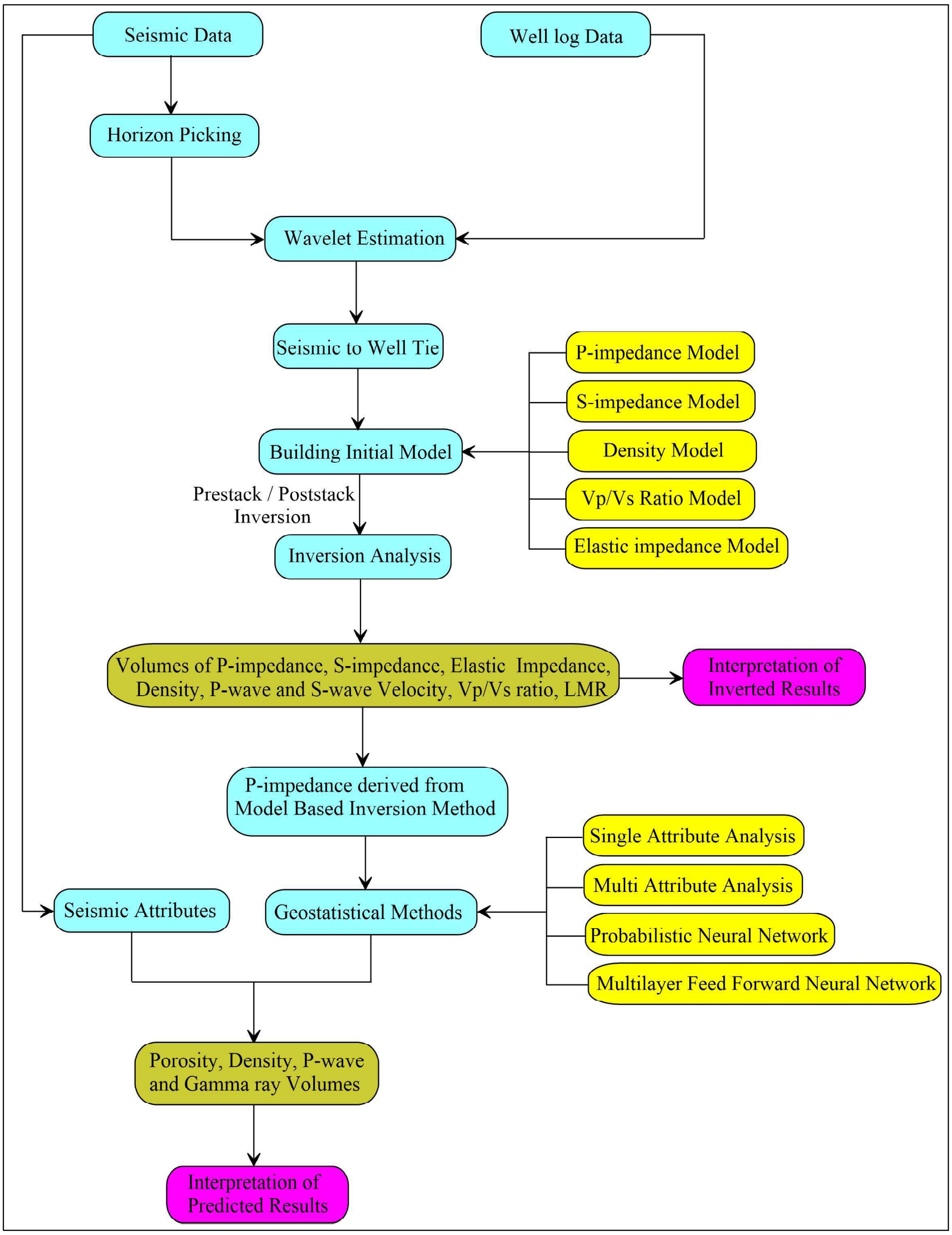


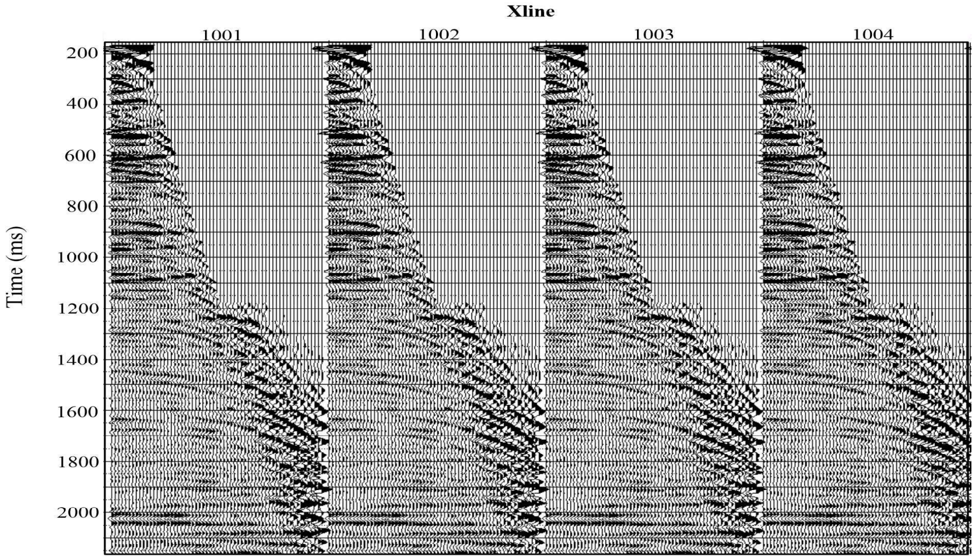
Figure 4.3: Research design of seismic inversion methods and geostatistical techniques adopted in this study

4.3 Steps in seismic inversion methods and Geostatistical techniques

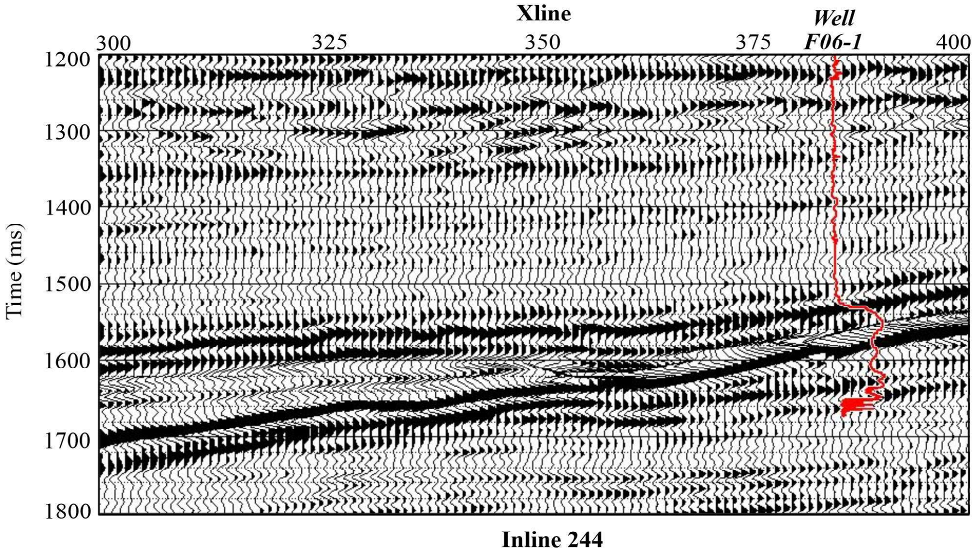
The methodology used in seismic inversion methods is described below in step by step fashion. The seismic data (both post-stack and pre-stack) and well log data have been used as input data.

4.3.1 Seismic data

In this study, two types of data have been used. A representative pre-stack data from Penobscot oil-field Canada, and post-stack data from F3 block, the Netherlands are shown in Fig. 4.4(a and b), respectively.



(A)



(B)

FIGURE 4.4: (a)Pre-stack seismic data and (b)Post-stack seismic data

4.3.2 Well log data

Well log data is used as an input with seismic data. Well log data shows the variation of petrophysical properties with depth. A representative well log data is shown in Fig. 4.5.

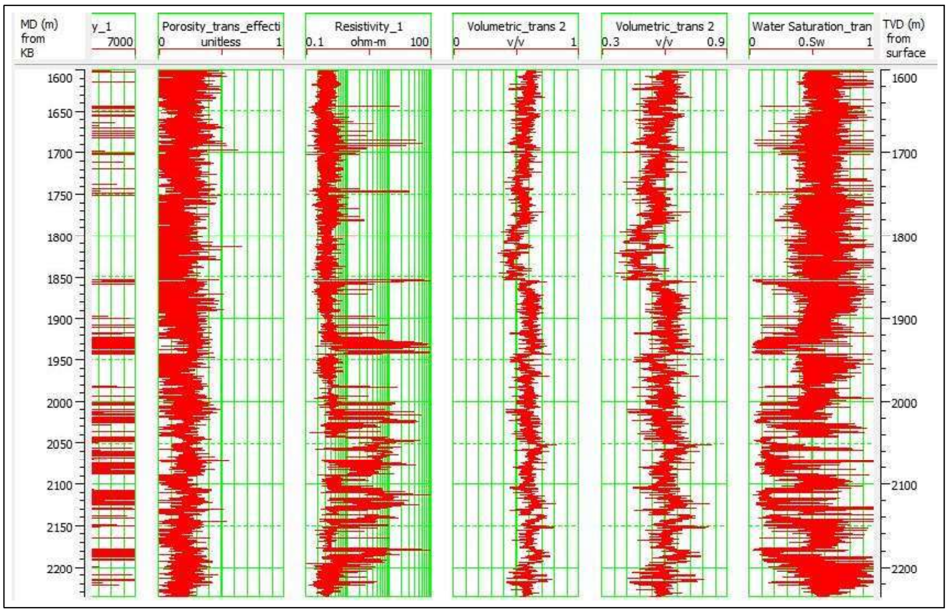


FIGURE 4.5: Well log data

4.3.3 Horizon picking

A theoretical layer of earth is generally known as a demonstration of stratigraphic surfaces and the boundary between two stratigraphic layers is known as horizons (Maurya et al., 2020). In the seismic section, these horizons reveal contact characteristics between two rock bodies containing different porosity, fluid content, density, seismic velocity, etc. Seismic data interpretation is executed on the basis of these horizons. These horizons are very significant in seismic inversion methods as these horizons work as a guide to interpolate well log properties between the wells. Picking the seismic horizon in the seismic section is a herculean job as it needs real technical expertise, understanding, time and concentration. The red-colored division line represents a manually picked horizon in Fig. 4.6.

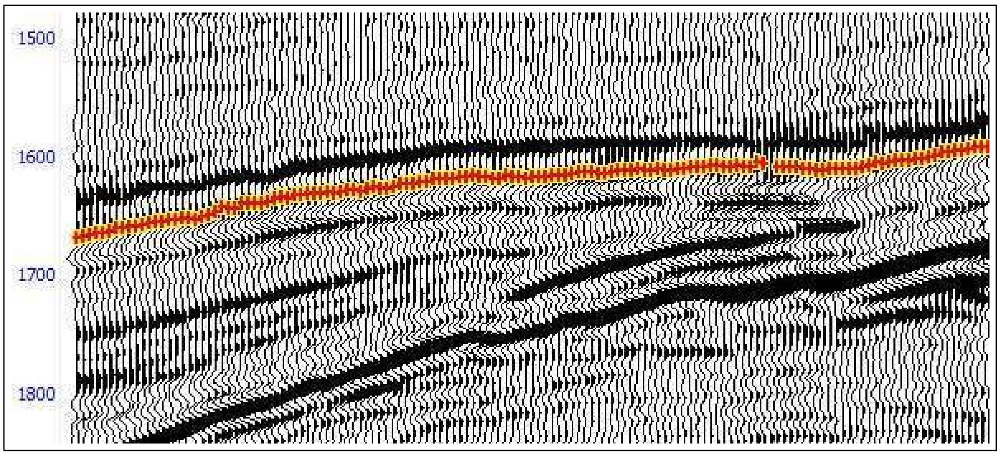


FIGURE 4.6: Horizon picking

4.3.4 Wavelet estimation

The process of wavelet extractions is as follows:

1. To extract and taper the seismic traces.
2. To compute the autocorrelation based on the length of preferred wavelet.
3. To compute the autocorrelation frequency spectrum.
4. To obtain the square root of the frequency spectrum modulus by silencing the zero hertz component.
5. To compute the inverse FFT. The original component of the inverse FFT output being the zero phase wavelet Russell and Hampson, 1991)

A seismic wavelet is the source signature of the seismic data and the relation between the geology (reflection coefficients) and the seismic data (traces) (Henry, 1997). Without knowing the wavelet, several valid interpretations of the subsurface cannot be made (Henry, 1997). Therefore, wavelet extraction is perhaps the most important step in the seismic well tie, which is the correlation of a synthetic seismogram computed from well log data with the help of seismic data. The synthetic seismogram is the convolution results between a wavelet and reflectivity derived from well logs. Fig. 4.7 reveals the extracted zero-phase Ricker wavelet.

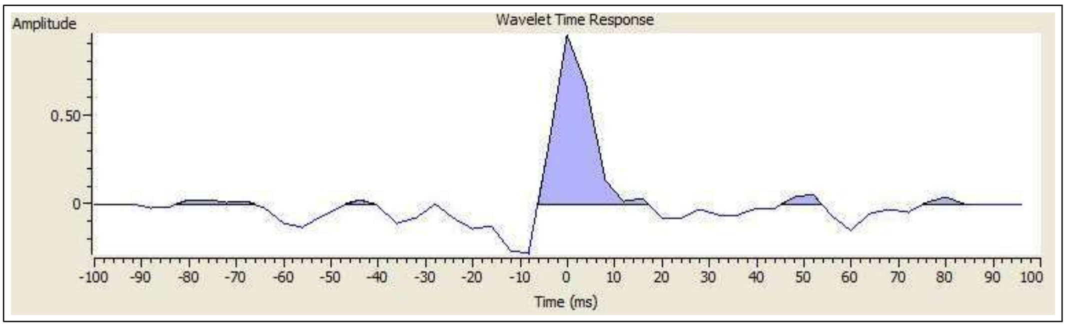


FIGURE 4.7: Seismic wavelet with statistical zero-phase Ricker wavelet

4.3.5 Seismic to well tie

Correction of the log data and seismic sections was finished using the check shot log. A check shot is a log that is capable of transforming other geophysical logs from depth to time domain, that correlate seismic and well log data. To integrate and calibrate information from well log data with the seismic was objective of seismic to well tie. The seismic to well tie is the procedure of manually matching the synthetic seismic waveform and reflection seismic waveform.

After extraction of the wavelet, the well log to seismic correlation was performed for all the wells individually. The method of this correlation is enumerated as follows:

- A synthetic trace was produced by utilizing well log data and comparing it with nearest seismic trace at the well location.
- Time squeezing and stretching was then implemented to the data in order to match the well-log and seismic reflectors.

The correlation coefficient (CC) and residual error have been computed between the seismic traces and modified synthetic traces from well log. A representative Fig. 4.8 indicates the results of a seismic well tie. The seismic well tie and wavelet estimation were performed for all the wells within the seismic survey. Each well has an optimum wavelet obtained from the preceding seismic well tie loop. Usually, the optimum wavelets obtained for each well is unique. The final wavelets were obtained by averaging all the optimum wavelets. The blue traces show pseudo synthetic traces produced using well log and wavelet. The red traces show seismic traces close to well location. The black traces show real seismic gathers.

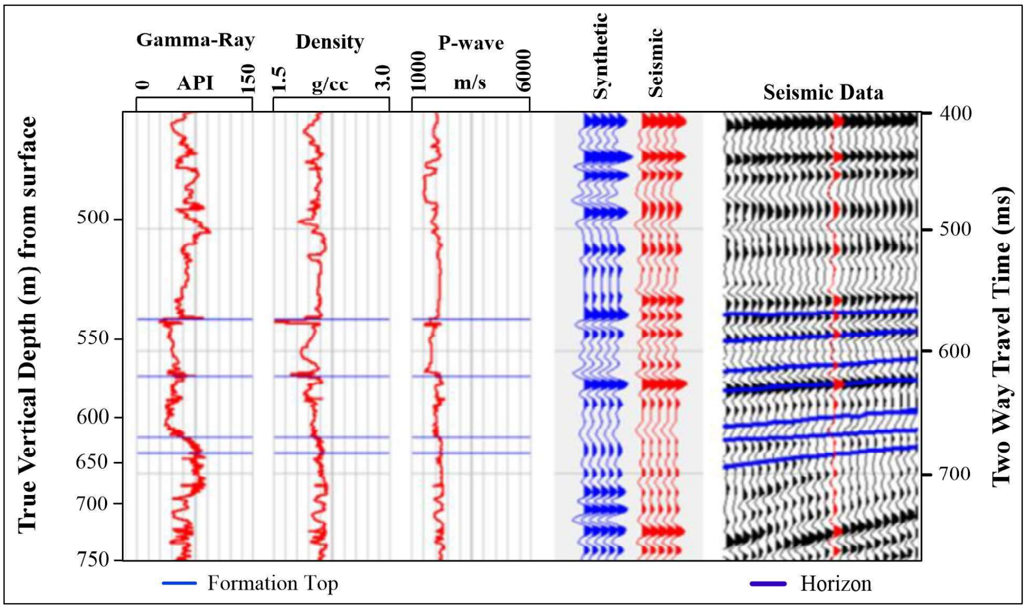


FIGURE 4.8: A representative seismic well tie using well log data with the help of seismic data

4.3.6 Building initial model

In this step, preliminary petrophysical properties models were configured. These preliminary models have been constructed by interpolating the petrophysical properties from well positions into the Crosslines and Inlines. As a guide for the interpolation interpreted seismic horizons were introduced. In a pre-stack inversion, P-impedance, S-impedance, and density models were constructed while in post-stack inversion, only P-impedance model was constructed.

4.3.7 Inversion analysis at well location

In this step, pre-stack and post-stack inversion methods were performed to estimate petrophysical properties. The composite trace near to well location was used to cross-verify with the well log data. This was performed for all the wells present in the study area. If found satisfactory, then this analysis could be used to predict volumes of petrophysical properties.

4.3.8 Interpretation of inverted results

If satisfactory results are gathered then, the algorithm would be performed for the whole volume. For this, the inverted P-impedance volume was derived from all post-stack inversion methods while inverted P-impedance, S-impedance, V_P/V_S ratio, density, lambda- mu-rho, and elastic impedance volumes were estimated from various pre-stack inversion methods. The interpretation of the entire study area depends upon these inverted results.

4.4 Use of geostatistical techniques for data interpretation

The geostatistical techniques use seismic data derived attributes and inverted impedance derived attributes as input to predict various petrophysical parameters away from the boreholes. These geostatistical techniques are further divided into four parts as single attribute analysis, multi attribute analysis, probabilistic neural network (PNN) and multilayer feed forward neural network (MLFN). For geostatistical analysis, these techniques use inverted impedances derived from MBI method as external attributes. The single attribute analysis represents individual use of the attributes. The multi attribute attributes analyze more than one attribute at a time to estimate a linear statistical relationship between well log property and the attributes. These statistical relationships are then used to predict petrophysical parameters. On the other hand, PNN and MLFN derive nonlinear relationships rather than linear relationships as in a single attribute and multi-attribute case. The present study is performed using Hampson Russell Software (HRS) (ver 10.2), a CGG Veritas software suit. In this process, inverted P-impedance (derived from various post-stack inversion) was used as an external attribute while seismic data derived attributes (seismic attributes) were used as internal attributes. Four types of geostatistical techniques, i.e., single attribute analysis, multi attribute analysis, PNN, and MLFN, have been used for the prediction of petrophysical properties.

In HRS, which is a statistical tool, the geostatistical processing is implemented in the EMERGE module, and it cannot differentiate between good predictions from a totally unrelated attribute or from a closely connected attribute. Quality control is useful to differentiate, but the risk of choosing a false relationship is greater by using small samples if established relationships are not reflected in the outcomes (Chen and Sidney, 1997).

4.5 Brief overview of methods applied in the present work

Pre-stack, post-stack seismic inversion and geostatistical techniques have been used as analytical tools in this study. A brief overview is described in the following paragraphs: MBI is a form of post-stack inversion that estimates acoustic impedance (P-impedance) from seismic data with inputs from well logs (Kushwaha et al., 2020). Another post-stack inversion method used in the present work is CI method. In this method, the inversion is interpreted as a convolutional process where a frequency domain operator is used to convert the seismic traces into acoustic impedance (Lancaster and Whitcombe, 2000; Maurya et al., 2020). MLSSI method is the third post-stack seismic inversion method applied here, but unlike other techniques, it provides a reflectivity series calculation that would estimate the seismic information with a minimum amount of (Sparse) spikes. In this scenario, non-uniqueness is expected to be taken care of by implementing the sparse criterion of reflectivity. To achieve this, the maximum likelihood deconvolution (MLD) was performed (Kushwaha et al., 2019). BLI method is the most common type of inversion, which presumes that the seismic amplitude is proportional to the coefficient of reflection and transforms the input seismic trace into acoustic impedance traces. The input seismic trace is normally wavelet processed (Lindseth, 1979).

The Earth's elastic properties could be found from the Pre-stack inversion of the seismic data. These properties help measure the reservoir's secondary parameters such as density, porosity, sand content and fluid saturation. In this regard, the simple convolutional model assumes zero-offset data. The algorithms that are often used to broaden seismic inversion for the handling of amplitude vs offset (AVO) data are SI, LMR transform, and EI. Data conditioning has been performed before applying SI method to show the effect of conditioning on the inverted results (Kushwaha et al., 2020). Gaussian noise has been added in raw data to show the impact of noise on inverted results using EI method.

Prediction of petrophysical parameters has been made by use of single attribute analysis, multi-attribute regression, PNN and MLFN. The basic principle behind these techniques is to find a connection between attributes and petrophysical parameters. These relations were then used to interpolate or extend the properties to the entire seismic volume with some external attributes like impedance as constraints. These techniques help interpret the fluid content, lithology, saturation and limits of the subsurface strata and productive zones (Pramanik et al., 2004; Chambers et al., 1994). Porosity, density, P-wave and gamma ray volumes have been evolved from geostatistical methods with inputs from seismic and well log data as internal attributes and inverted impedance from MBI, CI, MLSSI and BLI methods as external attributes. MBI, CI, MLSSI and BLI methods were applied to the F3 block, Netherland seismic volume. SI, LMR and EI methods were applied to the Penobscot region, pre-stack 3D seismic data. The geostatistical techniques (single-attribute analysis, multi attribute analysis PNN and MLFN) have been religiously applied to estimate various petrophysical parameters and to compare the various geostatistical techniques in predicting the parameters.

4.6 Software used for data analysis

Geophysical application software package Hampson-Russell (a subsidiary of CGG Veritas) has been used to execute the research in this study. Geoview was a well-database application for viewing logs. All post-stack seismic inversion procedures were accessible in various modules of the Hampson- Russell Software (HRS) and the same has been used for processing and interpreting the data. EMERGE was a tool of HRS for performing geostatistical analysis. MATLAB programming language and Surfer were used for developing figures for pre-stack inversion using SI method and also for some post-stack inversion methods. The thesis has been written on Latex.