"Seismic Impedance Inversion and Porosity Estimation from the acoustic impedance with well seismic callibration"

A

Project Report

submitted in partial fulfillment of the

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in

GEOSCIENCE ENGINEERING

by

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CANDIDATE'S DECLARATION

I/We hereby certify that the project work entitled **"Seismic Impedance Inversion and Porosity Estimation from the acoustic impedance with well seismic callibration"** in partial fulfilment of the requirement for the award of the Degree of BACHELOR OF TECHNOLOGY in GEOSCIENCE ENGINEERING and submitted to the Department of Department of Petroleum Engineering and Earth Sciences, College of Engineering(COES), University of Petroleum & Energy Studies, Dehradun, is an authentic record of my/our work carried out during a period from **Jan**, **2015** to **April, 2015** under the supervision of **Dr. U Kedareswarudu and Mr. Sonu Kumar.**

The matter presented in this project has not been submitted by me/ us for the award of any other degree of this or any other University.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Date: _____2015   **(Dr.U. Kedareswarudu)**

(Mr. Sonu Kumar)

Project Guide

ACKNOWLEDGEMENT

I wish to express my deep gratitude to my guide **Dr.U.Kedareswarudu and Mr. Sonu Kumar**, for all advice, encouragement and constant support he has given us throughout my project work. This work would not have been possible without their support and valuable suggestions.

I would like to thank all my **friends** for their help and constructive criticism during my project work. Finally I have no words to express our sincere gratitude to our **parents** who have shown us this world and for every support they have given us.

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TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

The undisputed leader amongst various tools for identifying potential exploration target is the 3D seismic survey. The reflections of seismic waves from subsurface layers illuminate potential hydrocarbon accumulations. As waves reflect their amplitudes change to reveal important information regarding the subsurface geology. However, seismic reflection data contains data beyond the location of reflector. The controlling property in this change is the contrast in impedance, which is product of density and velocity. Seismic reflection amplitude information can be used to invert for the relative impedance of rocks on both sides of the interface. This process is called seismic inversion for reservoir characterization.

This project gives a brief idea about the science and art of seismic inversion, and how oil and gas companies are using it to reduce risk in their exploration and hence increases the success ratio. An empirical relation is established between the porosity and the acoustic impedance which shows an inverse relationship between these two. Thus, the correlation of impedance with the porosity helps in determining the hydrocarbon potential of the formation and a low impedance zone (sweet spot) is our area of focus.

The impedance inversion is realized with the help of PETREL software and the variation in the impedance contrast along the depth is conclusively studied and the bright spot (lower impedance region) is the target for hydrocarbon exploration.

1. INTRODUCTION

1.1.   Seismic impedance Inversion

Seismic impedance inversion is a process of transforming the seismic reflection data into the quantitative rock property i.e. acoustic impedance.
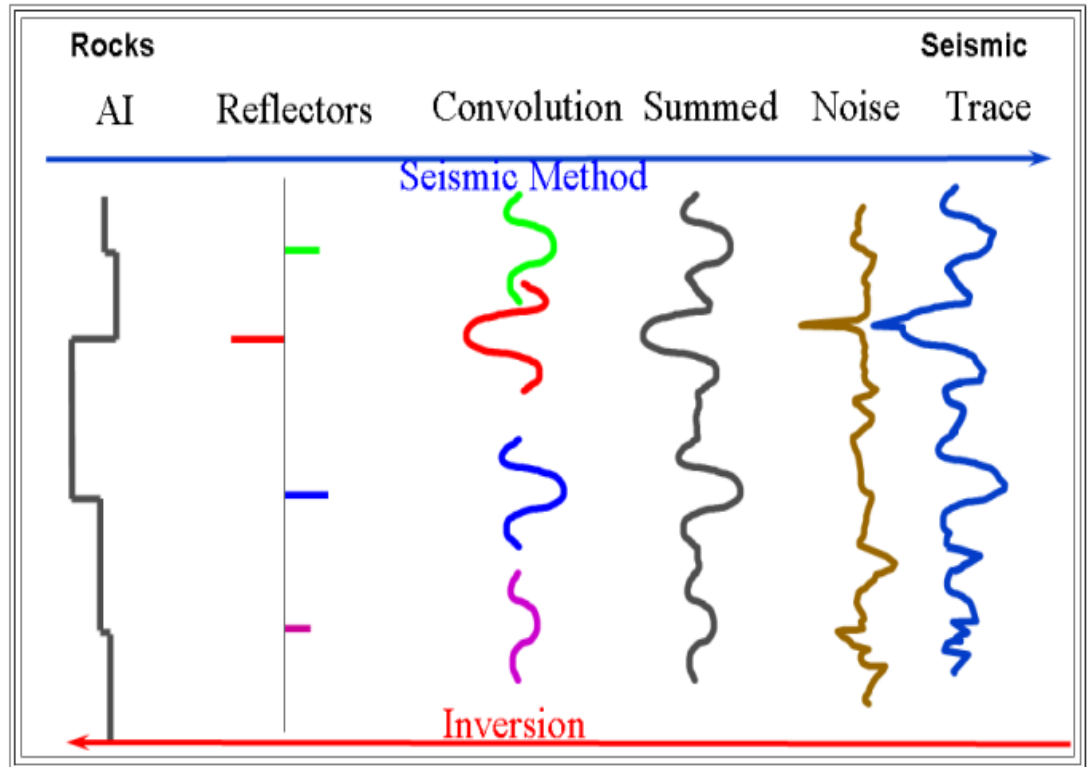
Figure 1. : Convolutional model for seismic trace and its inversion

The normal assumption is that the seismic trace is considered to be a primary only reflectivity model convolved with the seismic wavelet which is summed with some uncorrelated noise and can be represented by the equation:

Seismic = Wavelet * Reflectivity Series + Noise

$S(t) = R(t) * W(t) + N(t)$, where t represents time domain.

The inversion technique aims to reduce the wavelet effect from the obtained seismic trace and provide an acoustic impedance model of the subsurface.

1.2.   Why impedance inversion is required?

In a simplified way, the seismic signal can be described as the result of wavelet with the reflection coefficients that change at every layer when the velocity and density changes depending on the thickness of the layers, the instantaneous velocity surrounding depth and the frequency content

of the wavelet, tuning effects caused by thin bed configuration will affect the amount of information that can be resolved by the seismic signal. The Acoustic impedance attribute attempts to provide a better link between seismic and well data. The processing method used to generate this attribute is known as "Seismic Inversion". From the fact that in theory, the steps that created a seismic trace would be now run the inverse way back the rock properties embedded in the seismic signal. This process takes out the influence of the shape of the wavelet and compensates to some extent the tuning effects described above. The result of Seismic Inversion is much closer to well log data (Acoustic Impedance logs) and hence it brings seismic closer again to the rock features that generated the seismic signal in the first place.

1. More geoscientists understand the concept of impedance and geology than the seismic trace. Thus, working in the impedance domain is a great mechanism for integrating with the various disciplines in a multidisciplinary asset team.
2. Removes the effects of the wavelet within the seismic bandwidth.
3. Forces well ties to be made and understood.
4. Reservoir properties are separated from the overburden.
5. May provide quantitative and qualitative predictions on the reservoir properties.
6. Stratigraphic interpretation may be improved.
7. Interpreting in the impedance domain is frequently easier than in the seismic domain.

2. SEISMIC IMEDANCE INVERSION METHODOLOGY/PROCESSES INVOLVED

2.1 Noise separation

The seismic data received by a receiver have unwanted signals which are termed as noise. The noise can lead to wrong interpretation of seismic data thus the noise should be separated or reduced in order to get some meaningful data which can be interpreted precisely.

2.1.1 Noise separation by stacking.

Generally the noise is non-coherent in nature hence it occurs at different time in different seismic trace such that when the traces are added to each other the non-coherent noise get reduced and the coherent signal get amplified hence signal by noise ratio increases.

2.1.2 Noise separation by using filters.

The filters are used when a particular frequency or range of frequency is present as a noise hence that frequency or range of frequency should be eliminated from the obtained seismic data.

The filter includes high pass filter, low pass filter and notch filter.

- High pass filter allows higher frequency to pass and restricts the lower frequency.
- Low pass filter allows lower frequency to pass and restricts the higher frequency.
- Notch filter restricts a particular frequency from the data.

2.2 Wavelet Analysis

All modern seismic inversion methods require seismic data and a wavelet estimated from the data. Typically, a reflection coefficient series from a well within the boundaries of the seismic survey is used to estimate the wavelet phase and frequency. Accurate wavelet estimation is critical to the success of any seismic inversion. The inferred shape of the seismic wavelet may strongly influence the seismic inversion results and, thus, subsequent assessments of the reservoir quality.

The seismic data recorded by the sensors around the explosion are processed and massaged to extract meaningful signals, which may be visualized as an image of the subsurface. These images can then be analyzed with the goal of understanding something about the structure of the earth, such as the types and nature of the rock and whether fluids, such as oil or gas, exist within pores in the rock.

2.2.1 Wavelet extraction by Well-to-Seismic tie.

One way to calibrate the seismic data gathered at the surface with the properties of the earth is to drill a hole, or well, into the earth. We can more directly measure the characteristics of the earth at that point. This information can then be compared to the seismic data, a process called *a well tie*. Tying the well involves matching correlative events observed in the well (or the *well log*, typically acoustic velocity and bulk density measurements) with the seismic data. This process generates a waveform whose features can be used to assess and adjust the seismic data. This waveform is called a *wavelet.* (The wavelet is not the same as the mathematical structure of the same name.) The character of the extracted wavelet can also provide feedback about the quality of the well tie.
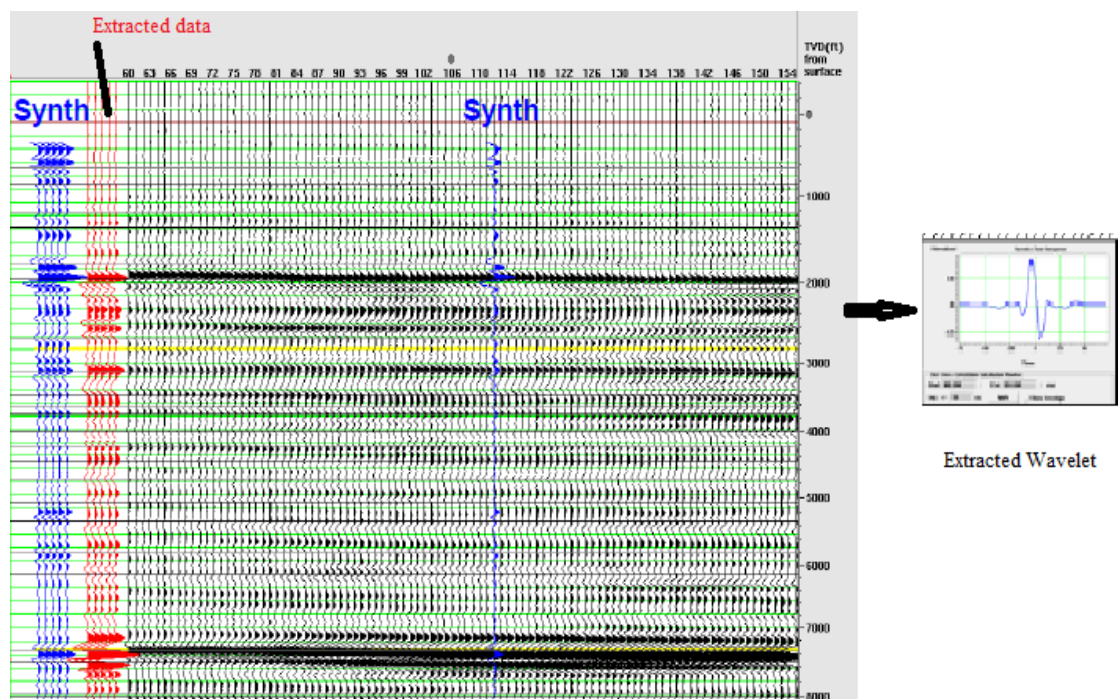

Figure 2: Well-to-Seismic tie for wavelet extraction

The wavelet is extracted by establishing the correlation between the seismic data set and synthetic seismogram as follows:
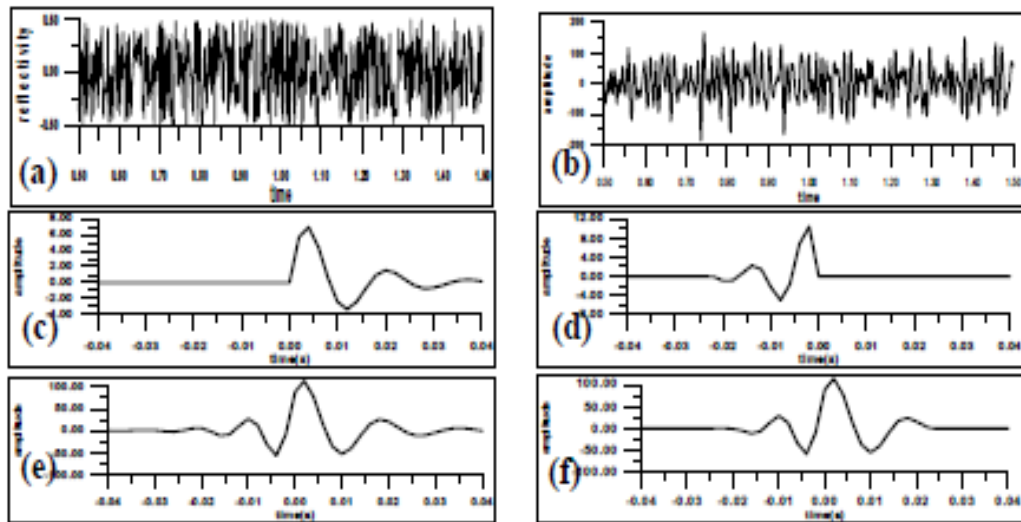
Figure1 Wavelet extraction on synthetic data
a: reflection sequences   b: synthetic record
c: extracted minimum phase wavelet   d: extracted maximum phase wavelet
e: extracted mixed phase wavelet   f: input mixed phase wavelet

 The wavelet is extracted using a correlation iterative stages and the wavelet is selected which has highest correlation or desired accuracy level. Here, the mixed phase wavelet is extracted due to its maximum value of cross correlation.

2.2.2 Wavelet extraction from Seismic data

The assumption made while extracting the wavelet from seismic alone is that the seismic trace obtained has suffered convolution but maximum number of the traces inherits their original wave properties i.e. frequency, amplitude and phase. Thus, the aim is to extract the dominant frequency, dominant amplitude and dominant phase. Thus, a wavelet is analyzed accordingly.

Thus, In case absence of well data the wavelet is extracted from seismic data only using dominant frequency, dominant amplitude, dominant phase or else an ideal zero phase wavelet is considered.

2.3 Deconvolution

Unwanted convolution is an inherent problem faced during acquisition of seismic data. Convolution represents the change in the input signal by virtue of the properties of subsurface lithology.

Deconvolution is the process of filtering a signal to compensate for an undesired convolution. The goal of deconvolution is to recreate the signal as it existed *before* the convolution took place. This usually requires the characteristics of the convolution (i.e., the impulse or frequency response) to be known.

2.3.1 Deconvolution using Weiner Filter

During deconvolution we aim to remove the effects produced during convolution and hence obtain a reflectivity sequence as an output. Mathematically,

Given a system $S(t) = R(t) * W(t) + N(t)$

Here * denotes convolution,

$W(t)$ is some input signal (unknown) at time,

$S(t)$ is the observed signal trace,

$N(t)$ is some unknown additive noise,

$R(t)$ is reflectivity coefficient.

Algorithm

Step 1- Noise Separation or Elimination

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

$R(t) * W(t) = G(t)$, where $G(t) = S(t) - N(t)$

Step 2- Deconvolution using Filters

$R(t) = 1/W(t) \{G(t)\}$

Thus, in order to do deconvolution we require an inverse filter with gain = $1/W(t)$.

$R(t) = $ Filter $\{G(t)\}$ where the gain of filter is $1/W(t)$, thus a reflectivity series is obtained as an output after deconvolution and the impedance is realized.

Note :

- The deconvolution is done using inverse Fourier transform of G(t) and W(t).
- Sometimes in order to enhance features the white noise is added to the gain of the filter**.**

3. Seismic Impedance inversion tool for hydrocarbon exploration.

3.1 General trend in Impedance with depth

Generally with respect to depth the porosity should decrease due to increase in overburden pressure which results in compaction.

$$\Phi = \Phi_0\, e^{-c/z}$$

Where, c is compressibility factor

Z represents depth

Φ_0 is the porosity of unconsolidated soil

Thus, there should be increase in impedance value with respect to depth because with increase in compaction both velocity and density increases hence impedance should increase.

3.2 Porosity estimation from impedance

Since, with increase in porosity (Φ) both density and velocity decreases hence impedance (**Z**) also decreases thus an inverse relation can be set between the porosity and the impedance.

$\Phi = k/Z$, where k is a proportionality constant.

The above empirical relation states that if porosity increases then impedance should decrease and vice-versa.
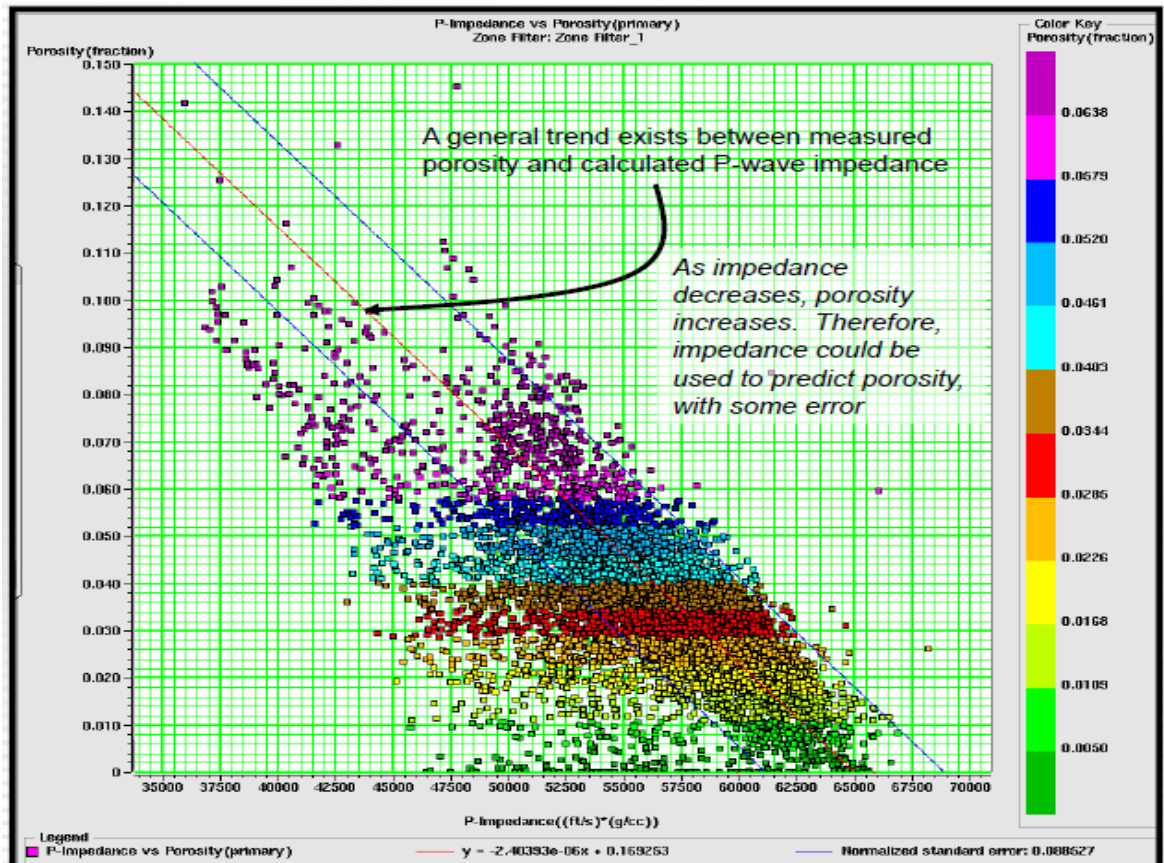
Figure 3. Relationship between the porosity and P-impedance

Thus, after realizing the seismic impedance inversion porosity estimation can be made with some error.

3.3 Target area for Hydrocarbon Exploration.

Since, the general pattern of impedance is that it should increase with increase in depth but the reservoir occurs in rocks which are porous and permeable in which the fluid get stored. Thus in these reservoir rocks the density and velocity of wave decreases which results in an area having lower impedance value hence it reservoir zone shows an anomalous region which has lower impedance value.

Thus while exploring oil and gas a low Impedance area is looked for and further prospecting is done to lower impedance anomalous region.

Target- Lower Impedance Zone

4. Seismic Impedance inversion using Petrel software.
4.1 Introduction to Petrel

Petrel is Windows based software for 3D visualization, 3D mapping and 3D reservoir modeling and Simulation. The user interface is based on the Microsoft Windows standards on buttons, dialogs and helps systems. This makes Petrel familiar to the majority of geoscientists today and ensures efficient usage of the application.

Petrel is a system for

- Seismic visualization and interpretation by using SEG-Y and ZGY data cubes in 2D and 3D windows.
- A seismic Calculator can be used for advanced operations on several cubes.
- Automatic Fault Extraction with the Ant tracker attribute.
- Seismic Volume Rendering, which allows the seismic volume to be more or less transparent.
- The new Petrel Geobody interpretation module employs state-of-the-art volumeblending technology to quickly isolate, extract, and integrate a body directly into a property model for true 3D volume interpretation.
- Building faulted 3D grids for reservoir modeling and flow simulation. A new approach for building faulted 3D grids is introduced which makes the grid generation process significantly faster while producing high quality results. There are few restrictions to the complexity of the fault pattern or fault types in Petrel.
- Gridding of 2D structural surfaces honoring inter-surface relationships (erosion, onlap, etc.) and the generated 3D fault model. This method of gridding structural surfaces (3D mapping) is a true 3D approach and is unique to Petrel.
- 3D visualization of geophysical, geological, petrophysical and production data. Petrel has an option to use 3D glasses for obtaining a true 3D effect (Virtual Reality).
- Flattening of the 3D grid using a horizon as datum.
- The 3D grid can be depth converted node by node by using different velocity models.
- Making an improved zonation of the reservoir by using the Well Correlation facility.
- Analysis of well data, upscaled wells and properties, including data transformations and a comprehensive variogram analysis package.
- 3D property modeling based on well logs and trend data (stochastic, deterministic). This includes a calculator for solving complex mathematical equations involving one or several 3D property models; i.e. Sw transforms based on porosity and permeability 3D models.
- Facies modeling using stochastic and deterministic methods.
- Fracture modeling using a Discrete Fracture Network (DFN) approach to create fracture properties for direct input to dual Porosity/Dual Permeability simulation.

- Volume calculations, data analysis and plotting.
- Upscaling of geometric grids and properties.
- Streamline simulation using FrontSim.
- Run ECLIPSE from Petrel. Set up an ECLIPSE Run in Petrel using Petrel grid and properties. E100 can be used for Black Oil simulation, and E300 for Compositional Simulation. There is also a library of more advanced Keywords which can be used in addition to the standard setup in Petrel.
- Post-processing of simulation result data.
- History Matching.
- Well design in 3D. Digitizing, editing and visualizing of well trajectories based on the generated geological models. Output spread sheets with detailed well report and synthetic well logs.
- Well Optimizer to create a series of cost-dependant realizations based on Target points and cost model.
- Improved documentation and reporting of the project work through tight integration with desktop tools like PowerPoint, Word and Excel.

The inversion in Petrel 2009.1 was carried using two methods which are available as attributes:

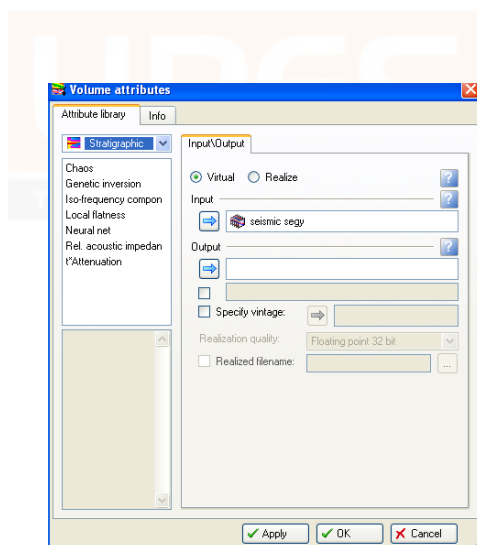**1. Relative acoustic impedance**

2. Genetic Inversion

Figure 4. Two methods of inversion available under the volume attributes

4.2 Relative Acoustic Impedance

Relative acoustic impedance is a running sum of regularly sampled amplitude values. Calculated by integrating the seismic trace, passing the result through a high-pass Butterworth filter, with a hard-coded cut-off at (10*sample rate) Hz. No parameters are required. This is a very fast and easy method and has been sometimes called "the poor-man Inversion". It estimates relative acoustic impedance by first integrating the seismic trace and then passing the result through a Butterworth filter. No parameters are required. It assumes that the

16

input data is zero-phase and broad bandwidth. Under these conditions, by integrating the real part of the seismic trace, Relative Acoustic Impedance can be obtained. The integration of the trace delivers an estimate of the natural log of the Acoustic Impedance. This attribute shows apparent acoustic contrast, indicates sequence boundaries, discontinuities. Within its limitations, it can be used as an early indicator of porosity or fluid content in the reservoir. The workflow to generate this attribute in Petrel is very simple. You can generate it out of the " Volume Attributes/Stratigraphic Methods/Relative acoustic Impedance " interface.
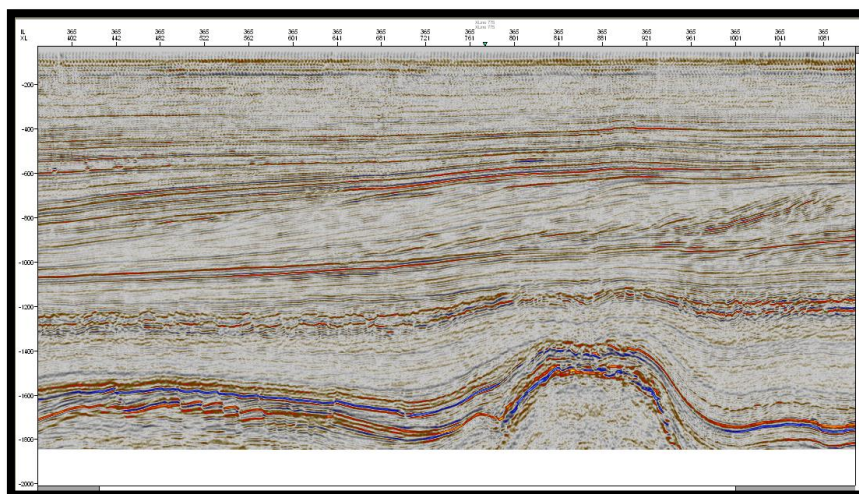
(a)
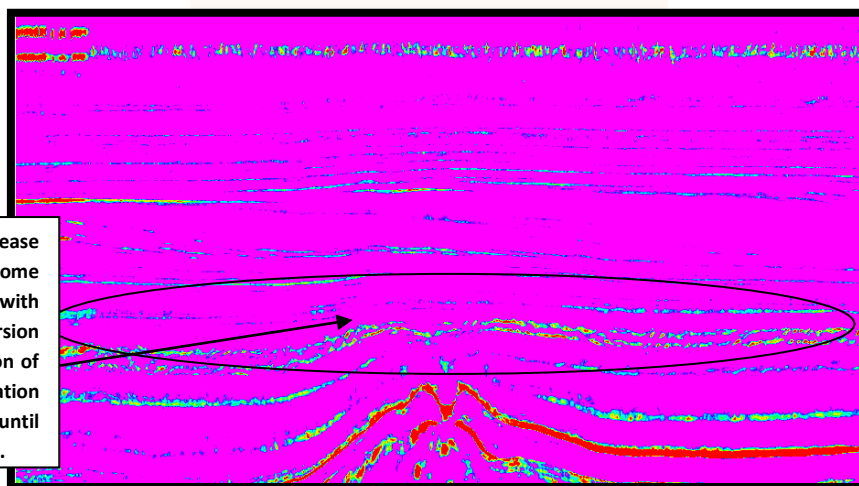
Usually the AI should increase with depth however in some areas it is found to decrease with depth. This method of inversion is a very crude representation of the impedance information hence its not reliable until confirmed with the well data.
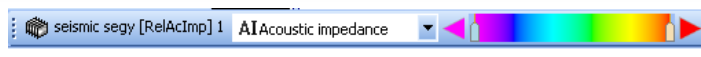
(b)

Figure 5. (a) original seismic cube with inline 375 (b) Relative acoustic impedance cube inline 375 shown in the interpretation window
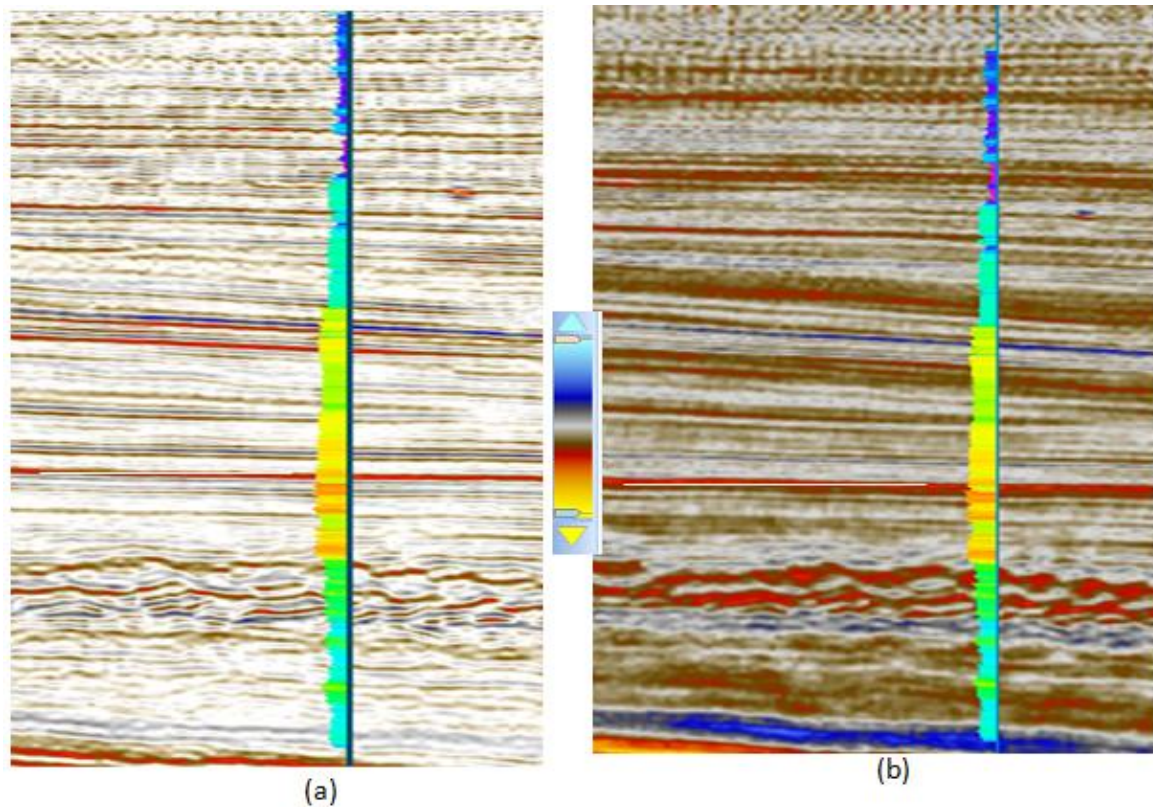
17

Figure 6 Comparison original seismic cube inline 365(a) and Relative acoustic impedance (b) with well logs displayed over it (horizon marked with white color).

4.3 Genetic Inversion

Genetic Inversion Seismic reflection data is the primary input for resolving structural and stratigraphic variations between points of well control in the majority of the world's sedimentary basins for the exploitation of hydrocarbon resources. Petrel brings a step change to this process with the fully integrated genetic inversion algorithm allowing geophysicists and geologists to more accurately predict inter well properties from seismic inside of Petrel. Horizon autotracking options allow you to pick directly on the impedance volume or it can be used as an input in the enhanced geobody isolation and extraction process for improved reservoir characterization. A more elaborated method, developed by Ivan Priezzhev (see Priezzhev et al, Genetic Seismic Inversion using a non-linear, multi trace reservoir modeling approach, EAGE, Rome 2008) and available in Petrel since the Petrel2008 release is the so called "Genetic Inversion". This innovative methodology has been patented (Priezzhev, Bejarano and Shmaryan, No. 09469/118001;94.0169). It determines a non-linear multi-trace operator that is applied to the seismic dataset in order to transform it in acoustic impedance, or -for that matter- in any other log property. The initial operator or filter is computed from the input well data using a genetic neural network algorithm. The following inputs are needed:

18

1) Acoustic impedance logs at the wells or some other logs directly related to acoustic impedance – density, velocity, porosity etc. The logs needs to be properly processed, de-spiked and smoothed. This is generally possible because the seismic has much lower frequency contents than the log data.

2) A post stack amplitude seismic cube.

All wells used as input need to be correctly tied to the seismic. This is usually achieved by means of generating synthetic seismograms. For the post-stack amplitude seismic there are no further requirements, such as zero-phase wavelet processing. Another interesting benefit is that it is not required to extract any wavelet to be used later on in the process. Instead of using a wavelet, the algorithm derives a non-linear operator. Please see dedicated literature referring to the "genetic algorithm" description. In simple terms, the following steps are calculated internally:

1) A neural network is trained to match the acoustic property at the wells using the genetic algorithm. Systematic shifting of the seismic amplitude data and logs serve as an input to train the neural networks.

2) The neural network derived operator is applied to the amplitude seismic data to produce the desired acoustic impedance property.

The quality of the training of the neural network can be investigated by comparing the results at the wells that have been used as input during the training exercise. The quality of the inversion results can be verified using so-called "Blind Wells". This means using wells for comparison that have not been part of the training.

It is important to emphasize the critical aspect of having a good well tie for the Well data and the seismic. Since the whole algorithm relies on training the Neural Network based on the AIMP logs from the wells, bad fitting wells, wrong Time/Depth curves and/or wrong edited density and sonic logs will dramatically reduce the reliability of the results or produce non existing artifacts in the data.

The training of the network can be done interactively (Virtual mode). For this, it is a good advice to generate a smaller cropped volume around the area of interest, generally close to a key well. Every time the process runs, it generates a control Acoustic Impedance log at every well used for the input. This log can be used to compare it against the original Acoustic Impedance log.

The interface to run the Genetic Inversion Process offers already good estimated default parameters.Additionally, it is a powerful feature to be able to run the Genetic Inversion in "Virtual" mode and fine tune the parameters while displaying

the result in just few seconds. Every time the process runs, a new control AIMP log is generated and can be evaluated using the windows shown above.

4.3.1 Introduction to Genetic Inversion

A new approach to derive an Acoustic Impedance Inversion volume is proposed in Petrel. Multi layer neural networks as well as genetic algorithm are combined together in order to provide a robust and straight forward seismic inversion.

The estimation of rock properties using seismic data and derived attributes has always been a very important but challenging task. There are several different methods for achieving this goal. All of them are based on strong and constraining a priori information. The required knowledge of an initial model (cf. for the stochastic inversions), or source wavelet (cf. Colored-, Sparse Spike Inversion), is in several cases hard to acquire, if not impossible. Moreover, the result of this kind of inversion is often biased by the input initial model itself.

In the case of Genetic Inversion, the required inputs are limited to the seismic amplitude, and the Acoustic Impedance well logs used as training data. Indeed no single unique wavelet, neither initial property modeling are needed as inputs prior to run the inversion. A genetic algorithm back-propagates the error in order to update the weights for the neural networks.

The advantage of this new method of generating a property estimation, is that the genetic algorithm constrains the convergence of the inversion in a way that the chance of achieving a global minimum error is much greater than in other previous neural network based inversions. Thus, success is quasi absolute. In addition, another advantage of this process is that it is not only restricted to conventional Acoustic/Elastic impedance inversion, but it can be extended to any kind of petro-physical attribute/parameter, which is linked in a meaningful, and straightforward way to the seismic amplitude or derived attribute data. To be more explicit, all the parameters contained in the wave-equation are possible candidates (e.g. velocity, density, porosity, bulk modulus...).

The Neural network used is a common Multi-layer network, with one hidden layer in the case of the Genetic Inversion (GI) module. The characteristics of the Neuronal workflow are as follows:

- Activation function (sigmoid function)

- Input/hidden layer relationship

- The bias of the input layer, and the one of the hidden layer.

The difference is located in the fact that the weights update is not done in a classical way. Traditionally, Neuronal processes use a Gradient descendent method (or more elaborated ones like "Conjugate gradient", "Newton"...) and back propagate the error in order to converge hopefully to the global minimum.

The introduction of a Genetic Algorithm into the Neural Network common workflow, represents a step forward with respect to the convergence risk which takes into account local minima as well as the computation time aspect.

For example: Initially, what is called population represents a set of 50 input weight combinations (randomly selected), which are all going through the neural network first iteration. The output result is then compared with the observed datasets (cf. the well logs) by calculating an error function. As soon as an error value is computed for each of the 50 input weight combinations, the process enters into the Genetic part of the algorithm:

- **Selection**: in analogy to the natural selection hypothesis of C. Darwin which favors only the best adapted individuals to survive; in this case the survival criteria is given by the individual with the smallest error.

- **Cross-over**: during that step "chromosomes" (here a "chromosome" will be one weight combination) are exchanging "genes" (a "gene" is here associated to a single weight, within one combination) between each other (the number of genes exchanged can be singular or multiple). This cross-over phenomenon is occurring with a given probability after and within each iteration.

- **Mutation**: Again, like in the natural evolution theory, genes are going to be replaced randomly within chromosomes. This is insuring for the process not to converge to a local minimum. The probability of occurrence is here as well a function of the iteration step itself, e.g. mutation is more likely to happen as soon as the evolution of the error function is reaching a plateau. Nevertheless, in most cases it is much lower than the cross-over probability.

It is important to note that the population at each iteration of the inversion has a constant number (cf. 50). Therefore, even if the selection is reducing the number of the population, by taking, for example the 10 best ones; applying "cross-over" and "mutation" to those selected combinations of weights will recreate a full set of 50 "chromosomes" into the population.
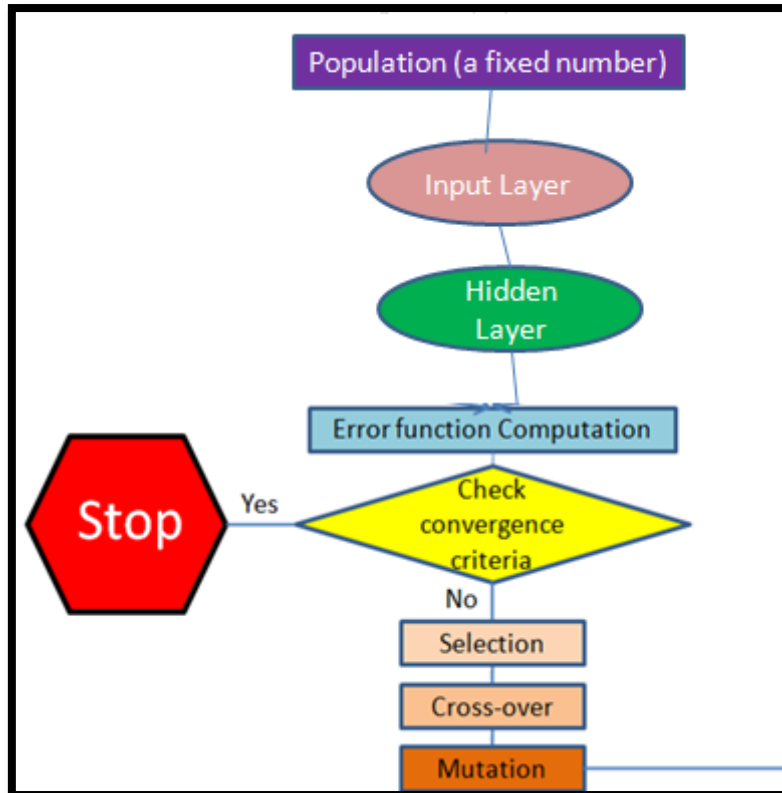
Figure 7. Genetic Inversion method in Petrel

The output of this workflow is a non-linear multi-trace operator which will be applied to the whole seismic dataset, and will transform it into the property described by the logs used during the training phase. This filter makes the parallel with the wavelet used in common Acoustic Impedance inversions. The derivation of the operator is supported by creating many shifted volumes of the original seismic cube and feeding them into the neural network engine to power the genetic inversion. Vertical shifts in the seismic volume are accounting for vertical mismatch of the non-linear operator, while lateral shifts compensate for lateral dissipation of energy (cf. the operator will take into account the geological structure characterized by the continuity of the seismic amplitudes).

4.3.2 Neural Networks Background

A neural network is an algorithm that takes multiple inputs and returns one or several outputs. These inputs may be coincident log values, coincident seismic attributes, coincident surface values or properties from the same cell.

Each input is multiplied by a weight, the result is summed and the result passed through a nonlinear function to produce the output.

To make the model produce the required output, the correct weights must be selected. This process is called training.

Relationship between the biological and artificial neurons

A biological neural network consists of billions of highly interconnected neurons. There are a lot of theories about how the brain processes information; but much is still unknown. However, experts do know the structure of a basic neuron and how it operates. This knowledge has inspired the development of Artificial Neural Networks. A neural network (biological term) is a collection of neurons, the tiny cells of which the brain is composed. The figure below shows a schematic illustration of the physical elements of a biological neuron. A basic biological neuron consists of the cell body, dendrites, axon and synapse. The dendrites conduct input signals to the cell body, like electrical cables. The axon is the output connection for signals emitted by the neuron. The synapses are the connections between neurons.
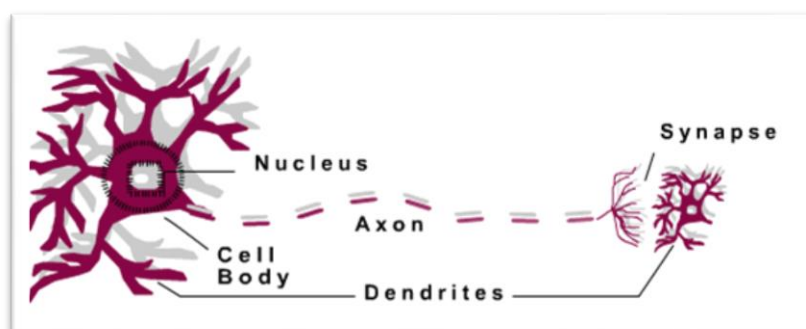

Figure 8: Theory of biological neurons applied and simplified to resemble real world

Theory of the biological neurons is applied and simplified to resemble the real world. The figure below shows a gross idealization of a neuron.
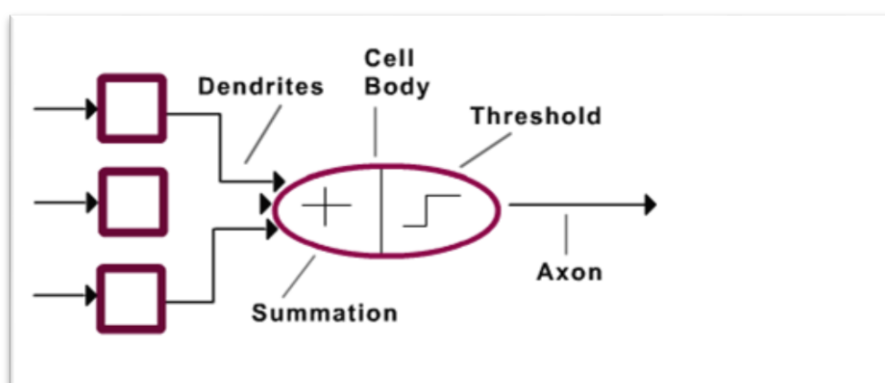

Figure 9: Gross identification of neuron

This leads to a way of characterizing the physical elements of a primitive artificial neuron, illustrated schematically below. An artificial neuron, a simplified model of a real neuron, is in fact a processing unit in computing. An artificial neural network consists of a number of processing units that are wired together in a complex communication network. Each processing unit receives a certain number of inputs X (n). It then computes a weighted sum of its inputs from other units. The weight of the connection is given by W (n) that measures the importance of the input X(n). It then outputs 1 or 0 according to whether this sum is above or below a certain threshold, for binary transfer function.
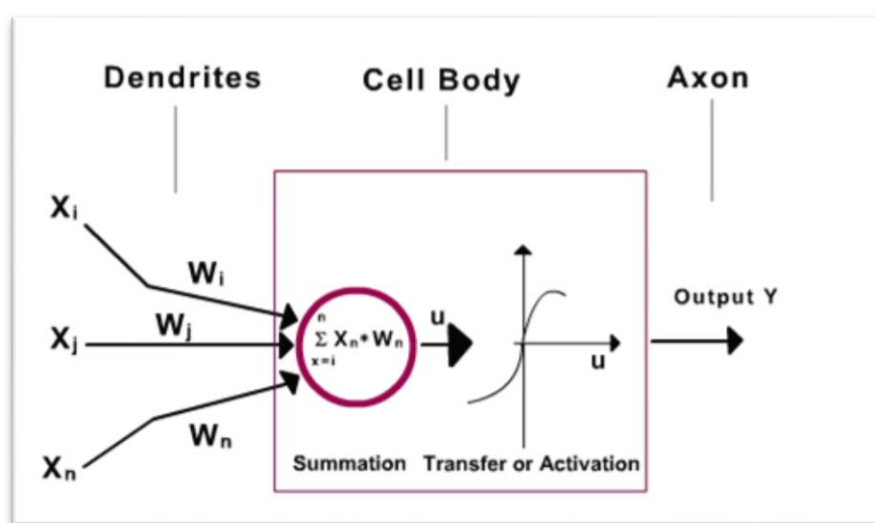

Figure 10: Figures from Neural Networks, by Christos Stergious and Dimitrios Siganos

Artificial Neural Networks learn by example. They cannot be programmed to perform specific tasks, and their operations can be unpredictable since the network finds out how to solve the problem itself; therefore the examples must be selected carefully to avoid wasting time and the network not functioning properly.

Conventional computer algorithms follow a set of instructions in order to solve a problem. Unless the specific steps that the computer needs to follow are known, the computer cannot solve the problem. That restricts the problem solving capability of conventional algorithms to problems that we already understand and know how to solve.

4.4 Workflow of Genetic Inversion

Figure 10: Workflow of genetic inversion

Genetic inversion has to be carried out through 3 steps a follows:

Step 1 Acoustic Impedance Computation

Step 2 Porosity Cube Computation

Step 3 Check for consistent well calibration

4.4.1 Genetic Inversion workflow : Acoustic Impedance computation

For this specific attribute (Acoustic Impedance), the Genetic Inversion is not the only required module to get the inputs needed. In fact, to fulfill all the desired input parameters we should have a seismic cube. The calibrated AI logs are however a main input a priori parameter.

Genetic Inversion Parameters

The Genetic Inversion module is located within the Volume Attribute library under the "Stratigraphic methods" class. As for the other volume attributes, the Input/output tab defines what input volume is used and how the result is stored. The Parameters tab defines how the neural network and genetic algorithm learns and handles the result for each iteration.

1. Learning inputs

2. Settings

3. Advanced options

Each part organizing a given set of parameters

Learning inputs:

All the inputs for the Genetic inversion will be located in the Input pane of Petrel.

- **Seismic cube**: You have to drop in the 3D volume you want to use for the learning step as well as for the inversion itself. You can choose all types of 3D cubes as input (e.g. cropped volume, seismic attributes, SEG-Y or ZGY format...). For performance reasons, it is recommended to use bricked volumes (ZGY format).

- **Well folder**: Select the global well folder or any sub-folder, containing the wells which will be used for the learning process.

- **Global well log**: Select one of the logs listed within the "Global well log" folder. It must be continuous, and have some explicit (linear or not) relationship with the Seismic cube.

- **QC well folder**: Select the global well folder or any sub-folder, containing the wells which will be used as the "Blind" wells. The relationship determined by Neural Network during the learning step will be computed at those wells so you can cross-validate the computed property and the observed one.

Settings:

- **Vertical range**: vertical extension of the seismic sub-volume (see figure 5). Set to *50* by default (depends on the resolution of the seismic).

- **Inline half-range**: horizontal half extension of the seismic sub-volume, with respect to the inline direction. Set to *1* (cf. number of inline interval) by default (depends on the lateral continuity of the structures with respect to the inline direction).

- **Crossline half-range**: horizontal half extension of the seismic sub-volume, with respect to the crossline direction. Set to *1* (cf. number of cross-line interval) by default (depends on the lateral continuity of the structures with respect to the crossline direction).

- **Resample parameter**: defines the sample increment within the seismic around the well sample in order to create the input vector containing the seismic

amplitudes for which the learning process is computed. Set to *3* by default (depends on the sampling rate and the resolution of the seismic). In conclusion, the higher the Resample parameter, the more important the concentration of samples per volume unit (this parameter is driven by the frequency content of the seismic). Figure 2 sums up schematically this option.

- **Top surface/marker**: select a "regular surface" for the upper limit where the learning process is computed. You can also use well-top markers.

- **Bottom surface/marker**: select a "regular surface" for the lower limit where the learning process is computed.
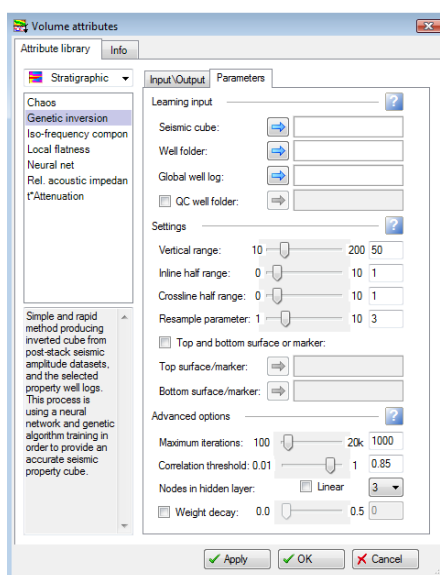

Figure 11. Different parameters for genetic inversion

Velocity (Vp, Vs...) and density logs (RhoB...) can be found within the global well logs list. We can derive (using the Well calculator) the Impedance from them (Impedance=Velocity x Density). Alternatively, you can use a more complex workflow from either "Synthetics" in Petrel, or the MMRD module (see. MMRD, Synthetics). The latter ones are not going to be described in details in this section.

Generally, the acoustic impedance and other types of reservoir properties are not interesting if they are computed outside the reservoir limits. You therefore have to specify the Top and Base surfaces of the area you want to use. Alternatively, you can select a specific area of the global seismic cube by using a cropped volume and running the inversion on the latter one (as Top and Base surfaces are not mandatory inputs).
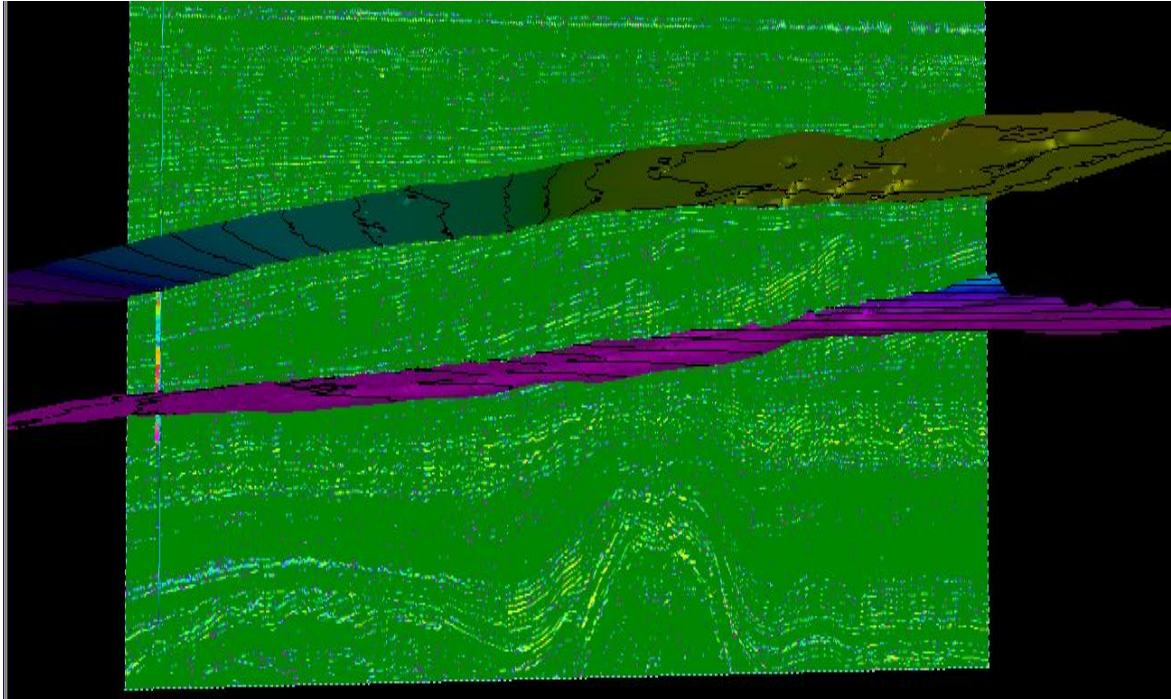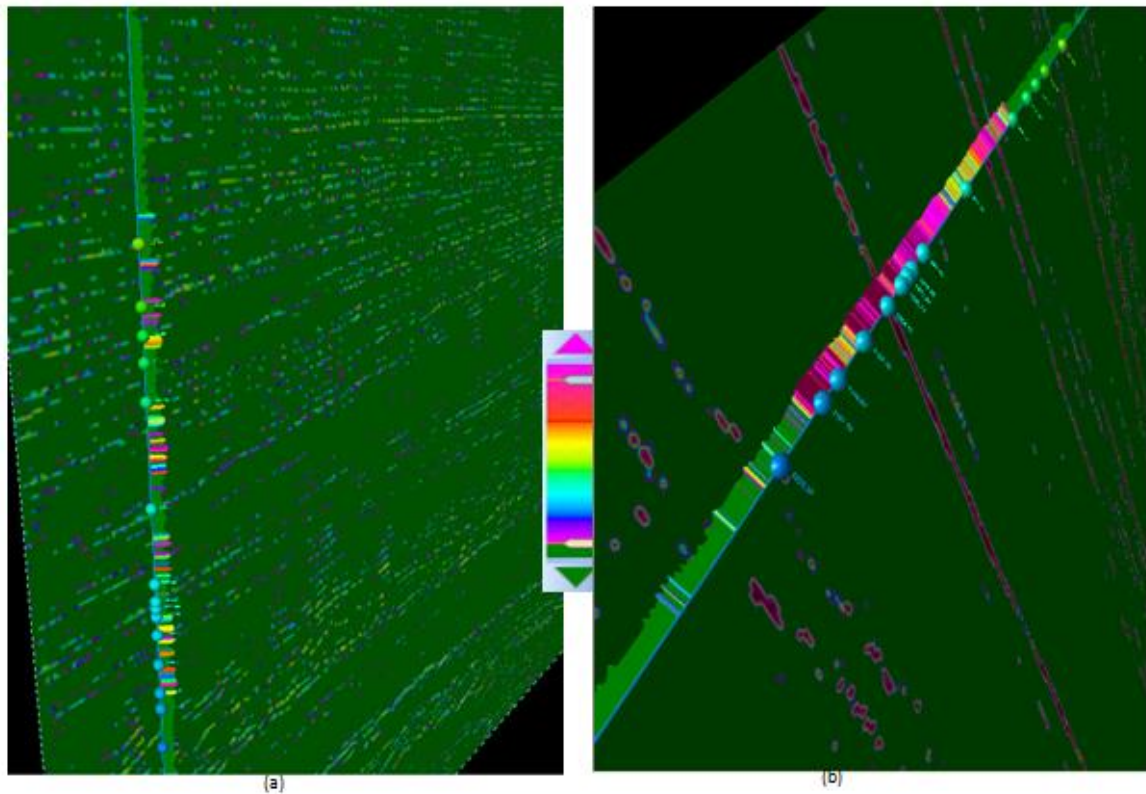
Figure 12: Genetic Inversion Cube

Figure 13: (a) Acoustic impedance log generated from genetic inversion on genetic inversion cube (b) Original seismic cube
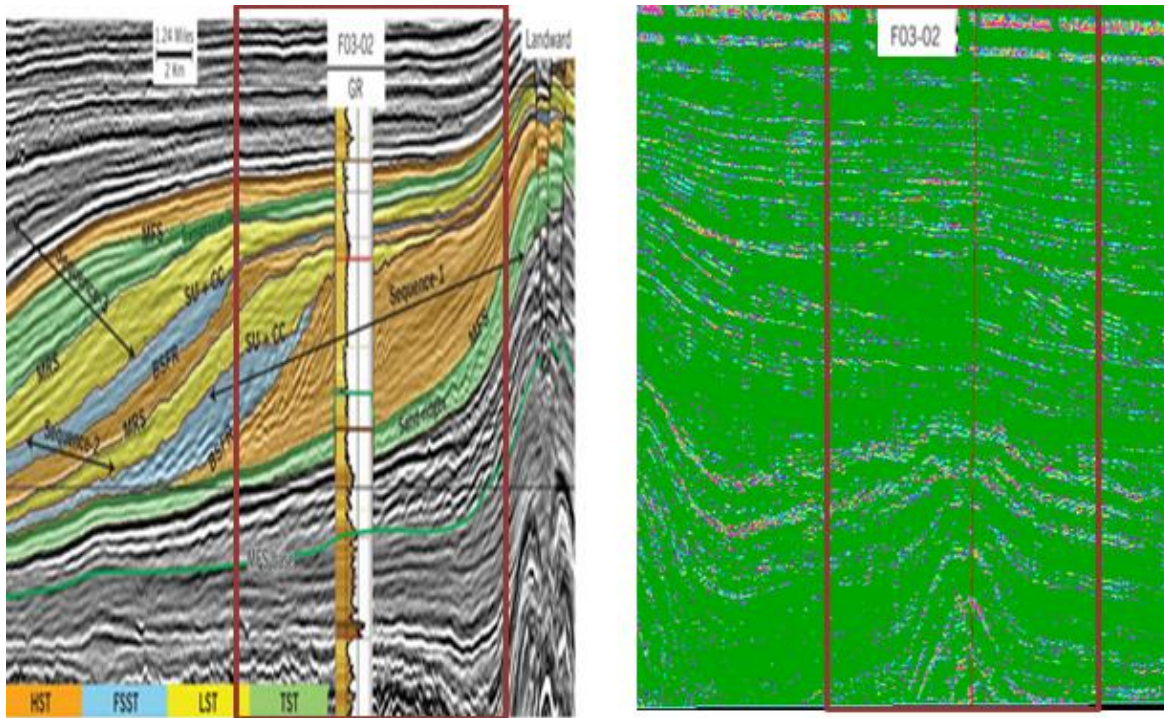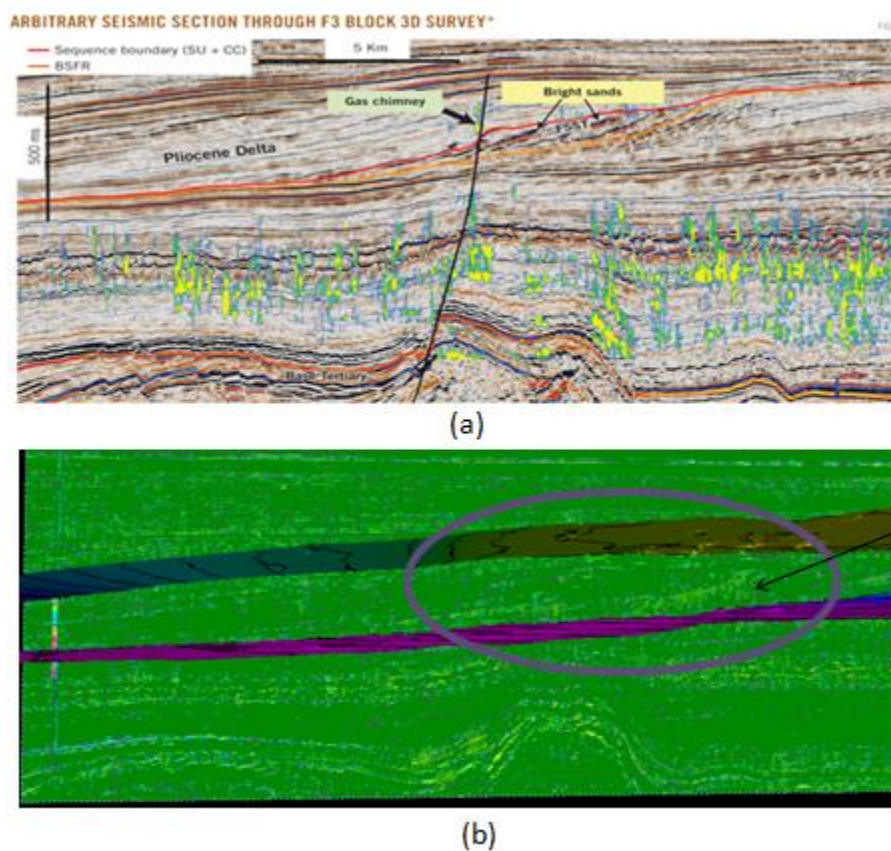
Figure 14: Well and seismic correlation figure obtained from the opendtect software information and the corresponding seismic section for same well on the genetic inversion cube

(a)

(b)

Gas chimney zone where well F03-2 was drilled and clearly depicted by acoustic impedance cube

As clearly described in the workflow above, the most important parameter used for the inversion is the set of wells. There are limits to the amount of logs you can use for the learning phase. A set made of too many wells will cause the inversion to fail because the number of unknown parameters will make the whole process unstable. The recommended number is around 10. Another important parameter is the spatial distribution of the boreholes with respects to the geological repartition of the facies.

5. Deriving Rock Properties using Acoustic Impedance

Acoustic impedance variation has a strong relationship with the rock types and the fluids in the reservoir. Geoscientists often use the impedance cube as a soft control to capture porosity distribution. The best way to proceed is to carry out a blind well test.

6. Conclusions

Seismic impedance inversion is a powerful tool for extracting reservoir rock and fluid information from the seismic data. Although most seismic surveys are designed for imaging alone but nowadays companies are applying impedance inversion and others to get more out of their investment in seismic data.
The seismic impedance inversion not only enhances the features which helps in stratigraphical interpretation but also provides estimation of porosity which can be utilized for qualitative as well as quantitative estimation of hydrocarbon reserves and hence minimize the risk factor involved in exploration of oil and gas and increases confidence level for interpretation which provides high success ratio.

1) The simplest one, RAI is also the fastest to generate and it only requires zero-phased amplitude seismic data as input. In spite of its simplicity, it can already be of great help already in showing potentially interesting areas of low Impedance for early exploration surveys, where no well data exists at all. In some special cases, there have been examples shown where AI delivers almost as good results as elaborated Inversion schemes. As it lacks the input from an extracted wavelet, it cannot resolve some subtle geological features. An interesting and surprising fact though is that it essentially delivers a quite comprehensive first overview of (relative) Acoustic Impedance using information that is purely coming from the

seismic. For all these reasons, many interpreters should use this simple and fast attribute, as it provides great value with little effort.

2) The second one, GI, requires more preparation to be used, especially because the input data needs to be provided by calibrated well log data. The user needs to pay attention at the quality of the synthetic seismograms and how good the well tie is. Also, it is assumed that the logs (Sonic & Density) have been properly processed in a petrophysical sense before being used to generate the AIMP logs at the wells. The possibility to optimize parameters using the virtual mode is of great help. GI will generally provide good results, which will contain the contribution of the AIMP logs from the wells. It is still a relative Acoustic Impedance result, but with more geological content than the simpler RAI. Examples discussed by clients in Russia have shown that it can be perfectly be compared to more sophisticated Inversion schemes, provided a good match between Acoustic Impedance logs and seismic can be achieved. As it requires well-log data, it might not be ideal for early exploration projects, but it definitely is worth for development or to be used as an intermediate result, while a large seismic inversion project is being processed. Thus, the two most important conclusions which can be made are that the stratigraphical features becomes more predominant by applying impedance inversion and the reservoir characterization (both qualitative and quantitative) can also be enhanced with the help of seismic impedance inversion.

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