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Geostatistical Estimation of Acoustic Impedance using Depth Seismic and Wells Data in a South-Western Iran's Oil Field

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Abstract

This study is carried out in one of the hydrocarbon reservoirs in South-Western Iran. Because of the high importance of geophysical and petrophysical studies of the reservoir and its role in exploration and production of hydrocarbon reserves, as well as the increasing use of rock-physics in the Petroleum Industry and its application in identifying the structure of the earth and determining the geophysical and hydrocarbon properties, full knowledge of rock-physics has particular importance. In this study, using petrophysical logs (acoustic logs, density logs and P-wave velocities), the acoustic impedance of Bangestan & Khami Groups formations after calibrating with core data at well locations, are estimated in the depth domain directly by geostatistical methods such as Gaussian Random Function Simulation (GRFS) approach using only seismic volume's trend, GRFS using only acoustic impedance volume's trend, GRFS approach using variography and Co-Located Co-Kriging of acoustic impedance volume and Kriging Approach using Variography and Co-Located Co-Kriging of acoustic impedance volume, and their results are compared with the conventional acoustic impedance and the most optimal method of geostatistical estimation of acoustic impedance (GRFS approach using only seismic volume's trend) is selected in order to use only depth seismic volume. Geostatistical methods are of the accurate and low-cost methods which can use in estimating petrophysical properties in the minimum time using core data, seismic volume and petrophysical logs.

Keywords: *Geostatistical estimation; Reservoir properties; Seismic data; Petrophysical logs; Drilling cores; Bangestan & Khami Groups.*

1. Introduction

By the development and progress of the methods which used geostatistical methods and well logs, more detailed studies are carried out on hydrocarbon reservoirs. Using seismic methods in evaluation of hydrocarbon reservoirs, secondary observation and control, increase in rate of oil production, and details of acoustic logs are combined, and an attempt is done to achieve an accurate and correct understanding of the study area. The estimation of various data such as seismic characteristics as well as petrophysical logs and lithological properties, in different ways in where these values are not available, has an important role, and by knowing and completing them, it is understood how to expand the parameters and variables in the reservoir. Properties such as density, porosity and seismic attributes control the rocks' elastic behavior. Specific methods for estimating petrophysical logs as well as combining seismic data and these logs are presented.

In this study, using log data (especially P-Wave velocity and density) and core data, acoustic impedance was calculated as seismic volume in depth domain. For this purpose, various software such as Petrel and Hampson-Russell were used in order to calculate the data.

The major goal of this research is to introduce a new technique of preparing acoustic impedance in depth domain in one of the South-Western Iran's Oil Field directly using seismic data and petrophysical logs by geostatistical methods and its calibration using core data to optimize exploration drilling operations.

In the common methods, in acoustic impedance generation, because the seismic volume is in the time domain, it is possible to use conventional methods. But if seismic volume exists only in-depth domain and there is no way to convert it to the time domain, you have to find other ways such as unconventional methods. Also, the control points are the wells; if other data, such as seismic data, do not match the well data very well (computationally and visually), they are only used as a trend. This will cause a reduction in the lateral accuracy of the results.

In this research, to provide the possibility of using seismic data that has more lateral resolution as the trend an attempt has been made, by combining methods and changing the parameters, and this lack in the Iran's Petroleum industry should be covered. The use of seismic data as the main data in the points between wells and also the well data as the major data in the location of the wells is to maintain the lateral continuity of this information and also should increase the accuracy.

For the first time in Iran, the acoustic impedance estimation of the formation using petrophysical logs, drilling cores and geostatistical were used to overcome the obstacle in one of the oil fields in the southwest of Iran. For the comparison, here we can use conventional acoustic impedance as a control point and the base.

Various methods have been used in this field so far. One of these methods, in which there is more trust in a model that is not only based on well logs and geological knowledge, but also based on seismic data. In this method, a 3D seismic data set is inverted in a geological and stratigraphic model using the geostatistical inversion method. On the one hand, uncertainty validity is determined by calculating statistics in 3D acoustic impedance cubes. On the other hand, co-located co-kriging allows converting resistivity into reservoir parameters through a petrophysical relationship according to well data [1].

In another method, snapshots of current and emerging trends in applied statistical rock-physics for reservoir characterization are presented. By combining the basic concepts and models of rock-physics as well as statistical pattern recognition and information theory by seismic inversion and geostatistical methods, the uncertainty in reservoir management was quantitatively measured and reduced [2].

In a study, egotistic intuitively are used to describe reservoir characteristics. Having said that, geostatistics is an increasingly important tool for preparing an integrated reservoir description. Although applied geostatistics for reservoir description is written to demonstrate the importance of geostatistics in improving the reservoir characterization process, it does not require prior knowledge of statistics or advanced mathematics. They provided several numerical and field examples as well as numerous images to explain the strengths and weaknesses of different methods [3].

3D seismic data and artificial neural network methods as well as geostatistics are used to estimate the reservoir characteristics of a sand formation. To solve the problem of indeterminacy of the seismic response for sands and to enable the estimation of reservoir properties from seismic markers, they tracked the main strata markers in the 3D seismic data volume for structural mapping and attribute analysis, after being properly tied to the seismic. The 3D seismic volume was inverted to obtain the acoustic impedance volume using the model-based inversion algorithm. Various sample-based seismic attributes, acoustic impedance volume and porosity logs were used as inputs for this purpose. These techniques are map-based geostatistical methods using acoustic impedance volume, stepwise multi-linear regression, probabilistic neural networks (PNN) using multi-attributes transforms and a new technique. In order to prioritize the actual effective porosity values in the wells, the estimated effective porosity map obtained from the PNN-based model for the upper sand was combined with the actual effective porosity values using geostatistical co-kriging technique. The consequences of this work in the exploration and development of hydrocarbons in the studied area have been discussed [4].

Using seismically derived attributes, it is showed how rock-physics can be used to estimate reservoir parameters such as lithology and pore fluids. They present an integrated methodology and practical tools for quantitative interpretation, uncertainty assessment and estimation of subsurface reservoir properties using well log and seismic data and demonstrate the advantages of this new methodology, while advising on the limitations and issues of traditional methods [5].

Karimi *et al.* [6] applied stochastic fracture network modeling in the same field. They obtained fracture indicators using various types of data such as acoustic impedance and other seismic attributes to build the structural model and geostatistical analysis was done. The SIS and SGS methods were used to construct the properties models.

Pirc and Deutsch [7], in the new edition of their book with a complete update of the latest tools, presented new methods in the field of petroleum geostatistics. In this edition, the key concepts of geostatistics such as data integration and geological concepts, scale considerations and uncertainty models have been paid more attention. They also presented new comprehensive concepts of basic geological modeling, data inventory, conceptual model, problem formulation, large-scale modeling, multiple point-based simulation, and event-based modeling.

Srinivasan [8], in his book, provided the details of reservoir engineering principles and the accompanying real-world applications, and succeeded in modeling oil reservoirs of all types and sizes with new tools and techniques. He described the process of applying reservoir modeling techniques and flow analysis methods in geological systems in subsurface exploration and development.

Acoustic impedance derived from seismic methods cannot be used in modeling directly for three reasons: These values are deterministic, they do not have 100 percent correlation at the location of the wells, and these values have lower vertical resolution than well data.

On the other hand, these should be used in modeling for the following reasons: By using seismic data, they have the most correlation outside the well locations, they have the most consistency with the properties of the well at the non-location of the wells, and these values have more horizontal resolution than the well data.

Considering these reasons, performing modeling in stochastics ways is necessary in order to eliminate the shortcomings. The model obtained at the well location will have 100 percent matching using geostatistical methods. These values will have the most consistency at non-well locations. These values have a horizontal resolution consistent with the seismic data (25 m by 25 m) and the models have a horizontal resolution consistent with the well data (1 m). So, the problem of uncertainty calculations is solved. But sometimes there is no seismic data in time domain, therefore we have to use depth seismic, and there is no conventional method to use.

2. Geological setting and stratigraphy

Abadan Plain is located in Khuzestan province. Most of Iran's oil reservoirs are located in large land fields in the Khuzestan region and near the Iraq borders. They have two main trends, the Arabian trend (N–S– NW–SE) and the Zagros (NW–SE) [9]. The studied area is an oil field which has a N–S trend in the southern part and an NW–SE in the northern part. It is located in the western part of the Abadan Plain, a structural zone situated in the western end of the Zagros Fold-Thrust Belt (ZFTB [10-11] (Figure 1a).

Figure 1. (a) The location of different structural zones in the southwest Iran. The studied area (yellow color) and the desired field is marked with a red color arrow, (modified based on Motiei [12]).

The Bangestan Group (Ilam and Sarvak Formations) and part of the Khami Group (Gadvan and Fahliyan Formations) are considered as the major reservoir rocks of the area. This formation is divided into three intervals including the upper (between the mid-Cenomanian to mid-Turonian disconformity), the middle (between the early Cenomanian and mid-Cenomanian disconformity), and the lower (below the early Cenomanian disconformity) in this study.

About 360 meters of stratigraphic thickness from the highest part of the limestone section in "Mauddud", the shale in "Ahmadi" section, the lower limestone section in "Sarvak", the shale-limestone clay in "Kazdumi" Formation, sandstone of "Burgan" Formation, shale in "Garau" Formation of Bangestan Group, limestone in "Dariyan" Formation, sandstone in "Zubair" section to the beginning of the shale-limestone in "Gadvan" Formation of the Khami Group are located in the lowest part along with the corresponding well log data and seismic data was used (Figure 1b).

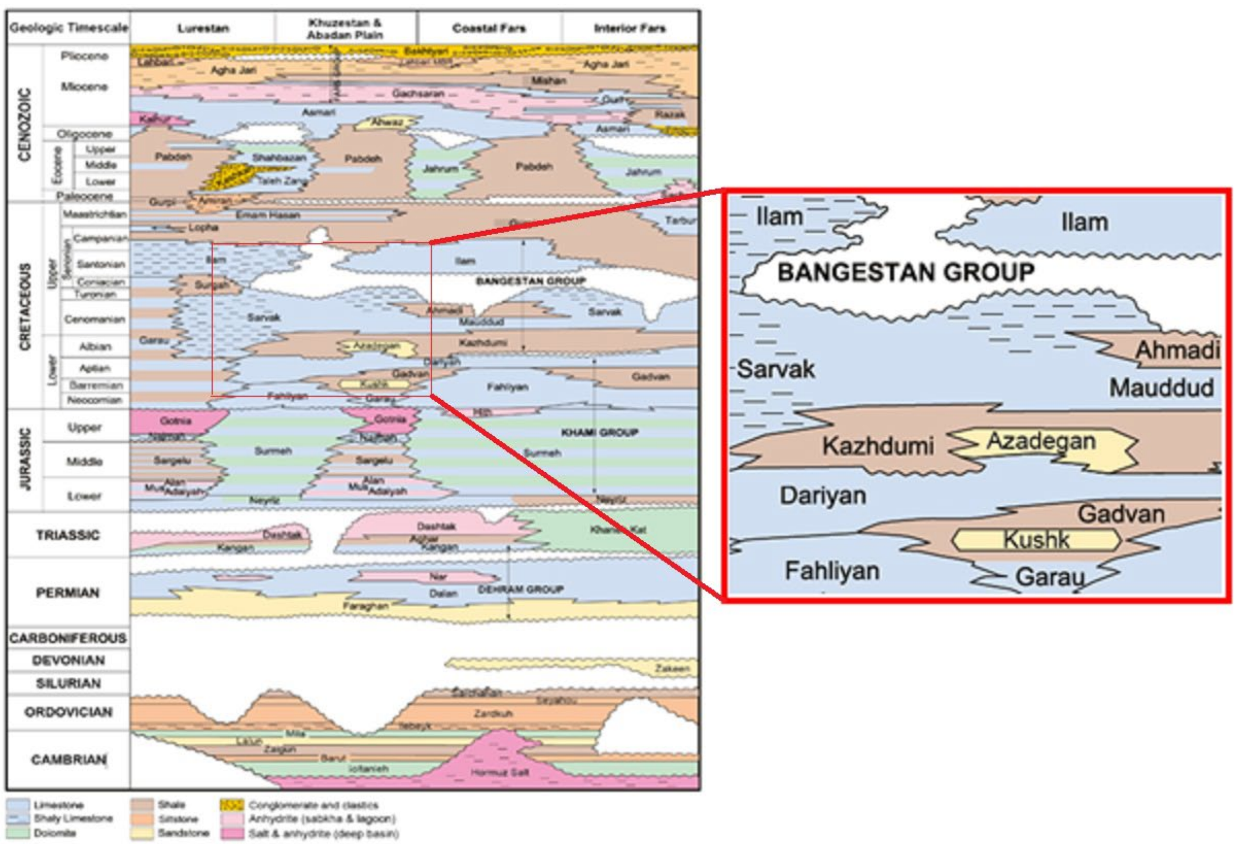


Fig. 1(b). Stratigraphical Column of the region (Modified based on Esrafili-Dizaji and Rahimpour-Bonab [13]).

3. Materials and methods

The input data of this research are Petrophysical log data such as density (RHOB) and P-Wave velocity (DT) logs in LAS format; The information and location of the 7 wells and drilling trajectory; Core information such as laboratory measurements of velocity and density; Top formations data (8 Formation Tops in Bangestan and Khami Groups); Seismic data (amplitude) in the form of post-stack seismic volume in the time and depth domains.

The output data of this research include completed data of petrophysical logs mentioned above (Predict the gaps and fill them in different ways, de-spiking and correlating them by top formations); Geostatistical estimation data (Acoustic inversion seismic data or Acoustic impedance) in the form of 3D seismic data in depth domain and comprise the results by conventional ones.

3.1. Research flow chart and instruction

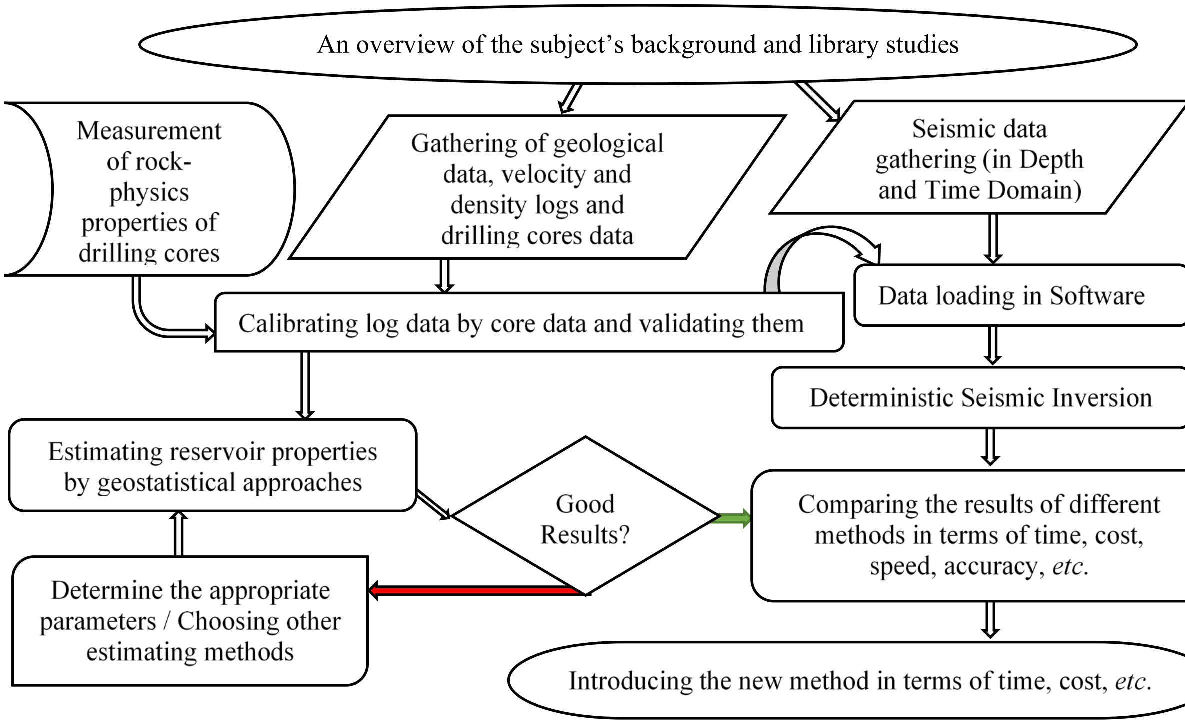


Figure 2. Research flowchart.

First, the well data, such as the position and drilling path of the well along with the petrophysical logs and well top data, were loaded into the software. They were validated by the core data. Then the necessary corrections were made on them and completed with common methods. Then conventional procedure of generating acoustic impedance were used in order to have a control point after depth conversion. Therefore, by geostatistical methods, acoustic impedance was estimated in the form of 3D seismic data in depth domain. The location of the estimation points is similar to the location of the points with seismic data. Finally, the optimal method obtained in this direction was introduced.

4. Results and discussion

4.1. Preparation of acoustic impedance from seismic data

4.1.1. Multi-attributes method (acoustic impedance estimation using well and seismic data)

The data consists of a series of wells logs corresponding to the target of the 3D seismic data. This approach has been one of the most successful to date in estimating porosity logs. A set of sample-based features is calculated from the 3D seismic volume. The goal is to obtain a multi-attribute transformation, which is a linear or non-linear transformation between a subset of features and values of the target attribute. The subset is selected by a forward stepwise regression procedure, which is incrementally obtained from the subset of larger features [14]. Here, using the Strata module of the Hampson-Russell software, the acoustic impedance is estimated by the seismic and well data. For this purpose, we use well data (Figure 3). Strata is a module that aims to integrate petrophysical logs and seismic data and obtain acoustic impedance.

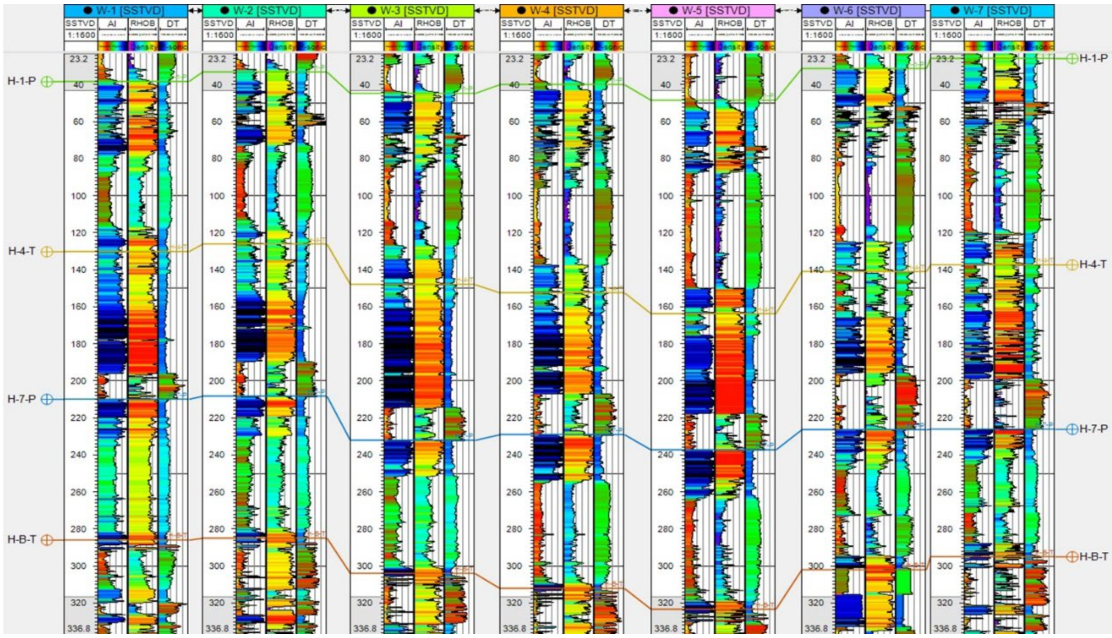


Figure 3. Final Logs data used (from left to right: AI, RHOB and DT for all wells).

4.1.2. Acoustic impedance

The final output of Strata module is the acoustic impedance in the form of 3D seismic data, which we introduce here. The amplitude seismic data volume model represented by SEISN is the input seismic volume. The acoustic impedance seismic data volume model represented by SAI is the inversion seismic volume.

These volumes will be converted to the depth domain. Also, in the final comparison with the created geostatistical acoustic impedance AI, SAI will be used as a basis for comparison:

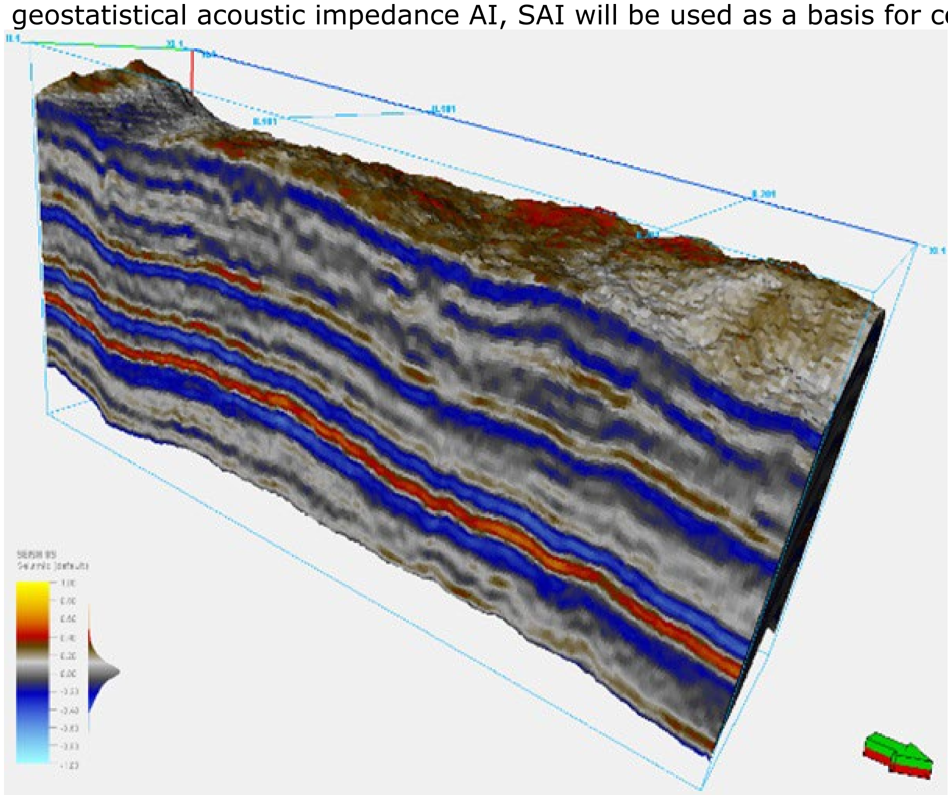


Figure 4. Seismic models as volumes: (a) Seismic amplitude.

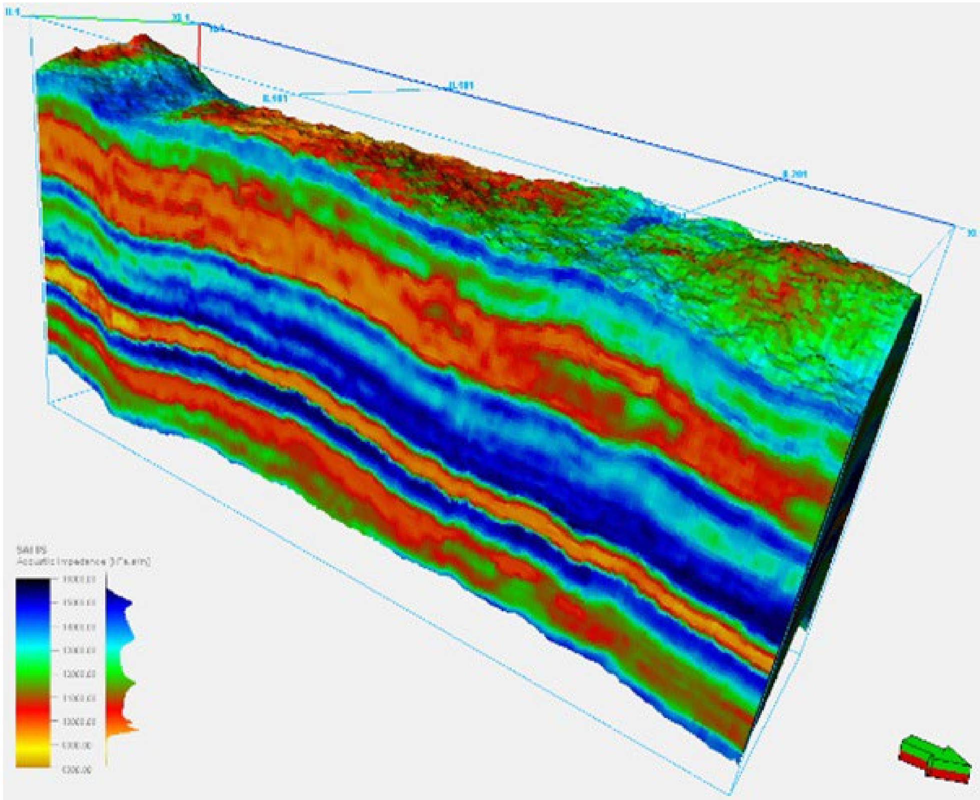


Figure 4. Seismic models as volumes: (b) Seismic acoustic impedance (CC=88.37% at Well locations). All the CCs are computed by corresponding volumes.

4.2. Acoustic impedance modeling by geostatistical approaches from well data

The data of drilling cores should be used in order to validate the petrographic logs; Thus, first by measuring the rock-physics properties of oil cores, collected the information; Then, we calibrate the desired data of rock-physics logs, including density and velocity, with the information related to oil cores and validated them.

Then we will complete these log data in the sections that seem incomplete and fix their deficits. Acoustic impedance similar to seismic data and in similar positions at intervals of 25 meters by 25 meters to existing seismic data in the format and form of 3D seismic data and depths of 360 meters estimate by geostatistical approaches including kriging, co-located co-kriging; Then we have to examine this output. If there is a need to change the accuracy and precision, we change the research approach or choose more suitable parameters and repeat this process until we reach a suitable result.

Finally, the desired data are compared with the results of different approaches. We do this for acoustic impedance. Therefore, this model is considered as the base and other models that are estimated are compared with it.

4.2.1. Choosing the approach and case of acoustic impedance modeling

The location of the wells on the seismic data and the section including all the wells is shown in Figure 5a and the acoustic impedance section including all the wells is shown in Figure 5b in Petrel software.

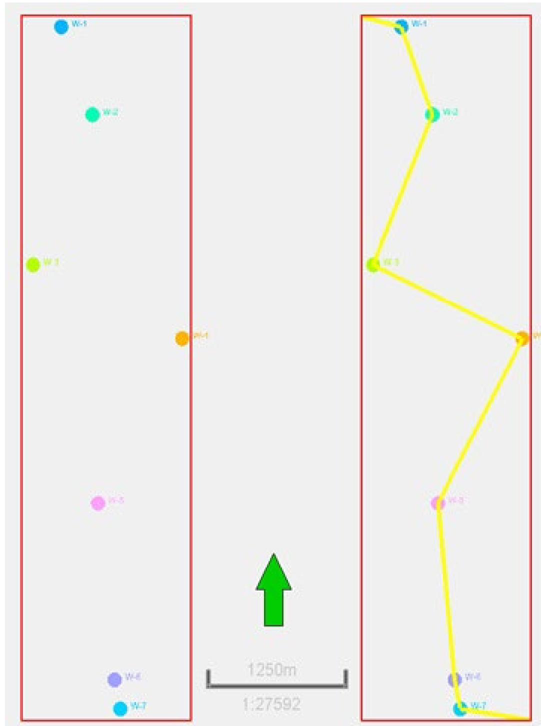


Figure 5. (a) Location of the wells on the map and the section including all the wells.

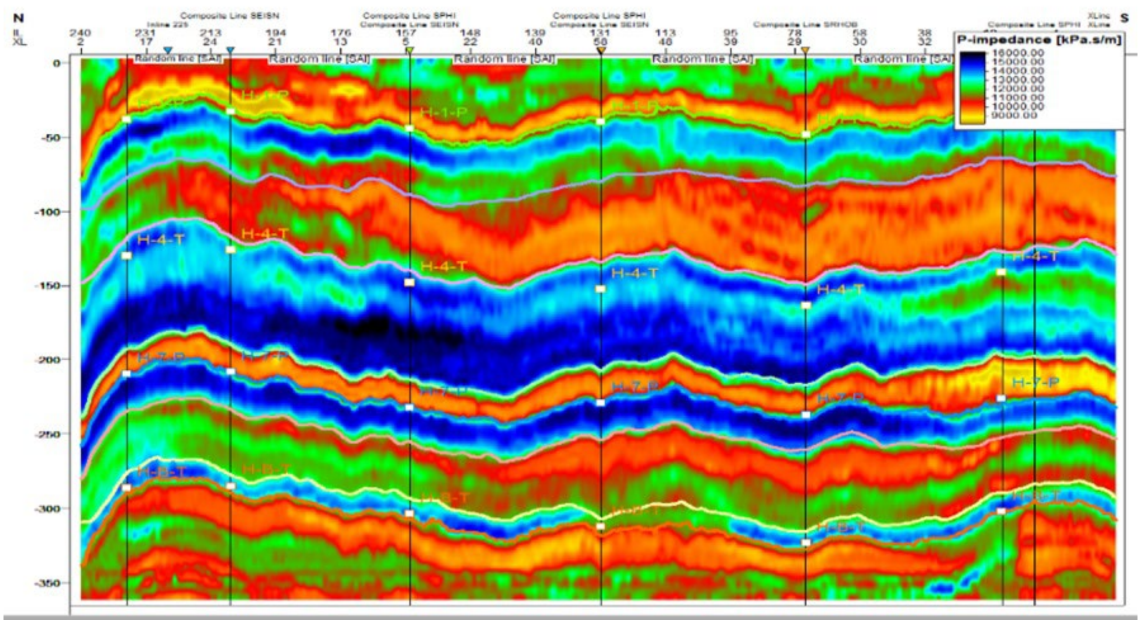


Figure 5. (b) Acoustic impedance section which included all the wells.

4.2.2. Selected eight-layer seismic case

The layers are selected based on the passage of the top formations and according to the seismic information; Therefore, the accuracy of these layers is of a maximum value. Another condition is the selection based on the difference of acoustic impedance. This means that the selected layers separate parts with distinct acoustic impedance. Eight layers are divided into seven zones and each zone is divided into smaller layers (totally 122 layers). The parameters are as follows (Figure 6):

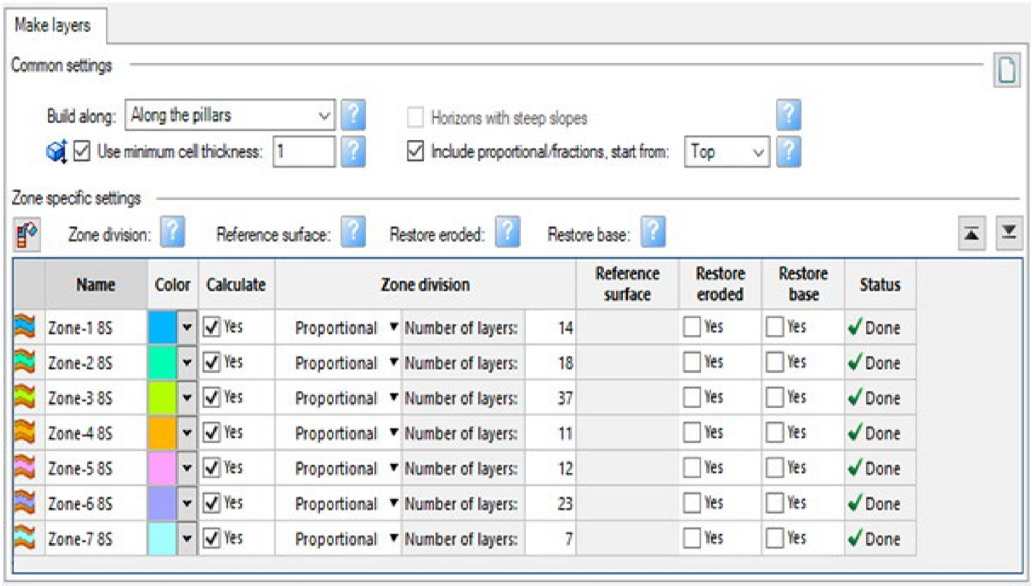


Figure 6. The parameters in selecting layers.

4.2.2.1. Approach 1: Gaussian random function simulation (GRFS)

The existence of a class of stochastic functions whose spatial distribution depends only on their first two moments is a very useful consequence of the central limit theorem. These functions are called Gaussian random functions.

Simulation is a process over time or an imitation of a real system. Sometimes use of precise mathematical models to analyze the relationships is possible, because of the simple relationships between the components of a system. In this case, the obtained results are more accurate. But most of the real models are very difficult, and mathematical models are also complicated to use. There are two types of simulation. In deterministic simulation, results are clearly obtained through deterministic relationships between events and statements without any random variation. In fact, in this simulation, we have no random variable and no degree of randomness of the event, instead mathematical equations are used. In this environment, each event that occurs uniquely determines the outcome [15].

In probability theory, a random process is a "mathematical object" usually defined as a set of random variables. Events will be obtained based on random values using the stochastic model. The output data is recorded and a new set of random values of the variables is repeated. These steps will be repeated until enough information is obtained. The distribution of these outputs represents the most probable estimates. It also shows us a frame of expectations, which ranges of data are more or less likely. This expectation frame expresses the value of the probability mass function in the discrete state and the probability density function in the continuous state. Of course, if needed in this way, co-located co-kriging or trend can also be used. This approach is very common to use because it is stochastic and does not cause problems in volumetric calculations and uncertainty analysis of reservoirs.

4.2.2.2. Approach 2: Kriging (K)

This approach is the same as using the simple or ordinary kriging approach. Again, if needed, co-located co-kriging or trend can also be used.

4.2.2.3. Approaches comparison

We prepare models of acoustic impedance in the approach 1 and 2. Only approach 1, that is, the approach of the Gaussian random function simulation represented by GRFS, is an approach which is "stochastic" or probabilistic and the other one is deterministic and is not used for uncertainty calculations, and here only it is used for more accurate calculation.

Then, the modeling of the acoustic impedance is done in the following four different ways and the necessary comparisons are made.

Method 1: Estimated acoustic impedance model of GRFS approach only using SEISN trends

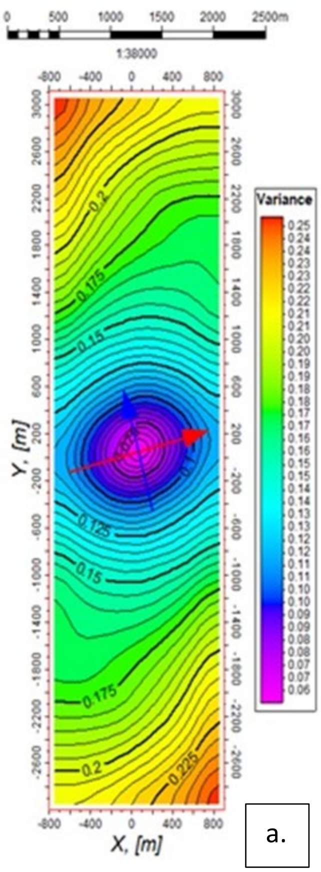
Method 2: Estimated acoustic impedance model of GRFS approach using only SAI trends

Method 3: Estimating acoustic impedance model of GRFS approach with variography and CL-CK of SAI volume

Method 4: Estimating acoustic impedance model of K approach with variography and CL-CK of SAI volume

Also, the well data should be upscaled in order to compare with the corresponding seismic data and use in the models. It should be noted here that the AI log used in this representation, resulting from the product of the logs of the density (RHOB) and the P-wave velocity (P), is physically very similar to the trace of SAI at the well location. This topic has already been raised by Talebi *et al.* [16].

4.2.3. Variography of seismic data and acoustic impedance



Because of the lack in seismic logs, horizontal and vertical variography is only done on SEISN and in the rest of the data, because of the better vertical resolution of Logs compared to Seismic volume, horizontal variography is done on Seismic volume and vertical on Logs. The red arrow shows the Major direction and the blue arrow shows the Minor direction. For these variographies, vertical range, minor range, major range, sill and the method of fitting curve to variograms are shown in Figures 7, 8.

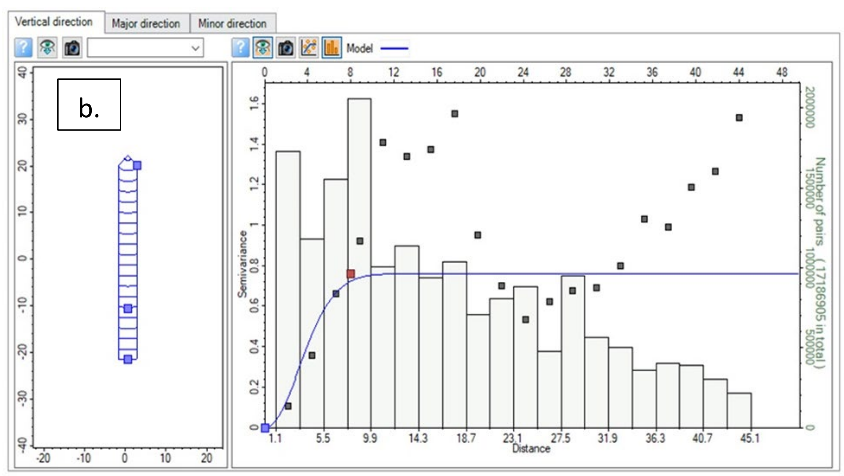
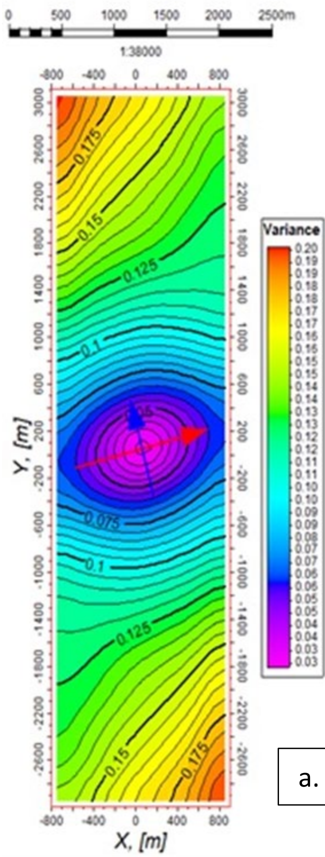


Figure 7. Variography map on SEISN: (a) Horizontal (Major Direction=75°), (b) Vertical (Major Range=1000m, Minor Range=775m, Vertical Range=8m, Sill=0.7593, Gaussian).



a.

Figure 8.(a) Variography map on SAI: Horizontal (Major Direction=75°).

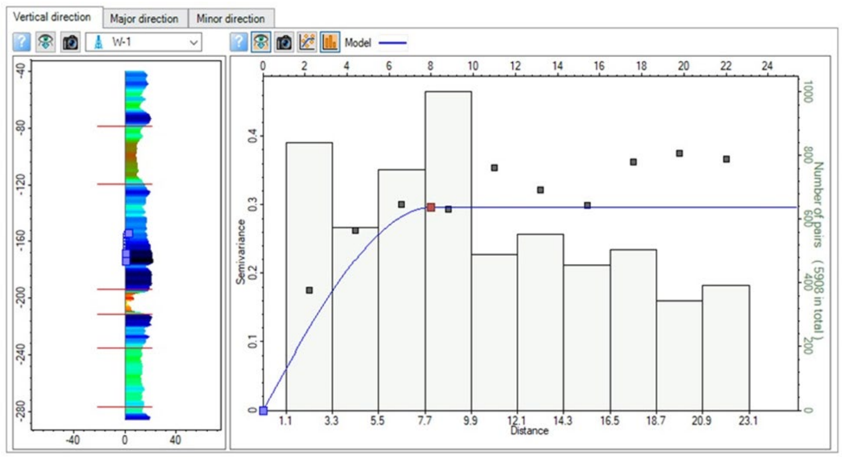


Figure 8. (b) Vertical (Major Range=930m, Minor Range=620m, Vertical Range=8m, Sill=0.296, Spherical).

4.2.4. The acoustic impedance modeling

The results of the acoustic impedance modeling were shown in the form of the following models with accuracy and specific form (Figure 9).

4.3. Comparison of acoustic impedance obtained from two approaches

The acoustic impedance data obtained from two geostatistical and multi-attributes approaches are compared here and evaluated in terms of accuracy, price, speed of execution. Notes: a. The green state does not require seismic inversion; b. the red state is known as the best state due to its probability; c. the blue color mode is the most accurate, but due to the fact that it is deterministic (for this reason, it is the most compatible with the seismic model), it is deficient for uncertainty calculations; d. Time and costs are included based on the seismic volume which is used.

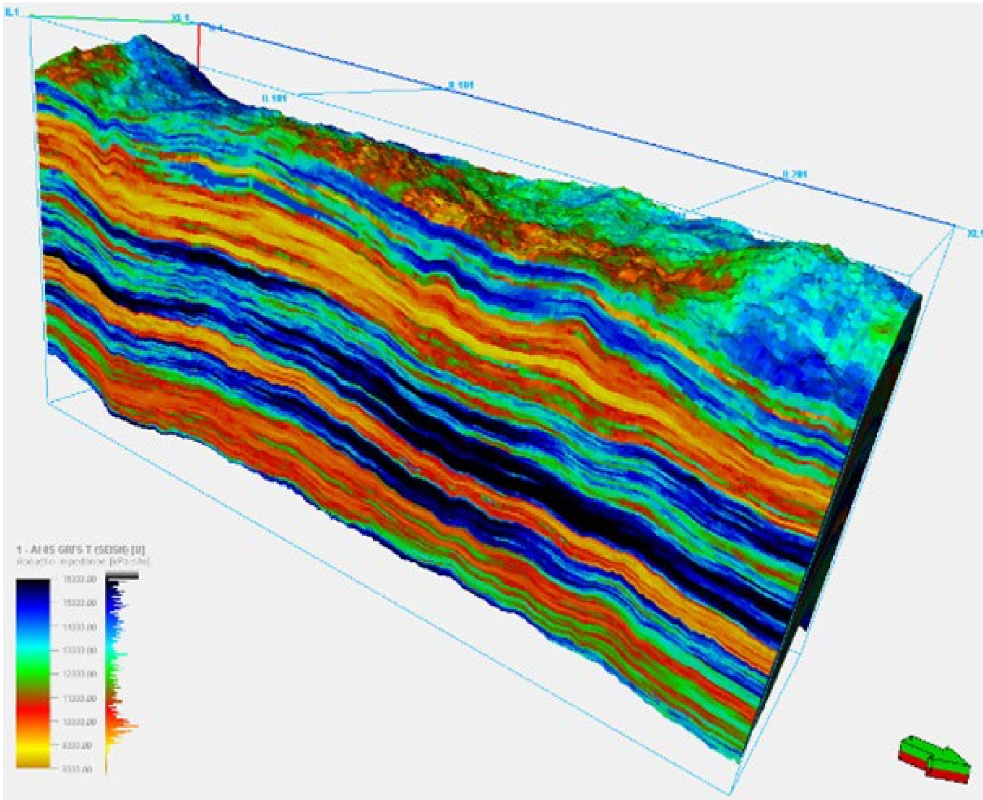


Figure 9. Acoustic impedance model estimated from (a) GRFS using only SEISN trend (CC=81.60%).

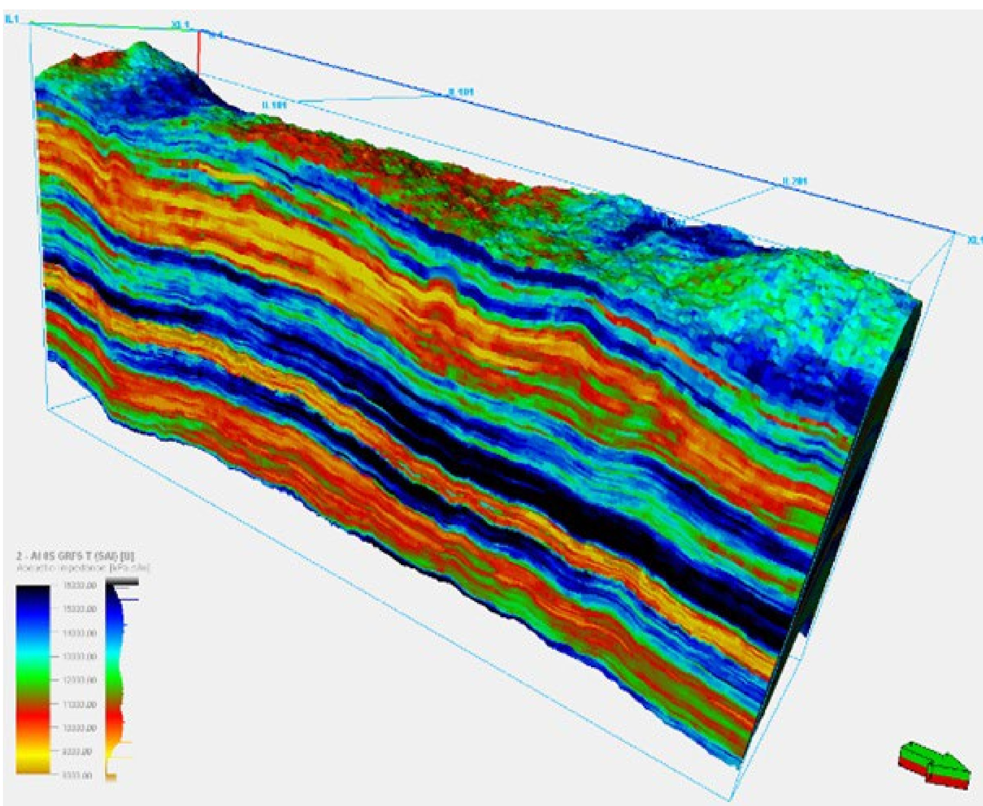


Figure 9. Acoustic impedance model estimated from (b) GRFS using only SAI trend (CC=89.66%).

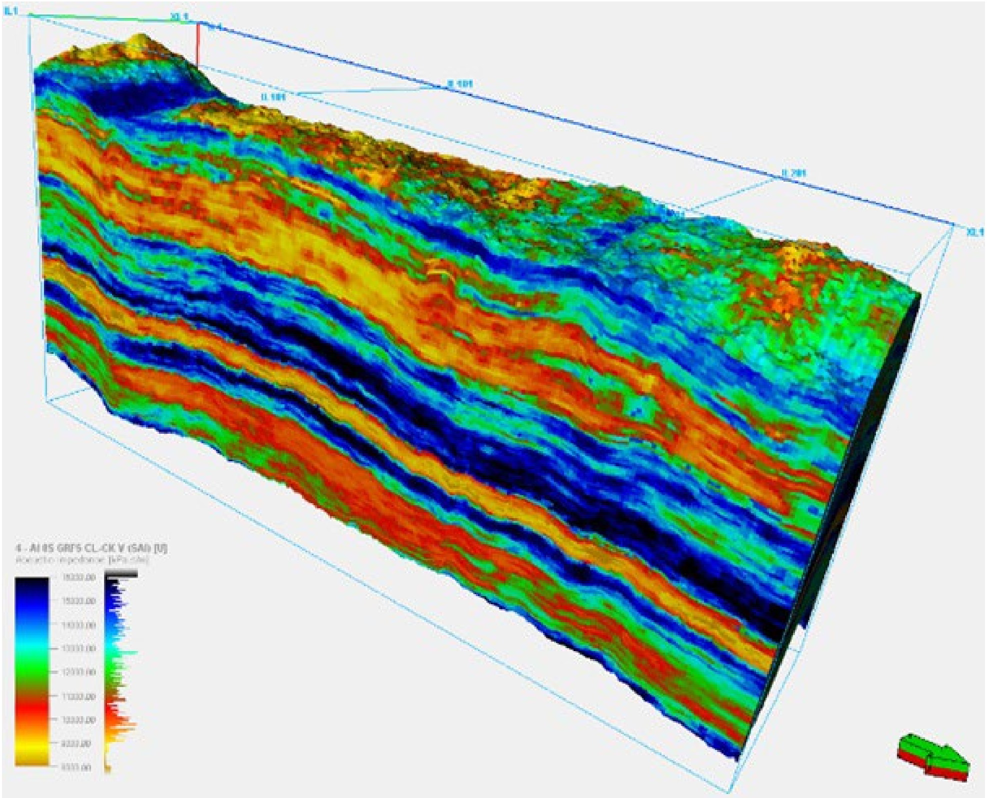


Figure 9. Acoustic impedance model estimated from (c) GRFS using variography and CL-Ck of SAI (CC=93.88% (CL-CK Correlation=87.19%)).

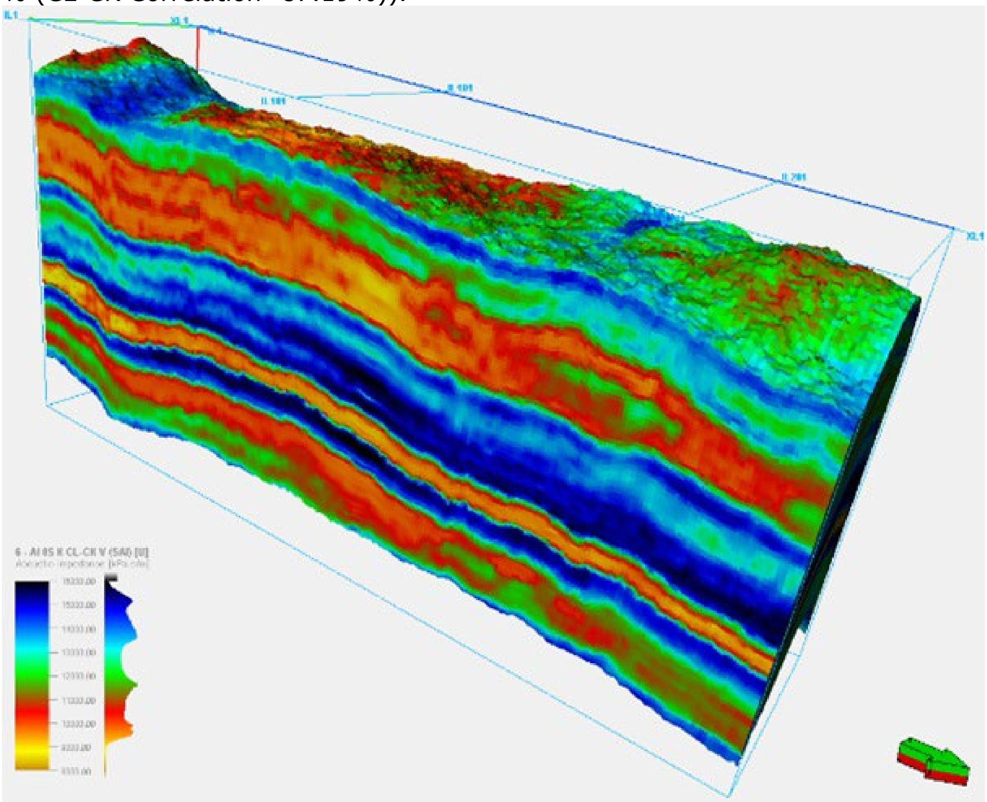


Figure 9. Acoustic impedance model estimated from (d) K using variography and CL-Ck of SAI (CC=99.75% (CL-CK Correlation=88.37%)). All the CCs are computed by corresponding SAI.

4.3.1. Comparison of acoustic impedance models

The comparison of the modeling types of models for the acoustic impedance in terms of accuracy, time and cost of modeling is summarized in Table 1. The final accuracy is the product of the accuracy and the average accuracy of the corresponding seismic data at the location of different wells (88.37%). In general, the most optimal methods can be summarized as follows in Table 2 .

Table 1. Comparison of all methods in acoustic impedance modeling.

Method	Accuracy (%)	Final accuracy (%)	Time (man hour)	Cost (man hour) $	Total cost ($)
1	81.60	72.11	90	20	1،800
2	89.66	79.23	170	20	3،400
3	93.88	82.96	180	20	3،600
4	99.75	88.15	180	20	3،600

Table 2. Optimized methods.

Method	Only Depth Seismic	Max Accuracy	Min Time	Min Cost	Optimized Method
1	Yes	Unacceptable	Optimal	Optimal	Unacceptable
2	No	Suitable	Acceptable	Acceptable	Suitable
3	No	Optimal	Acceptable	Acceptable	Acceptable
4	No	Acceptable	Acceptable	Acceptable	Optimal

5. Conclusion

This study is carried out in one of the hydrocarbon reservoirs in South-Western Iran. Using petrophysical logs (acoustic logs, density logs and P-wave velocities), the acoustic impedance of Bangestan & Khami Groups formations is estimated by geostatistical methods such as kriging and its derivatives, after calibrating with core data at well locations. Geostatistical methods are accurate and low-cost methods in estimating petrophysical properties in the shortest possible time using petrophysical logs, core data and seismic volume.

According to the research, it is necessary to perform modeling in stochastics ways in order to eliminate the shortcomings. Using geostatistical methods, the values obtained at the well location will have 100 percent matching. These values will have the most consistency at non-well locations. These values have a horizontal resolution consistent with the seismic data and the models have a horizontal resolution consistent with the well data. The problem of the small number of wells is solved with this method. The problem of uncertainty calculations is solved.

According to these issues as well as the comparisons made in the previous sections, if there is seismic data in time domain and velocity data are available, method 3 *i.e.*, the estimated acoustic impedance model of GRFS with variography and CL-CK of SAI has the most accuracy and the best performance among these methods. But, if there is no time seismic data, we only can perform method 1 *i.e.*, the acoustic impedance model estimated by GRFS using only SEISN trend. Of course, in situations where there is no need to calculate uncertainty, other methods can be chosen according to time, cost and accuracy.

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