Seismic Inversion and Lithological Characterization of Reservoirs: Case of Penobscot, Nova Scotia Offshore (Canada)

Sanda Oumarou, Djeddi Mabrouk, Tabod Charles Tabod, Jean Marcel, Jean Marcel Abate Essi, Thibaut Aloys Ekani Mebenga, and Simon Ngos III

Abstract

Seismic inversion is a method of processing seismic data to predict different properties of rocks such as density, compressibility, velocity, water saturation, porosity, permeability, and layer thickness. This is how it seems important to us to use seismic inversion to characterize the nature of reservoir rocks. This work uses the different types of seismic inversion that are related to AVO analysis to perform lithological analysis of hydrocarbon reservoirs using 3D seismic data from Penobscot located in offshore Nova Scotia (Canada). These are elastic inversion, acoustic inversion, and inversion by attributes which constitute the methods used. The results allow good discrimination of different layers of hydrocarbon reservoirs using a combination of attributes. Thus, the cross-plotting of the density and the Poisson ratio made it possible to highlight four facies.

Keywords

Seismic inversion · Reservoir · Characterization · Lithology · Seismic attributes

1 Introduction

The inversion of seismic data is an imaging technique widely used by the petroleum industry. Thus, there are two types of seismic inversions, namely deterministic inversion and probabilistic inversion. The latter requires the combination of several data types, while deterministic inversion is sometimes performed with a reduced number of data. In the lithological characterization of reservoirs, elastic inversion, acoustic inversion, and inversion by attributes are suitable approaches for this type of study. In this work, it will therefore be a question of presenting the contribution of seismic inversion in the lithological characterization of reservoirs (Adeoti et al., 2018; Alamsyah et al., 2016; Bosch et al., 2012; Helland-Hansen et al., 1997) in the study area. The Penobscot area is located in the Scotian Basin, which is 300,000 km^2 in area with an estimated depth of 18 km, dated to the Triassic to the present day. Structurally, tectonic movements marked the area with horst, grabens, and fractured zone structures. Between the Jurassic and the Cretaceous, four formations were counted, namely the Mississauga Formation, the Logan Canyon Formation, the Dawson Canyon Formation, and the Wyandot Formation (Cummings & Arnott, 2005; King et al., 1974; Mandal & Srivastava, 2017; McIver, 1972).

S. Oumarou (✉) · J. Marcel
National Institute of Cartography, PO Box: 157, Yaoundé, Cameroon
e-mail: oumarousanda22@gmail.com

S. Oumarou · T. A. E. Mebenga
Department of Physics, University of Maroua, PO Box: 814, Maroua, Cameroon

D. Mabrouk
Department of Geophysics, M'Hamed Bougara University of Boumerdès, PO Box: 35000, Boumerdès, Algeria

T. C. Tabod · J. Marcel
Department of Physics, University of Yaounde 1, PO Box: 812, Yaoundé, Cameroon

T. C. Tabod
Department of Physics, University of Bamenda, Bamenda, Cameroon

J. M. A. Essi
Institute for Geological and Mining Research, PO Box: 4110, Nlongkak, Cameroon

S. Ngos III
Department of Exploration, University of Maroua, PO Box: 08, Kaélé, Cameroon

S. Khomsi et al. (eds.), *Selected Studies in Geophysics, Tectonics and Petroleum Geosciences*, Advances in Science, Technology & Innovation, https://doi.org/10.1007/978-3-031-43807-3_11

2 Materials and Methods

The methodology used in this work is based on seismic inversion and AVO effects. Inversion is defined as a mathematical technique for estimating the characteristics of a system, knowing its response to a given excitation. Thanks to the AVO effects, we will use three forms of seismic inversion which are elastic inversion, acoustic inversion, and inversion by attributes in order to do the lithological analysis of reservoirs. The elastic inversion takes place by relying on the Vp and Vs velocities which provide information on the lithological prediction. This inversion is justified if we take into account the elastic parameters (amplitude, frequency, and phase) from the seismic which have lithological information through the seismic attributes. Through AVO analysis, the acoustic impedances of P and S waves are calculated and used in lithological discrimination, reflecting the use of acoustic inversion. Also, the extraction of AVO attributes such as $\lambda\rho$ and $\mu\rho$ by inversion makes it possible to make a lithological prediction of hydrocarbon reservoirs (Khalid et al., 2015; Sanda et al., 2020). To carry out a lithological characterization of reservoirs using seismic data, it is therefore necessary to combine these three types of inversion for at least two reasons. First, the three methods are related because they are all derived from AVO effects and elastic parameters. The second reason is based on the importance of combining the different approaches to improve the quality of the results. Thus, the methodology implemented to achieve these objectives can be structured in four stages:

- Identification of reservoirs using instantaneous attributes (instantaneous amplitude, quality factor, energy)
- Calculation of the attributes Vp, Vs, and Vp/Vs
- Determination of acoustic impedances
- Calculation of the attributes $\lambda\rho$ and $\mu\rho$
- Lithological analysis of reservoirs using the integrated approach of three methods.

To apply this methodology, we used 3D seismic data from Penobscot located in offshore Nova Scotia (Canada) and the OpendTect seismic interpretation software from dGB Earth Sciences.

3 Results

The results of this work allow the discrimination of lithofacies which constitute the different layers of hydrocarbon reservoirs. To do this, we present here some results which are the combination between density and an attribute obtained by the elastic inversion method (Poisson ratio). Then, it was shown that the crossing between P-impedance and Poisson ratio makes it possible to highlight the different lithologies of the zone.

In Fig. 1, the association between density and fish ratio allows us to define four different facies that reflect the potential layers of the reservoir. The first facies are blue in color with density values between 0.3 and 1 g/m^3, which could be the clay layer. Facies 2 is green with a density between 1 and 1.5 g/m^3 representing sands. Regarding the third facies, it is the cloud of points of the yellow color between (1.5–2 g/m^3); this facies would correspond to the sandstone layer. The last facies of density between 2 and 2.5 g/m^3 of maroon color would be considered as limestone. Confirmation of these results is done using well data.

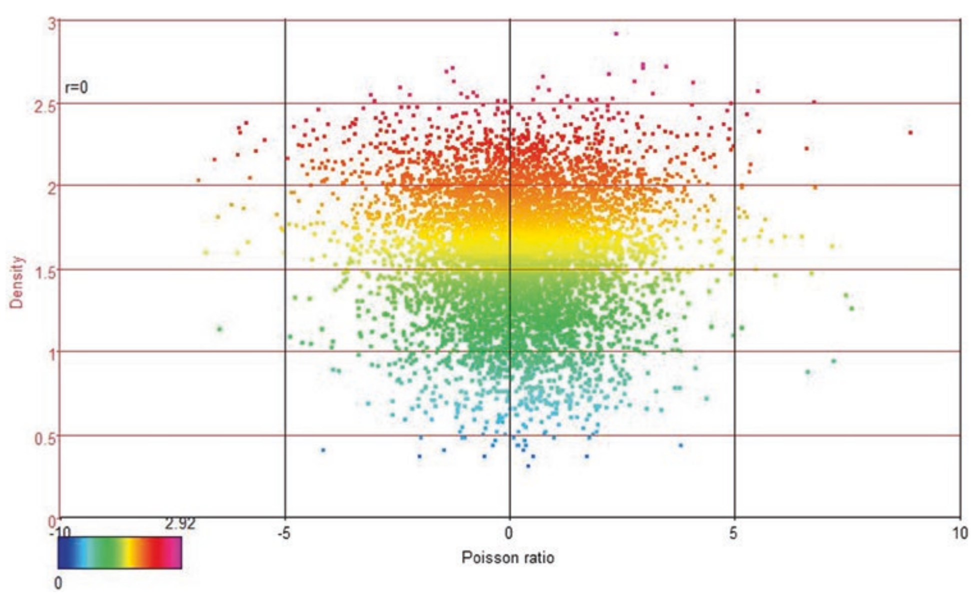

Fig. 1 Cross-plot of density and Poisson ratio

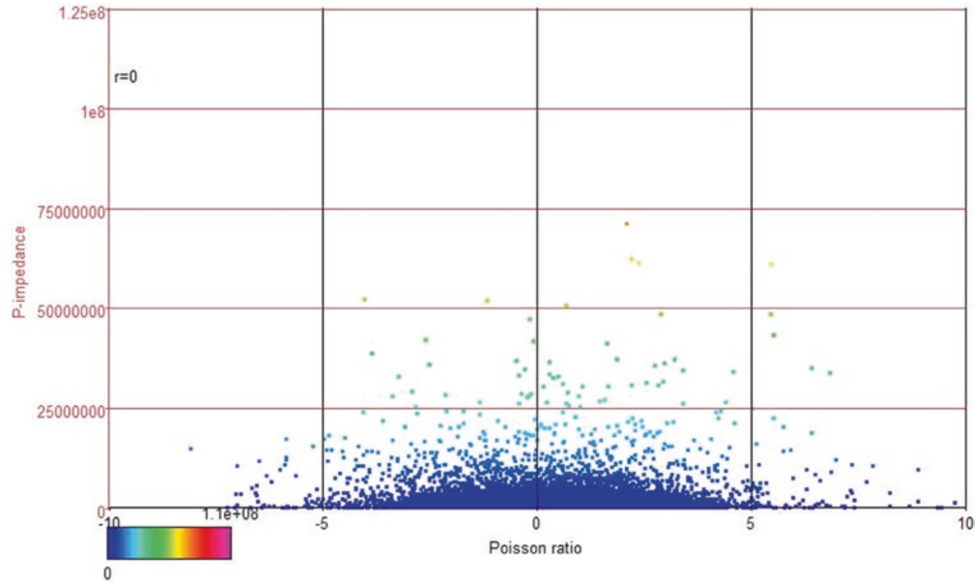

Fig. 2 Cross-diagram between P-impedance and Poisson ratio

Figure 2 presents the results of the crossing between the P-impedance and the Poisson ratio where we note the presence of only two types of facies which are distinguished by the colors blue and green. Thus, it is noted that this crossing plays the role of lithological discrimination in the case of two layers.

4 Discussion

It is often noted that the acoustic impedances do not provide quality results due to the variable nature of the seismic wavelets and a poor ratio between signal and noise, which justifies the use of the approach integrating the three methods of seismic inversion resulting from AVO effects. The difference of this approach from other seismic inversion methods is in the use of attributes. For methods such as stochastic inversion, model-driven inversion, sparse spike inversion, and simultaneous inversion (Pernia Soto et al., 2014; Sancevero et al., 2008), lithological characterization of reservoirs is done by creating a model using a lot of attributes, while the used approach boils down to the lithological analysis of the association of attributes resulting from the different inversions.

5 Conclusions

Seismic inversion is an approach well suited to the lithological characterization of reservoirs because it makes it possible to highlight the lithological discrimination of the layers by using the crossing of attributes obtained by the various inversions defined in the framework of this work.

References

Adeoti, L., Adesanya, O. Y., Oyedele, K. F., Afinotan, I. P., & Adekanle, A. (2018). Lithology and fluid prediction from simultaneous seismic inversion over sandfish field, Niger Delta, Nigeria. *Geosciences Journal, 22*, 155–169.

Alamsyah, M. N., Handono, B. W., & Syafriya, A. (2016). 3D seismic reservoir characterization and delineation in carbonate reservoir. Extended Abstract Prepared in Conjunction with Oral Presentation at AAPG/SEG International Conference and Exhibition, Melbourne, 13–16 September 2016, pp. 1–14. https://doi.org/10.1190/ice2015-2210675.

Bosch, M., Justiniano, A., Alvarez, G., Morales, D., Azuaje, V., Gomez, Y., & De Souza, T. (2012). Seismic inversion and statistical classification of lithology and fluids at Rubiales field, Colombia. SEG Technical Program Expanded Abstracts 2012. https://doi.org/10.1190/segam2012-0849.1.

Cummings, D. I., & Arnott, R. W. C. (2005). Growth-faulted shelf-margin deltas: A new (but old) play type, offshore Nova Scotia. *Bulletin of Canadian Petroleum Geology, 53*, 211–236.

Helland-Hansen, D., Magnus, I., Edvardsen, A., & Hansen, E. (1997). Seismic inversion for reservoir characterization and well planning in the Snorre Field. *The Leading Edge, 16*(3), 269–274.

Khalid, P., Ahmed, N., Khan, K. A., & Naeem, M. (2015). AVO-derived attributes to differentiate reservoir facies from non-reservoirs facies and fluid discrimination in Penobscot area, Nova Scotia. *Geosciences Journal, 19*, 1–10. https://doi.org/10.1007/s12303-014-0048-0.

King, L. H., MacLean, B., & Fader, G. B. (1974). Unconformities on the Scotian Shelf. *Canadian Journal of Earth Sciences, 11*(1), 89–100.

Mandal, A., & Srivastava, E. (2018). Enhanced structural interpretation from 3D seismic data using hybrid attributes: New insights into fault visualization and displacement in Cretaceous formations of the Scotian Basin, offshore Nova Scotia. *Marine and Petroleum Geology, 89*, 464–478.

McIver, N. L. (1972). Cenozoic and Mesozoic stratigraphy of the Nova Scotia Shelf. *Canadian Journal of Earth Sciences, 9*, 54–70.

Pernia Soto, L. R., Piazza, J. L., Chenot, D., & De Margon, C. (2014). Predicting lithology and porosity of carbonate reservoirs using geostatistical stochastic pre-stack inversion for

geomodeling constraint. International Petroleum Technology Conference. https://doi.org/10.2523/IPTC-17685-MS.
Sancevero, S. S., Remacre, A. Z., Mundim, E. C., & de Souza, P. R. (2008). Application of stochastic inversion to reservoir characterization process. *Earth Science Frontiers, 15*(1), 187–195. https://doi.org/10.1016/S1872-5791(08)60021-4.
Sanda, O., Mabrouk, D., Tabod, T. C., Marcel, J., Essi, J. M. A., & Ngos, S., III. (2020). The integrated approach to seismic attributes of lithological characterization of reservoirs: Case of the F3 Block, North Sea-Dutch Sector. *Open Journal of Earthquake Research, 9*, 273–288. https://doi.org/10.4236/ojer.2020.93016.