Egyptian Geophysical Society
EGS Journal, Vol. 17, No. 1, 167-174 (2019)

POROSITY PREDICTION FROM THE POST-STACK SEISMIC INVERSION RESULTS OF THE SAND CHANNELS AT SIMIAN GAS FIELD, EGYPT'S OFFSHORE WEST NILE DELTA

S.A. ALY[1], K.S.I. FARAG[1], H.F. EWIEDA[2] AND A.M.A. MAHDY[1]*
(1) Geophysics Department, Faculty of Science, Ain Shams University, Abbassia 11566, Cairo, Egypt, * Corresponding Author: E-mail: alimahdy@sci.asu.edu.eg
(2) Tri Ocean Energy, Cairo, Egypt.

التنبؤ بالمسامية الناتجة عن الانعكاس السيزمي للانهيارات الرملية للقنوات الرملية في حقل غاز سيميان ، دلتا النيل الغربي في مصر

الخلاصة: تحاول الدراسة استنتاج توصيف الخزانات تحت السطح من خلال إلقاء الضوء على الخصائص البتروفيزيائية من خلال تكامل الخصائص البتروفيزيائية والأرصاد الزلزالية ثلاثية الأبعاد (3D) في حقل غاز سيميان في الجزء الشمالي من مصر. يتم تحقيق هذا الهدف باستخدام تحليل الانحدار على خصائص الانعكاس الزلزالي في مرحلة ما بعد الصلابة ، والعلاقة التي تمت صياغتها بين سجل المسامية المقاسة وخواص الانعكاس الزلزالي المشتقة في موقع البئر. بعد استخراج العلاقة ، يمكن أن يتم اشتقاق مكعب المسامية بشكل معقول من نتائج خصائص الانقلاب. يجري التحكم في الخصائص الفيزيائية والشروح في البئر ، وتكون تقديرات المسامية الناتجة عن خصائص الانعكاس مناسبة لاتخاذ قرارات إدارة المكامن. وأخيرًا ، يمكن للمسامية التي يمكن التنبؤ بها أن تقود تقود إلى توزيع واقعى للمسامية يساعد في تتبع تباينات الخزانات داخل منطقة الدراسة.

ABSTRACT: *The study attempts to infer the characterization of subsurface reservoirs by enlightening the petrophysical properties prediction through the integration of petrophysical characteristic and the three-dimensional (3D) seismic observations at Simian gas field in the northern part of Egypt. This goal is accomplished using regression analysis on the seismic post stack inversion properties, a well-made relationship between the measured porosity log and the seismic inversion properties derived at the well location. After extraction the relationship, the porosity cube can be derived reasonably from the results of inversion properties. Being controlled by the physical properties and annotations at the well, the resulting porosity estimations from inversion properties are suitable for making reservoir management decisions. Finally, the predictable porosity can deliver a geologically realistic porosity distribution that helps to trace the reservoirs heterogeneities within the study area.*

INTRODUCTION

The furthermost problematic properties to undertake in the subsurface reservoir characterization is the porosity and permeability; yet frequently they have the main influence on reserves and production forecasts, and subsequently on the economy of a prospect. The necessity for estimating them arises from the fact that porosity and permeability may differ meaning fully over reservoir volume, but can only be experimented at the well locations, often through using different technologies at different scales of thought. A key to the above mentioned difficulty needs the integration of rock physics, petrophysics and subsurface seismic in order to guarantee the reliability of analysis and results. Elastic properties - and then seismic data - are frequently affected by porosity and lithology. In some cases, they may also be affected by the pore fluidre placement, that is constrained by the permeability. A precise estimation of the porosity and permeability is of quit importance because they translate into higher success rates in the infill drilling, and scarcer wells required for draining the reservoir.

Counting the parameters obligatory for the definition of a reservoir, porosity is one of the furthermost significant and at the same time the most problematic to compute. The pore volume of clastic rocks usually consists of intergranular openings between the mineral grains. Occasionally it may be the main factor to be considered in the evaluation of the characteristics of a clastic rock as a potential economic reservoir may be fracture and fissure porosity is every so often present or not. In carbonate reservoirs, even if many types of porosity may be distinguished, but as remote as reservoir evaluation is concerned, the porosity may generally be studied as the contributed effect of two distinct causes: (i) matrix porosity with pore spaces generally small and accordingly low permeability; and (ii) fracture, fissure and joint porosity with large pore size and high permeability.

Quantitative evaluation of the porosity of a rock is frequently as problematic as it is significant. The key problems arise in the occurrence of dispersed shale or when the reservoir rock demonstrates several types of porosity.

Porosity maybe defined by numerous methods. Some of these varieties is the use of core samples; others are built on well-log data and mathematical models. Of specific interest are the techniques of porosity estimate from transit time analyses that make use of the interval velocities got from seismic traces. Well observations deliver respectable vertical resolution of the geologic strata, however are at sparse locations. In contrast, the 3D seismic method offers dense and areal sampling but with noticeably lower vertical resolution. The integration of the 3D seismic data with the petrophysical measurements at the wells can meaning fully expand the spatial distribution of porosity. The application of seismic attributes is a widely used technique to decrease the spatial doubt of the parameter prediction. Meaningful the spatial distribution of petrophysical parameters between wells in a hydrocarbon reservoir is an actual vital role in tracing the furthermost economical and optimal production opportunities by flow simulation.

Among the last decades, numerous approaches for mapping or estimating the rock properties from seismic data were industrialized and tested with the purpose of providing supplementary information for comprehensive reservoir characterization. The first deterministic inversion methods for acoustic impedance mapping were established in the late 1970s and became to be known generally as recursive inversion (Lavergne and Willm, 1977; and Lindseth, 1979). These days, most of the research efforts in this field are intensive in the inversion and interpretation of variations of seismic reflection amplitude with the change in distance between the source and receiver (amplitude vs. offset) from the pre-stack data. But, the post-stack data obtained from the recorded P-waves are still broadly used because of their ready availability and low time-consuming processing. Because wells in a reservoir field are every so often spaced at hundreds or even thousands of meters, the vital goal of a seismic inversion way in the context of reservoir characterization is to provide models not only of acoustic impedance but also of other applicable physical properties, such as effective porosity and water saturation, for the inter-well area. Such quantitative interpretations may occasionally involve the use of other seismic attributes beside the old-style seismic reflection amplitudes (Rijks and Jauffred, 1991; Lefeuvre et al., 1995; Russell, 2 004; Sancevero et al., 2005; Soubotcheva, 2006).

The total porosity prediction using the seismic inversion properties carried out in this paper. The seismic inversion method that is used in this paper categorized as deterministic (Model -based) inversion method (Russell, 1988). Despite the fact that many most recent papers have established some advantages of geostatistical methods over the deterministic methods (Robinson, 2001), The latter, with respectable quality datasets, delivers geologically plausible acoustic impedance and further rock properties at a considerably lower computational cost.

LOCATION AND GEOLOGY

The gas field studied is located in the northern part of Egypt (Figure 1). The Simian Fields are found offshore Egypt as a part of the proven gas reserves in the Western Delta Deep Marine concession (WDDM) of the Nile Delta. Imaged by exceptionally high-quality seismic data the complex sinuous submarine channel systems present an ideal opportunity to test the potential offered by seismic inversion which could handle the strong lateral variations that exist in the potentially seismically thin (less than 15m) target horizon. The whole reservoir is covered by 3D seismic data. Acoustic travel time log and check shot data are presented to determine the time-depth curve of the well viait’s synthetic seismogram.

Submarine channels are abundant in the WDDM concession and have played a key role in the transport of sediment down slope from the Nile shelf to the deep-sea (Catterall et al., 2007). It is through these channels that accumulation of reservoir quality Pliocene sands has built up in discrete stratigraphic intervals (Aal et al., 2000). The net sand content of these intervals is expected between 30 to 90% and worldwide analogues suggest that the Pliocene sands are likely to be unconsolidated, have excellent reservoir quality and porosity in the range of 24 to 36% (Aal et al., 2000) (Figure 2).

Two separate periods of deposition have been identified in the WDDM concession, the Pliocene and the Pleistocene. Pliocene channels are smaller, less incisional with minor levees. In contrast Pleistocene channels are up to 4km wide and 500m deep, and are associated with levees up to 250m thick (Catterall et al., 2007)

MATERIALS AND METHODS

Porosity prediction from seismic data is a very significant technique because it allows the description of porosity distribution even far from drilled wells, Show ameliorate characterization of known reservoirs in their economic and technical sides and delivers much more information than does the ordinary seismic processing in the exploration for new hydrocarbon fields.

Post-stack seismic inversion has been widely used in the petroleum industry for subsurface geological inferences (e.g., lithology, porosity, etc.) based on the seismic analysis tied to well logs (i.e., resistivity, sonic and density). The method increasingly confirms the usefulness of the inverted seismic data and is informative for seismic interpretation (Buiting and Bacon, 1999). Post-stack inversion is used to transform the seismic reflection data into acoustic impedance as it uses normal incidence reflections and requires only the near offset stacked data (rather than full aperture stacked data) to obtain physically and geologically reliable results. Analysis of the post stack seismic data has been used as an effective tool for hydrocarbon exploration in many areas around the world. The goal of seismic inversion procedure in the case of reservoir characterization is to map the physical properties such as porosity, water saturation and lithology for the inter-well areas.

Russell (1991) defines the model-based inversion, initial guess from a-prior information, as an iterative modeling scheme, in which the starting geological model is built in, from the available a-prior information, and its whole calculated response is literarily compared to the seismic data within a satisfied tolerance, in which the comparison is used to iterate to get the better model. The inversion requires the initial value of impedance. An initial model, for the model- based inversion, is generated, using the acoustic impedance logs, calculated at the well location. The inversion algorithm modifies the impedance log to minimize the misfit between the measured and synthetic seismic data. As it is to be expected with the impedance inversion, a good match between the seismic and synthetic data can be achieved. Figure (3) shows the seismic section at well location and

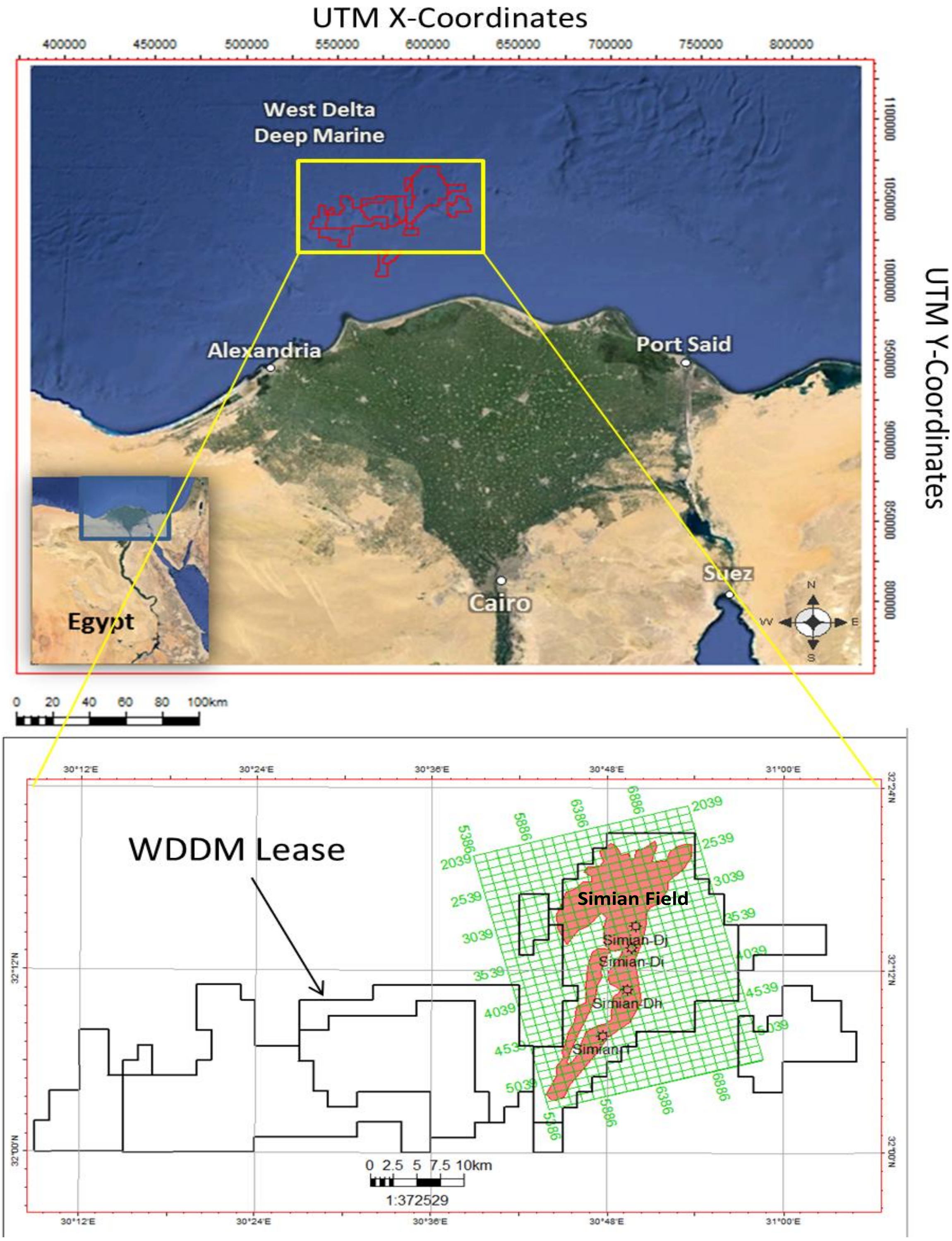

Figure (1): Satellite image (upper) showing the general location of the Simian gas field within the Egypt's offshore West Delta Deep Marine (WDDM) concession and index map (lower) showing the conducted seismic surveying lines and the available stratigraphic-control wells.

impedance log calculated from the well log data and placed on seismic section. The inverted acoustic impedance for the section is illustrated in Figure 4. The inverted impedance section around the well “X” shows the low impedance at depth range 2,600 to 2, 660 m which is the gas- bearing sand encountered.

A common way to extract porosity from the seismic data is to use the acoustic impedance inversion results. One can estimate the porosity from the inverted AI, using a mathematical relation between the AI and the porosity derived from well log. These special designed methods have been recently used by, e.g, Adekanle and Enikanselu (2013) and Das (2016), any others. Figure

5shows the best linear fit for gas- bearing sand (between the AI and Neutron- density combination derived porosity for the well "X". Where the Neutron -density combination porosity is derived from the following equation:

$$\Phi N\text{-}D = (\Phi N+\Phi D)/2 \quad \textbf{(Equation1)}$$

where Φ_N is the porosity derived from Neutron log and Φ_D is the porosity derived from Density log respectively. The inverted acoustic impedance is transformed into porosity from the relations obtained from cross plot (Figure 5) using the following equations (1) for the seismic section.

$$Porosity = -0.00004(AI) +0.34693 \quad \textbf{(Equation2)}$$

Figure (6) shows the porosity image of the seismic section, according to equation (2) that the provided specially designed porosity calculation, methods based on the direct post-stack seismic inversion results, has been proven for the gas bearing channel at simian field. From the practical side (Figure 5) it is noticed that the best convent of total porosity range, that can derive based on inverted response matching with seismic data, has been found between19 and 24%. We also find that the calculated porosity at the range less than 19% will be overestimated while above 24% will be underestimated. This is because the effect of gas on the Impedance **(See Table 1)**

RESULTS AND DESSUCSION

Acoustic impedance in the inverted seismic section varies from 3349to 5026m/s*gm/c.c. This variation is due to the sand, clay, siltstone, shale and gas-bearing sand. The top of Simian Channel is observed in the well "X" at about 2600 m and in the seismic section around 2580ms. Inverted porosity of the seismic sections varies from 15 to 25 %, respectively. The main porosity section follows the trend of seismic signature and structures of the study area. The low impedance zones observed in both section having gas-bearing sand potential and show relatively high porosity compared to the porosity of high impedance zones. Lithologies of gas-bearing generally vary across a continuum, from wholly sand sediments through siliciclastic shales to shaly sand. High silica results in high impedance shales (Prasad et al., 2002).

This special designed method of prediction of porosity have been implemented to shallow offshore seismic data of Simian field. Good fit observed between the AI and porosity in the field. Wavelet of 200 ms long from Simian is extracted for the seismic calibration to achieve good inversion results. Model-based inversion have applied throughout the whole drilled depth for both methods. The RMS error for porosity prediction is found to be 0.01 for the gas-bearing sand where the porosity range is between 19 and 24% (Figure 7). The main porosity section follows the trends of seismic signature and structures of simian field. AI varies from 3349 to 5026 m/s*g/cc and porosity ranges from 15to 25% characterizing the gas-bearing sand at Simian field. The lithology of the gas-bearing zones is generally sand sediments to significant shaly sand sediments.

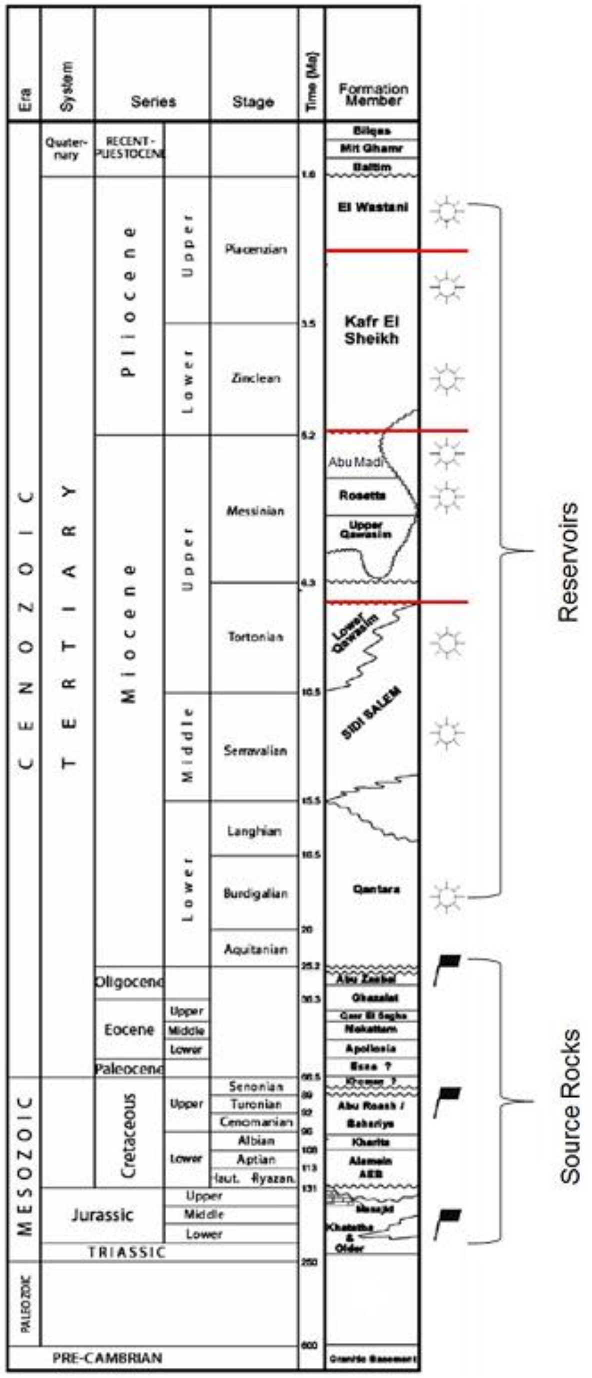

Figure (2): Generalized Stratigraphy from Nile delta area following Vandré et al. (2007). Source rocks occur pre-Miocene with reservoir deposited later. The most distinct seismic discontinuities are highlighted in red.

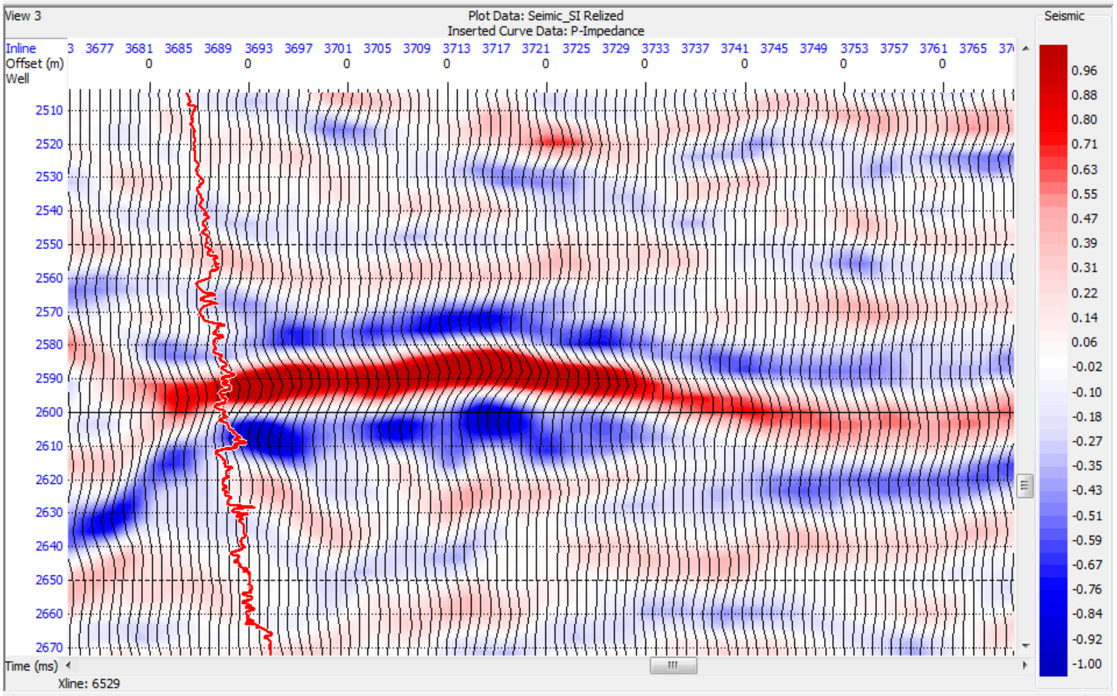

Figure (3): Post-stack seismic inverted Section at the well Location, that represented by its Impedance log (red Color).

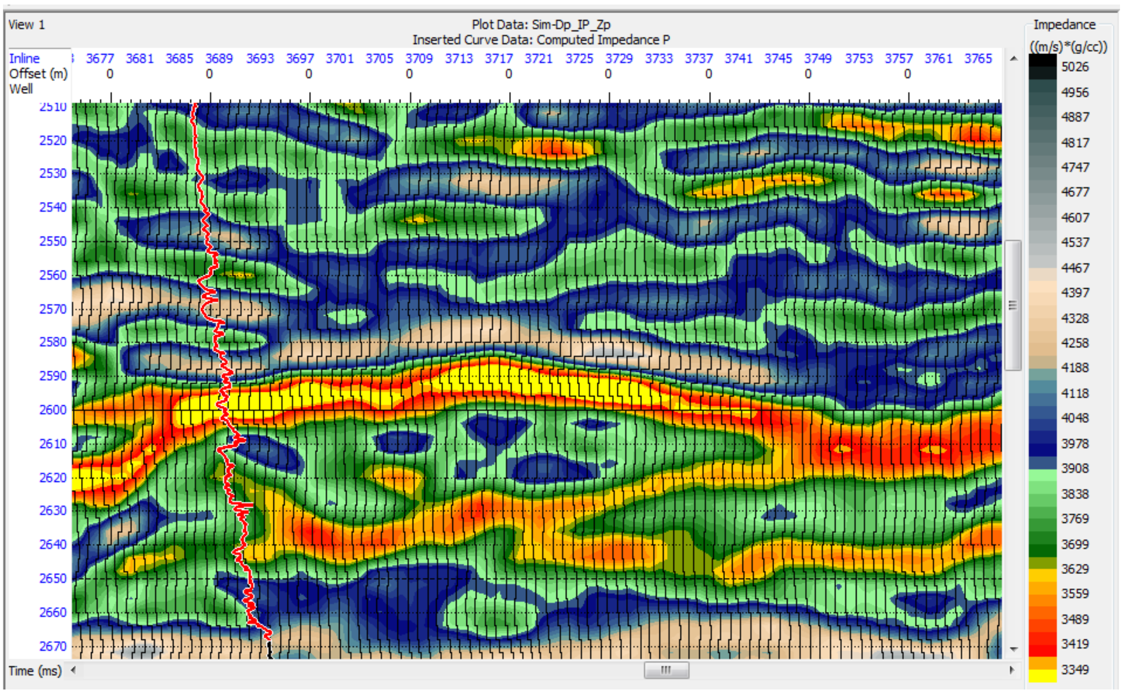

Figure (4): Inverted seismic section (Model-based Inversion) with lateral variation in acoustic impedance for the seismic section and inserted with it the Impedance log (red Color) in the Well location.

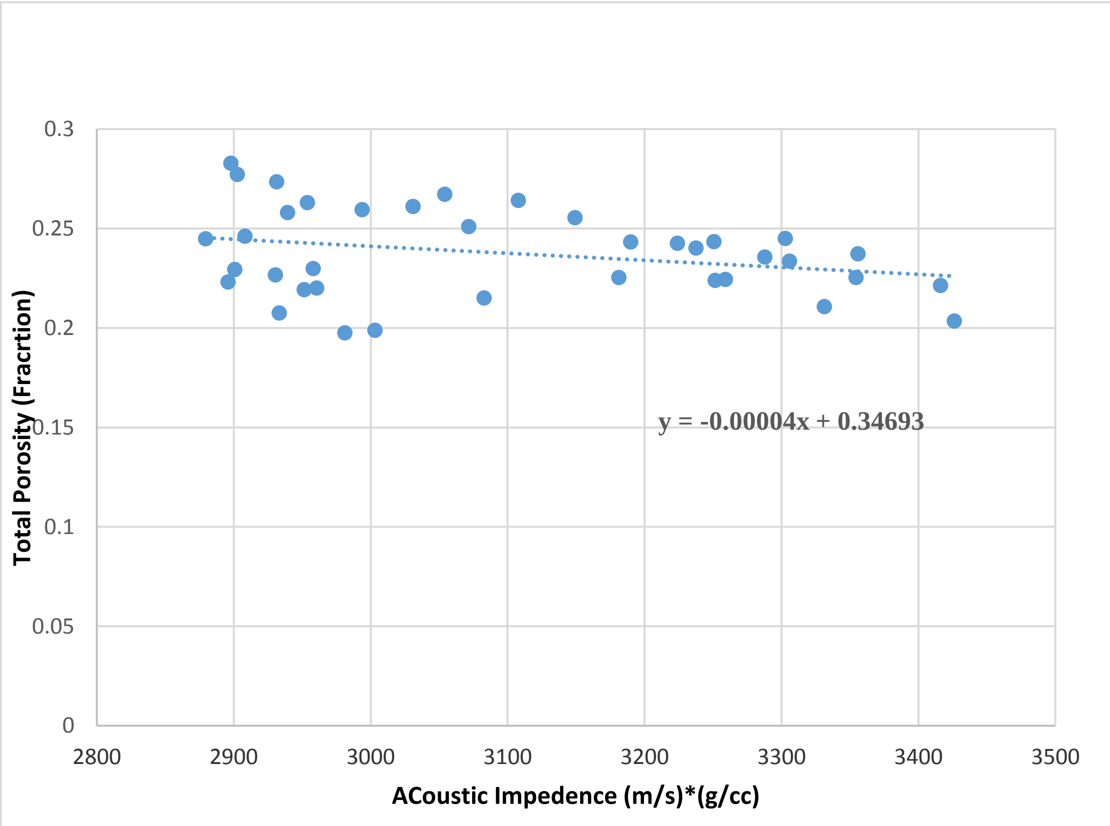

Figure (5): A cross plot between the acoustic impedance and neutron -density combination derived porosity for the gas-bearing sand to linear trend of point for the well" X".

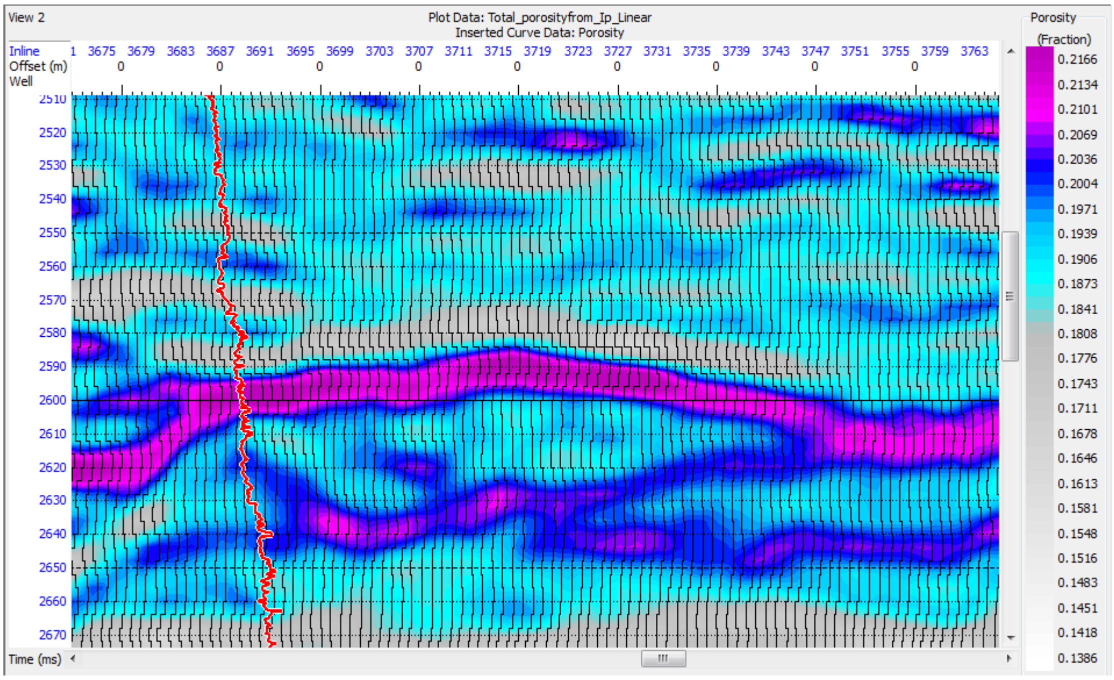

Figure (6): Inverted porosity section using the model-based inversion results of the post-stack seismic section interval using the transformation of AI to Porosity for the gas -bearing sand.

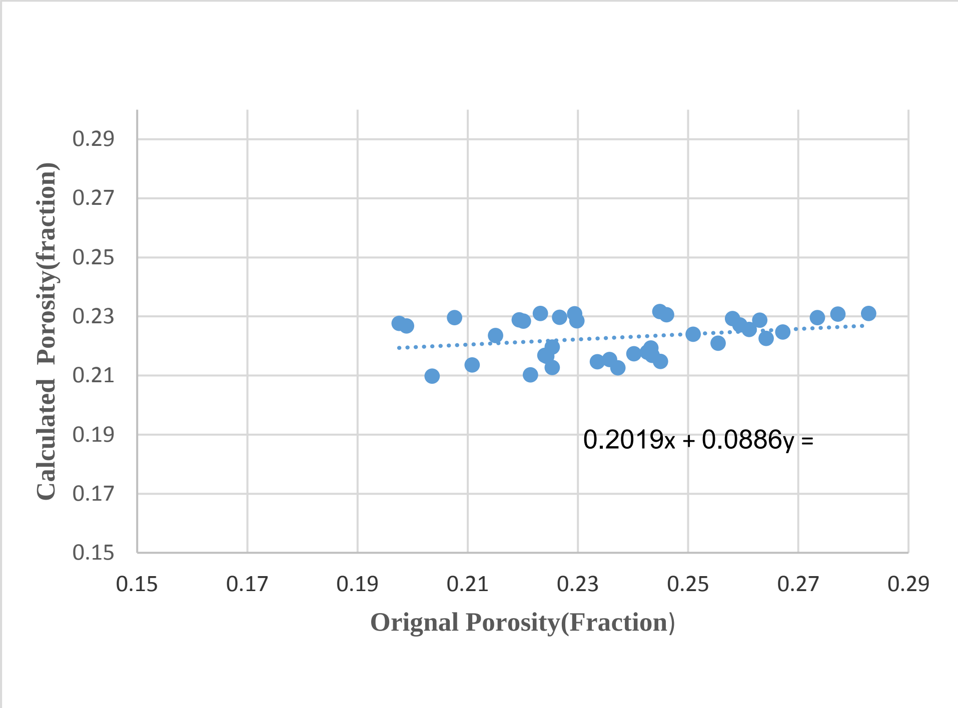

Figure (7): Cross plot between the Calculated Porosity and Original Porosity (Neutron -density combination derived porosity) for the gas-bearing sand in Simian Field.

Table (1): Typical calculated porosity values, with corresponding inverted acoustic impedance, compared to the original porosity values of different subsurface levels for the gas-bearing sand of simian channel (value approximated to second decimal point).

Acoustic Impedance (m/s*g/cc)	**2867.99**	**3030.96**	**3224.06**	**2957.96**	**3331.4**	**2981.16**
Original Porosity (%)	0.28	0.26	0.24	0.23	0.21	0.2
Calculated Porosity (%)	0.23	0.23	0.22	0.23	0.21	0.23

The gas-bearing sand is marked very clearly through the model-based inversion of AI for the porosity mapping. Porosity predicted by the transformation of AI shows 22 %, whereas the model-based inversion estimates 25 %. Direct inversion of porosity estimation is close in agreement with the actual porosity of gas-bearing sand.

CONCLUSIONS

The direct estimation of porosity from seismic inversion has been implemented, using the porosity wavelet. The AI and porosity wavelet have the exactly opposite polarity due to the negative trend between AI and porosity. This work demonstrated an uncommon porosity prediction methodology from post-stack seismic data. It is shown, how the difference is between the original and the calculated porosity for gas bearing sand in Simian Channel expresses the method.

The low impedance zones observed in the seismic section of Simian, having gas bearing sand, show relatively high porosity compared to the porosity of high impedance zones. Top of Simian Channel is marked by low impedance and nearly high porosity. Sediments of Paleocene age is observed with low impedance and high porosity. The shales/unconsolidated sediments measure a high porosity with low impedance and the more porous sand are in an intermediate range. Such porosity prediction scheme can be more validated when alarge number of wells or core porosity data are available in the future.

ACKNOWLEDEMENT

The authors are grateful to the Egyptian General Petroleum Corporation (EGPC) for their kind approval and providing us with the available seismic and well log data for academic purposes. The CGG Averts is acknowledged for providing Hampson Russell software during all phases of the research.

REFERENCES

Aal, A.A., Barkooky, M., Gerrits, M., Meyer, H., Schwa nder, M., Zaki, H., 2000. Tectonic evolution of the Eastern Mediterranean Basin and its Significance for Hydro carb on prospectively in the ultra-deep water of the Nile Delta. The Leading Edge, 10861102.

Adekanle A. and Enikanselu P.A., 2013. Porosity Prediction from Seismic Inversion Properties over 'XLD' Field, Niger Delta. American journal of science and industrial research .2013, Pp31-35.

B. Das, R. Chatterjee, 2016. Porosity Mapping from Inversion of Post-Stack Seismic Data. Georesursy = Georesources. 2016. V. 18. No. 4. Part 2. Pp. 306-313

Bateman, R.M., 1985. Open hole Log Analysis and Formation Evaluation, Pretice Hall PTR, New Jersey. 1985. 647 p.

Buiting, J.J.M., Bacon M., 1999. Seismic inversion as a vehicle for integration f geophysical, geological and petrophysical information for reservoir characterization: Some North Sea examples. Petroleum Geology of Northwest Europe: Proceedings of the 5th Conference. Geological Society, London.1999. V. 5. Pp. 1271-1280.

Calderon, J.E., 2007. Porosity and lithologic estimation using rock physics and multi-attribute transforms in Balcon Field, Colombia. Leading Edge 26 (2), 142–150.

Catterall, V., Redfern, J., Ha nsen, D. M., Gawthor p e, R., Badalini, G., 2007. Controls on the 3D seismic geomorphology of sub marine channel systems: Nile Delta slop e, Egypt. In: Petroleum Geoscience Collaboration Conference.

Kumar, R., Das, B., Chatterjee, R. and Sain, K.A., 2016. Methodology of Porosity Estimation from Inversion of Post-Stack Seismic Data. Journal of Natural Gas Science and Engineering. 2016. V. 28. Pp. 356-364.

Lefeuvre, F.E., Wrolstad, K.H., Zou, K.S., Smith, L.J., Maret, J.-P., Nyein, U.K., 1995. Sand–shale ratio and sandy reservoir properties estimation from seismic attributes: an integrated study. SEG Expanded Abstracts 95, 108–110.

Leiphart, D.J., Hart, B.S., 2001. Comparison of linear regression and a probabilistic neural network to predict porosity from 3D seismic attributes in Lower Brushy Canyon channeled sandstones, southeast New Mexico. Geophysics. 2001. V. 66. Pp. 1349-1358.

Leite, E.P., Vidal, A.C., Bueno, J. F. and Duarte, R. D. C., 2010. 3D Acoustic Impedance and Porosity Mapping from Seismic Inversion and Neural Networks. SEG Annual Meeting. Denver. 2010. Pp. 2226-2230.

Lindseth, RO., 1979. Synthetic sonic logs: a process for stratigraphic interpretation. Geophysics 44, 3–26.

Løseth, H., Wensaas, L., Gading, M., Duffaut, K., and Springer, M, 2011. Can hydrocarbon source rocks be identified on seismic data? Geology. 2011. V. 39. Pp. 1167-1170.

Prasad, M., Pal-Bathija, A., Johnston, M., Rydzy, M., and Batzle, M., 2002. Rock physics of the unconventional. The Leading Edge. 2002. V. 28. Pp. 34-38. Rao, G. N. Sedimenation, stratigraphy, and petroleum potential of

Rasmussen, K.B., Maver, K.G.1996. Direct inversion for porosity of post stack seismic data. European 3-D Reservoir Modeling Conference. Stavanger. 1996. Paper id: SPE 35509.

Rider, M.H., 2002, The geological interpretation of well logs, 2nd edition. Rider-French Consulting Ltd. 2002. 280 p.

Russell, B., Hampson, D., 1991. Comparison of poststack inversion methods. 61St Annual International Meeting, SEG, Expanded Abstracts. 1991. V. 10. Pp. 876-878.

Russell, B.H., 1988. Introduction to Seismic Inversion Methods. Society of Exploration Geophysicists, Tulsa, OK 86pp.

Shrivastava, C., Ganguly, S. and Khan, Z., 2008. Reconstructing Sedimentary Depositional Environment with Borehole Imaging and Core. International Petroleum Technology Conference: A Case Study from Eastern Offshore India. Kuala Lumpur, Malaysia. 2008.

Singha, D.K., Chatterjee, R., Sen, M.K. and Sain, K., 2014. Pore pressure prediction in gas-hydrate bearing sediments of Krishna-Godavari Basin in India. Marine Geology. 2014. V. 357. Pp. 1-11.

Soubotcheva, N., 2006. Reservoir Property Prediction from Well-logs, VSP and Multicomponent Seismic Data: Pikes Peak Heavy Oilfield. Saskatchewan. M.Sc. Thesis. Department of Geology and Geophysics, University of Calgary, Alberta, 94 pp.

Vandré, C., Cramer, B., Gerling, P., Winsemann, J., 2007. Natural gas formation in the western Nile delta (Eastern Mediterranean): Thermogenic versus microbial. Organic Geo chemistry 38, 523-539.