7th International Conference & Exposition on Petroleum Geophysics

"HYDERABAD 2008"

P - 87

Seismic Velocities for Pore-Pressure Prediction. Some Case Histories.

Patrizia Cibin* , Luigi Pizzaferri, Mauro Della Martera
– Eni E&P Division (Milano, Italy)

Summary

Seismic velocities have long been used to estimate pore pressure, indeed both these quantities are influenced by variations in rock properties such as porosity, density, effective stress and so on, and high pore pressure zones are often associated with low seismic velocities. This paper describes how some seismic velocity types can be used to estimate pore pressure along sections or in volumes. Some case histories are presented to illustrate their use also in connection with the extension of the study area, the scope of work and time and costs constraints.

Introduction

In hydrocarbon exploration and production activities, an accurate prediction of pore pressures is often critical for success. Abnormal pore pressures, if not foreseen, can give drilling problems like kicks, blowouts, borehole instability and lost circulation. Furthermore, the pore pressure estimate can also be used to evaluate faults sealing, an important aspect if they bound the reservoir; or it can be considered during the evaluation of the maximum possible column of hydrocarbons in place without exceeding the fracture pressure of the overburden. With a reliable pore pressure prediction, not only drilling costs can be substantially reduced but also the costs of an exploratory campaign.

An over pressured formation, when compared to a normally pressured layer, at the same depth generally shows the following properties: higher porosity & temperature and lower bulk density effective stress & lower interval velocity. It is very difficult to define relationships linking all these five variables to pore pressure. The most often used methods link porosity, effective stress and velocity ([1], [2], [3], [9]).

Methods

There are many velocity analysis techniques used for determining the velocity field suitable for a pore pressure study. The main methods are:

- Stacking/DMO/Migration velocities (from conventional time processing and Pre Stack Time Migration)
- Continuous Velocity Analysis (CVA)
- Residual Velocity Analysis (RVA)

Reflection Global Tomography (Grid Tomography) The methodologies are ordered for increasing complexity of the geological model, the precision of the results and the relevant time and costs.

Stacking and time migration velocities are computed using well known and standard techniques. Stacking velocities can be applied to the pore pressure prediction only if the geological and lithological models are not too complex and dips are almost negligible. The Pre Stack Time Migration velocities can partially compensate for the model complexities. Both velocities can be used quite successfully where the theoretical conditions for the application of Dix equation are valid. Of course, also the density of the picked velocity functions is important for the lateral details.

With Continuous Velocity Analysis (CVA) techniques the PSTM velocities are used as the central reference function in a range of velocities that will be applied to the data. At each CMP gather a series of faster and slower functions is assigned; their number inside the range is optimally determined looking at the data by several tests. Each gather is stacked after NMO correction with all the selected functions. The stacked traces are scanned to find the highest amplitude at every time sample and an optimum stacked trace is then generated by extracting the corresponding amplitudes and time from the original stacks. At each of these pick times the velocity used to generate the optimum stack is then calculated. With CVA method a very dense and detailed velocity field can be generated and the pore pressure inversion can highlight over pressure anomalies.

The Residual Velocity Analysis is carried out in the pore pressure prediction context in order to find possible small velocity anomalies in a layered velocity field generated in a 3D PSDM workflow. The RVA is performed on depth CRP gathers and if the gathers are not flat, the residual hyperbolic moveout, picked in an automatic way, is used to update the initial velocity. The picking of the depth delay is performed in a vertical mode, without taking into account the horizons, allowing the introduction of small intra-layer variations. It is recommended when a PSDM elaboration has been already performed and the earth model is not very complex. ([10], [11])

Reflection Tomography has been used in geophysical earth model updating for many years; with the traditional methodology, seismic events must be picked for a consistent set of reflecting horizons (in time or depth domain). This procedure allows the creation of a layered earth model which is correct for depth imaging purposes wherever the geometries are quite complex or when it is required a very detailed velocity field.

An improvement of Reflection Tomography is the Grid Tomography, where any locally coherent reflection events can be used together with the main horizons, in a global sense, to update the velocity model increasing the resolution and stabilizing the inversion process. With this method velocity anomalies having small lateral and vertical dimensions can be detected if the grid parameters are well defined. Of course this is very important, in terms of costs and reliability of Pore Pressure Prediction studies. ([7], [8]).

The more applied relationships between seismic velocity and effective stress or pore pressure are defined by the Bowers or Eaton Equations ([4], [5], [6]).

Examples

In this paper, we show some applications of the different methodologies mentioned above to build the velocity field and convert it into pore pressure on real cases.

The first application is an example of seal integrity assessment for a deep Oligocene structure in the Nile Delta (Egypt) performed by using a Migration Velocities field. The generated Interval Velocity Volume (Fig.1) was converted into Pore and Fracture Pressure Volumes by using appropriate inversion algorithms calibrated respectively to the existing well pressure and leak off pressure data. The excess of pressure due to the buoyancy effect of the expected hydrocarbon column was added to the pore pressure. The Fracture Pressure and Seal Integrity map extracted from the relative volumes along the depth target horizon are shown in figure 2 and 3. Since the pre stack seismic data (CMP gathers) were not easily available and the time to perform the study was quite short, we were forced to use the migration velocities. However, the study results were considered more than satisfying, they gave indications that the maximum column of hydrocarbons (with gas and oil hypothesis) had to be reduced due to the fracturing in the sealing cap rock.

In another case history from offshore China we computed seismic interval velocities with three different methods and inverted them into pore/over pressure in order to compare the effect of the velocity on the geopressure results.

In the area under study, situated in offshore China, the scope of work was to evaluate the hydrodynamic setting of the prospect and identify possible overpressures related to the occurrence of hydrocarbon accumulations.

Besides, it was required to generate pore/overpressure volumes in order to evaluate the overpressure distribution and in particular the sealing capacity of the main faults bounding the prospect.

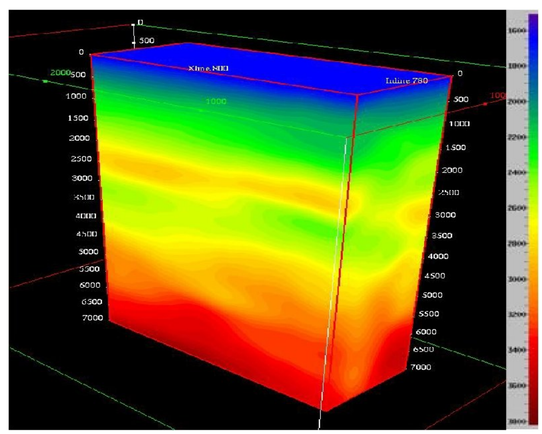

Fig. 1 – Interval Velocity Volume

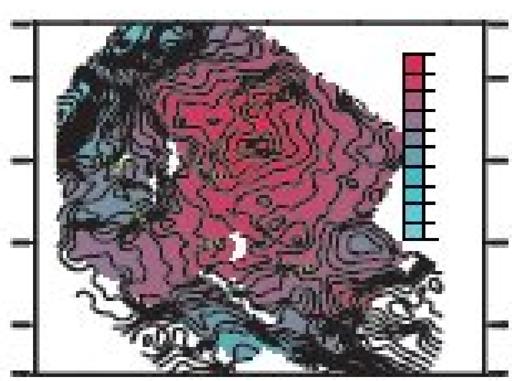

Fig 2 – Fracture Pressure

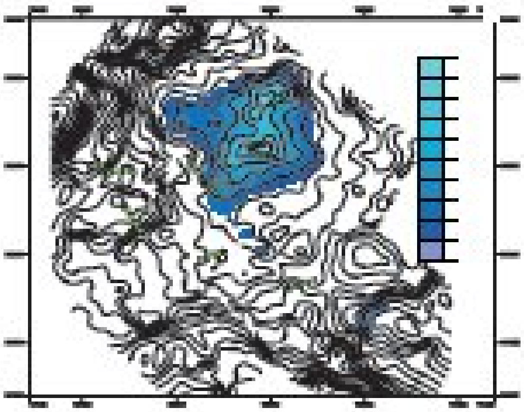

Fig. 3 – Seal Integrity Map

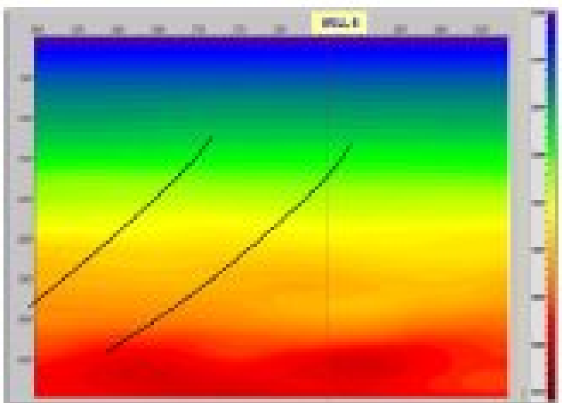

Fig. 4 - Interval Velocity - CVA Methodology

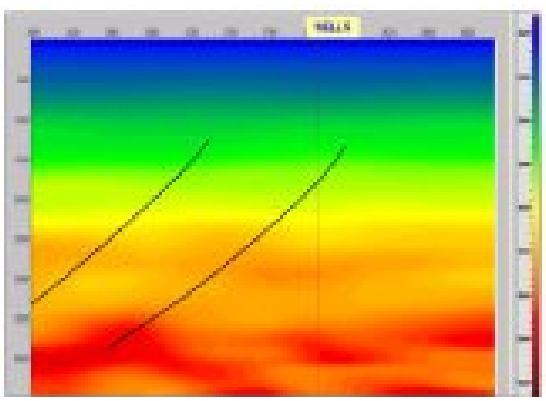

Fig. 5 - Interval Velocity - RVA Methodology

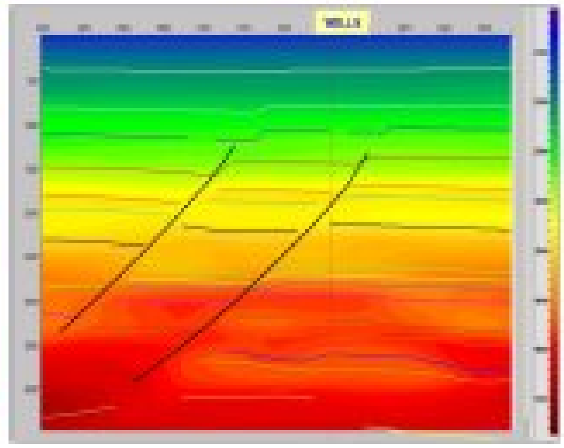

Fig. 6 - Interval Velocity - Grid Tomography Methodology

The pore pressure prediction study was carried before a new well (nr. 5) was drilled; three interval velocity volumes generated by CVA, RVA and GRID Tomography methods were computed and inverted into pore/over pressure volumes using an appropriate inversion algorithm calibrated to the existing well data

The relationship between seismic velocity and effective stress in this area is better defined by the Bowers Equation. The parameter set was the same for all the inversion processes.

In Figure 4 the interval velocity section near the Well 5 is extracted from the volume computed with CVA methodology; the initial velocity field was derived from time processing velocity functions.

Also a PSDM interval velocity volume was built and used as starting point for the next two methods, RVA and Grid Tomography and it has been used to evaluate the corrections produced by these two methodologies.

In Figure 5 the resulting updated interval velocity section obtained by application of RVA is displayed.

The same line is considered also to show the results obtained applying the Grid Tomography methodology (see Figure 6). Only with this methodology the horizons and the relevant seismic events superimposed to the section are used during the computation. They can be useful to get better results where the structures are more complex or where the velocity fields are more variable, without introducing artifacts.

Comparing the three over pressure volumes generated by the inversion of the interval velocity volumes, we can observe that they are quite different mainly in the deeper part, where zones with small overpressures are predicted in the depth range of 3200-3700 m for CVA (Fig. 7) and RVA (Fig. 8) methods while they are present in the depth range of 3700- 4000 m for GRID (Fig.

9)technique. The final choice fell on GRID results because of their greater geophysical reliability and better geological consistency.

Besides, the over pressure volumes were analyzed in order to evaluate the ‘shale’ overpressure distribution and in particular the sealing capacity of the faults in the area The results obtained from Tomography point out, more than the others, this hypothesis.

After the well was drilled, the results were compared with the measured pressure data in the reservoir levels (WFT). These comparisons allowed to perform a consistent evaluation of the methodologies applied to compute the velocity field: the Grid Tomography approach resulted the best of the three.

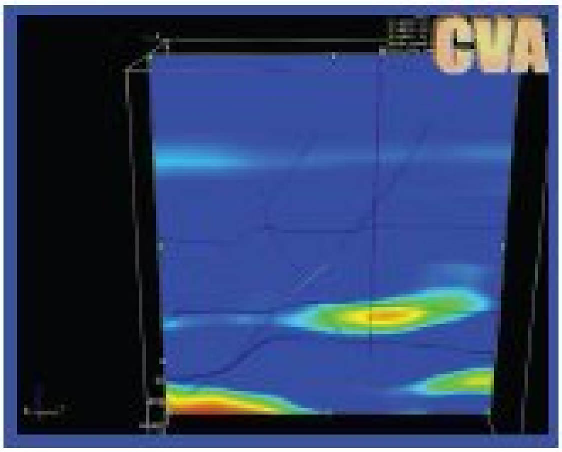

Fig. 7 – Over Pressure - CVA Methodology

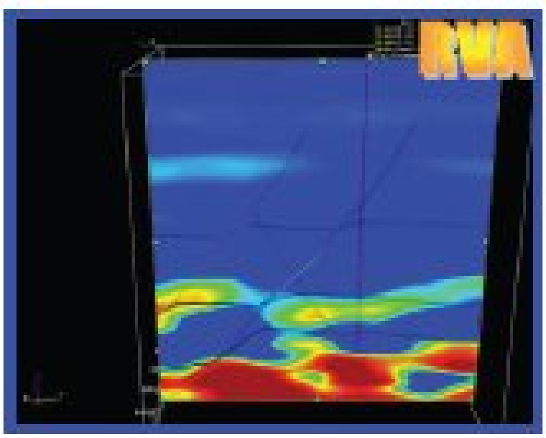

Fig. 8 – Over Pressure - RVA Methodology

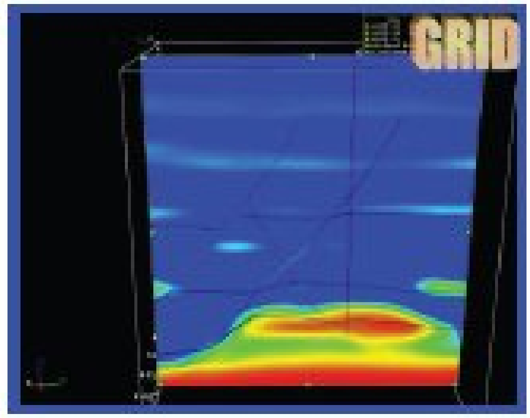

Fig 9. – Over Pressure Grid Methodology

Conclusions

The case histories presented in this paper show that when seismic pre stack data is not available and the time scheduled to perform studies on regional scale is quite short, even a not very detailed velocity field can give very good results and information on sealing integrity (see Egypt case history). Although CVA method is a method working in time domain, it in general gives quite good results at quite a low cost. Of course more rigorous methods (RVA and Grid Tomography) give better results but but are more suited to small study areas (around a new well location). To apply these techniques, pre stack seismic data must be available and a sufficient time frame must be allocated to the project: this last condition is not always met.

From the comparison among the three applied methodologies (CVA, RVA and GRID), it appears that the best fitting with the pressure measurements performed along the well is obtained by the Grid Tomography technique.

Although small, the sudden increase in the over pressure profile at about 3600 m is well predicted by GRID. Also looking at the over pressure sections elaborated from GRID velocity field it can be observed a better definition of pressure trends following the faults planes. These results validate the hypothesis that the main fault bounding the prospect is sealing in the deeper part of the section.

References

- Bellotti P., Giacca D. Pressure evaluation improves drilling performance O&G Journal, Sept 11 (1978).

- Bowers G.L.. Pore Pressure Estimation from Velocity Data: Accounting for Overpressure Mechanisms Besides Under Compaction, IADC/SPE Drilling Conference n 27488, p.515-530. (1994)

- Bowers G.L.. Determining an Appropriate Pore-Pressure Estimation Strategy. Offshore Technology Conference (OTC 13042). (2001)

- Bowers G.L.,. Detecting high overpressure, The Leading edge Vol.21, No. 2, p.174. (2002)

- Bowers, G.L. Pore pressure estimation from velocity data: Accounting for pore pressure mechanism besides undercompaction. SPE Drilling and Completion (1995).

- Best Practice Procedures for Predicting Pre-Drill Geopressures in Deep Water Gulf of Mexico, DEA Project 119 (2001).

- Colin M. Sayers, et al. Pore pressure prediction from Seismic tomography. Offshore Technology Conference (OTC 11984) (2000).
- Colin M. Sayers, et al. Seismic pore-pressure prediction using reflection tomography and 4-C seismic data. The Leading Edge (2002) - Colin M. Sayers, An introduction to velocity-based pore-pressure estimation.. The Leading Edge (2006).

- Satinder Chopra et al. Velocity determination for pore pressure prediction.. The Leading Edge (2006).

- Huffman R Alan The future of Pressure Prediction uging Geophysical Methods. AAPG Memoir (2002).

Ackowledgments

The authors thank the management of Eni E&P Division, Petrobel, IEOC, Eni China, Chevron, CNOOC and Partners in CACT for the permission to publish these results. They also thank Antonella Roveda Antonio Cascone, Giuliano Ravagnan, Luca Dragonetti, Alberto Pedretti (Eni), for their contributions.