Pore Pressure Modeling Using Multivariate Geostatistics*

Flávia Braz Ponte[1], Francisco Fábio de Araújo Ponte[2], Adalberto da Silva[2], and Alberto Garcia de Figueiredo Jr.[2]

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[1]Queiroz Galvão Exploração & Produção, Brazil (flavibponte@gmail.com)
[2]Federal Fluminense University, Brazil

Abstract

Sedimentary basins are subject to pore pressure anomalies caused by subcompaction mechanisms, fluid expansion, hydrocarbon generation and tectonism. In this context, pore pressure modeling using multivariate geostatistics has attracted the attention of geoscientists and engineers as a framework to attain more accurate estimates and predictions of geopressure fields. A reliable pore pressure model clearly affects safety and costs issues related to drilling operations.

Geostatistics is a branch of Statistics that develops and applies models representing natural phenomena whose proprieties vary according to its spatial location and could not be explained by deterministic functions. Its primary objective is to estimate the values and to predict uncertainty of a sampled variable over an area of interest. Its main tool is the variogram, a function directly extracted from the sampled data that describes the spatial structure of the phenomenon. It results in an image of the phenomenon that honors sampled data and provides an estimate uncertainty map associated with the model. During oil exploration and exploitation operations, the acquisition of direct or primary data, such as well data, is scarce due to the elevated costs, which makes the estimates of the numeric model and the characterization of the reservoir less realistic. Thus, to increase the accuracy of the final models, indirect or secondary data such as sampled seismic data are used, which results in a better pore pressure model.

In this study, we tested two multivariate geostatistical methods: locally varying mean kriging (LVM) and collocated cokriging, in order to estimate the distribution of geopressures in an exploration relevant marine basin at depth levels. These tests take into account pore pressure-related information derived from seismic velocity data. This integration results in a more consistent pore pressure model. Multivariate geostatistical techniques are promising tools for generation of high quality maps of pore pressure distribution and are fast, robust and easy to implement.

Methodology

Pore pressure gradients from five wells on the Equatorial Margin of Brazil were used as the primary variable. This dataset is a compilation of information from formation tests, mud weight, pore pressure estimations from drilling parameters, leak-off tests (LOT) and unexpected occurrences of kicks. The compressional wave interval velocity from a 3D cube is used as the secondary variable. This cube was estimated based on data from the 17 2D Pre-Stack Depth Migration (PSDM) seismic lines. In short, the generation of the geostatistical models presented in this study consists in four main stages: (1) Data preparation and QG; (2) Statistical exploratory analysis; (3) Variography and (4) Estimate model.

Results

At the first step, 1D pore pressure models gradients were performed at the studied wells using available pore pressure data. The existence of an overlaying carbonate layer deposited above the anomalously pressurized siliciclastic interval difficult the pore pressure trend estimation using well logs data. Thus, the pore pressure trend was built using drilling parameters and calibrated with well data pressure.

As a second step, the top of the abnormal pressure zone (APZ) and the stratigraphic interval of interest were defined. The study emphasized pore pressure anomalies and zones prone to operational risks. It is expected that, according to depth, elastic wave velocities in rocks increase and transit time decreases due to porosity reduction. However, if there are significant changes in the behavior of these variables, such as a decrease in velocity, as can be seen in Figure 1, where the wells with high-pressure show velocities lower than the wells with normal pressure, it possibly marks a geopressured zone occurrence (e.g., Sayers et al. 2006).

The resulting 3D pore pressure volume encompasses pore pressure information from wells as predicted variable as well as a pore pressure volume estimated from seismic interval velocity, as secondary information. These data were integrated using cokriging and LVM approaches, respecting variogram parameters and producing a high quality 3D pore pressure volume with reliable predicted pore pressure values at any location in the study area.

From the LVM (non-stationary) approach shows a more detailed estimative of the geopressured cube, while cokriging results leads to a smoother model due to the applied weights on the primary and secondary variables. Considering both values in the interpolation, the collocated cokriging conceals relevant information that is otherwise relevant with other estimation techniques. On the other hand, LVM estimative are an important tool in cases where little information is available and detailed information of any variable is necessary, honoring the values of the primary variable. In any case, these tools, in comparison with traditional methods of kriging, present considerable advantages and accuracy in their estimations due to the use of secondary variables, as can be seen in Figure 2.

Conclusions

In this paper, we present a case study of an area on the equatorial margin of Brazil. Pore pressure gradients from five wells were used as primary variable. This dataset is a compilation of information from formation tests, mud weight logs, pore pressure estimations from drilling parameters, leak-off tests and unexpected occurrences of kicks. As a secondary variable, a 3D cube of seismic interval velocity was used.

The exploratory analysis shows that the predictive and secondary variables are satisfactorily correlated, allowing us to perform LVM and collocated cokriging procedures. Comparing the resulting volumes, LVM estimates gives the most reliable interpolation, presenting more detailed and realistic maps with better resolution. In both cases, the resulting map showed high pressure throughout the interval of interest. This interval corresponds to a clayey section from the Upper Cretaceous with anomalous pore pressure fields.

This study demonstrated the feasibility of the application of multivariate geostatistical technique to establish a numerical 3D representation of a relevant and potentially hazardous exploration and exploitation variable (pore pressure distribution) using ordinarily available data for prediction and quantification purposes.

Reference Cited

Sayers, C.M., L.D. Den Boer, Z.R. Nagy, and P.J. Hooyman, 2006, Well-constrained seismic estimation of pore pressure with uncertainty: The Leading Edge, v. 25/12, p. 1524-1526.

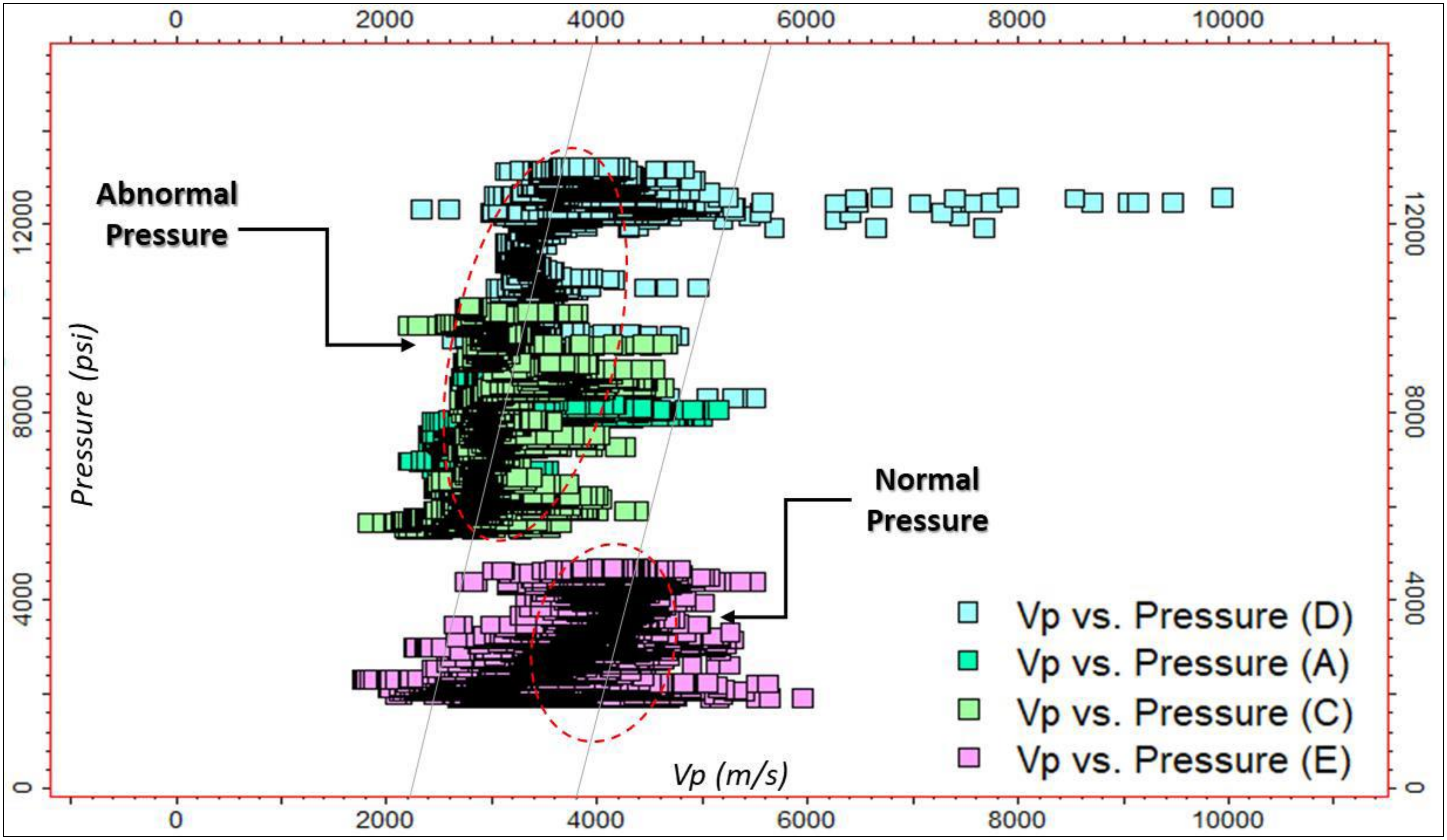

Figure 1. Scatter plot of Vp X pore pressure into the siliciclastic interval (interest interval).

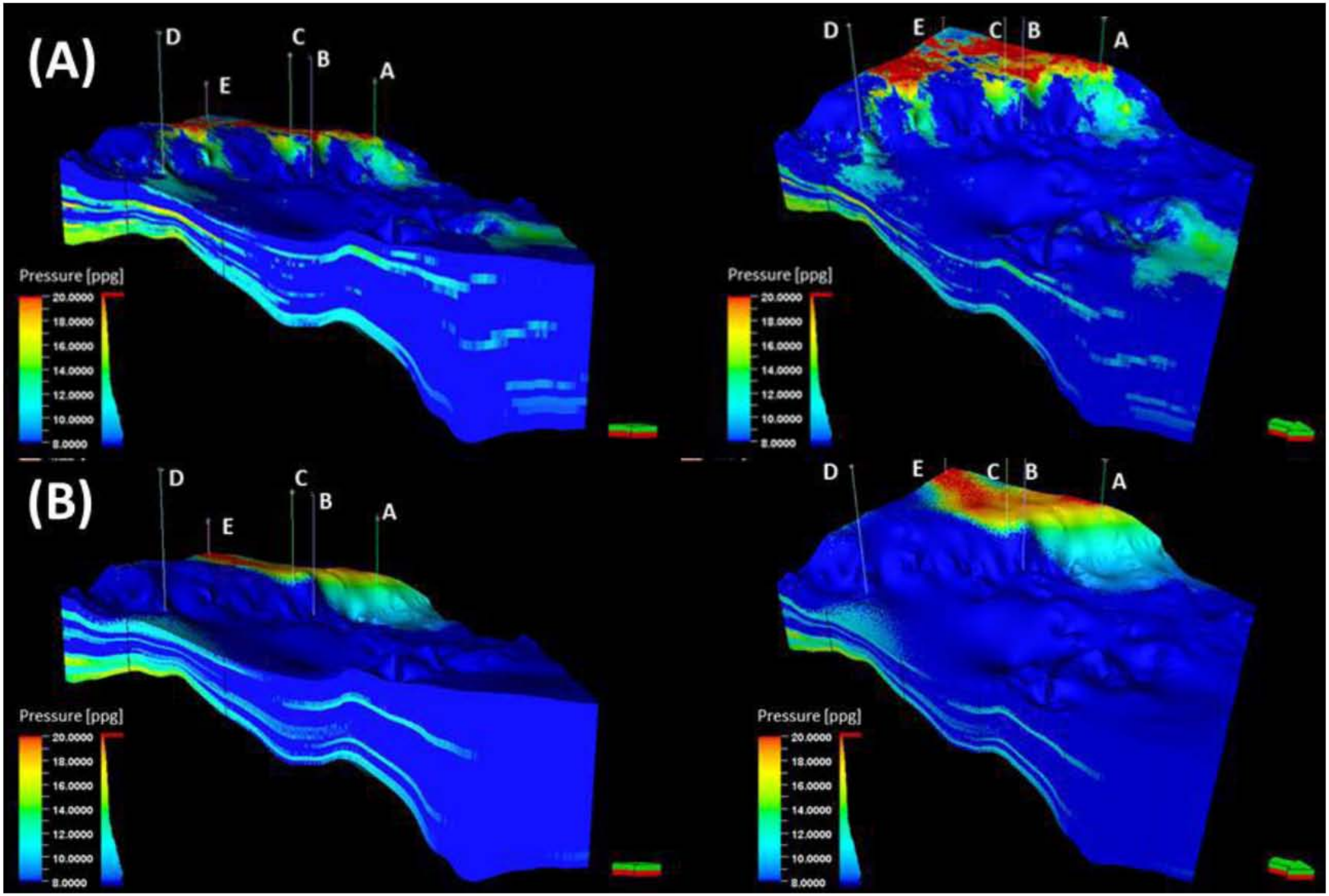

Figure 2. Equivalent mud weight estimated using (A) LVM techniques and (B) collocated cokriging.