Submission code: 96KK940P6G

See this and other abstracts on our website: https://home.sbgf.org.br/Pages/resumos.php

Geostatistical mapping of Devonian sucessions in the Parnaíba Basin based on well log interpretation

Jorge Sousa, Wagner Lupinacci (GIECAR), Vinicius Motta, Alexandre Cardoso, Gabriel Marins, Francisco Abrantes Junior (Universidade Federal Fluminense)

Geostatistical mapping of Devonian sucessions in the Parnaíba Basin based on well log interpretation

Please, do not insert author names in your submission PDF file

Abstract Summary.

The Devonian period, marked by marine transgressions and anoxic events, favored the deposition of organic-rich shales in epicontinental seas. In the Parnaíba Basin (NE Brazil), these conditions led to the accumulation of Pimenteiras shales and overlying Cabeças sandstones. This study analyzes their spatial distribution using well log data (GR, RHOZ, DTCO, SP, DRDN) and geostatistical kriging to interpolate formation thickness maps. Results show Pimenteiras thickening along a north-south axis and thinning at basin margins, while Cabeças is thicker in the east, thinning westward. These trends align with paleoenvironmental models of marine incursions from the west and sediment input from the east (Cabeças delta). The integration of well logs and geostatistics proves valuable for refining stratigraphic models in intracratonic basins.

Introduction

The Devonian Period, which occurred between approximately 419.2 and 358.9 million years ago, marked a time of significant transformation of the Earth's surface, characterized by global oceanic anoxia events accompanied by major marine transgressions and the formation of epicontinental seas during the Late Devonian (Carmichael et al., 2019). These events coincide with the deposition of organic matter (OM) -rich shales in ancient epicontinental seas worldwide (Uveges et al., 2019). In Brazil, Devonian shales are recorded in intracratonic basins, particularly in the Solimões Basin (Jandiatuba Formation; Wanderley Filho et al., 2007), the Amazon Basin (Barreirinha Formation; Cunha et al., 2007), the Parnaíba Basin (Pimenteiras Formation; Vaz et al., 2007), and the Paraná Basin (Ponta Grossa Formation; Milani et al., 2007). The Parnaíba Basin covers an area of approximately 600,000 km², reaching a maximum sedimentary thickness of 3,500 meters in its depocenter (Vaz et al. 2007). The basin extends across the Brazilian states of Piauí, Maranhão, Tocantins, Pará, Ceará, and Bahia in the northeastern region of the country. The Pimenteiras Formation comprises gray to black shales with minor intercalations of siltstones and fine-grained sandstones, which commonly exhibit hummocky cross-stratification (Vaz et al., 2007). Andrade et al. (2020) state that the Pimenteiras Formation was deposited from the Eifelian to the Frasnian ages and represents one of the most significant marine transgression events recorded in the Parnaíba Basin. The Cabeças Formation, which ranges from Eifelian to Famennian, consists of fine- to gravelly-grained sandstones exhibiting tangential and sigmoidal cross-stratification, with minor interbedded siltstone layers (Ponciano and Della Fávera, 2009). The upper portion of the formation comprises diamictites, striated surfaces, polished and striated clasts, and rhythmically laminated layers resembling varves (Caputo et al. 2005).

Method and/or Theory

The basis for analyzing the thickness of subsurface geological formations lies in the interpretation of well logs. Geophysical well logs are continuous records of the physical properties of rocks penetrated by a well, obtained using specific logging tools deployed into the well. To differentiate between shales (Pimenteiras Formation) and sandstones (Cabeças Formation), and to determine their respective thicknesses, the logs utilized was the gamma ray (GR) log, density (RHOZ), neutron (DTCO), spontaneous potential (SP) and DRDN. Only wells with the Cabeças and Pimenteiras Formations complete were considered. The thickness of each formation at each well is calculated by subtracting the depth of the top of the unit from the depth of its base. For example, the thickness of the Cabeças Formation at a given well is determined as follows:

Thickness_Cabeças = Depth_Base_Cabeças − Depth_Top_Cabeças.

The same approach is applied to the Pimenteiras Formation. These thickness values, combined with the geographic coordinates of each well, serve as input data for subsequent mapping and interpolation procedures. Once the thicknesses of the Pimenteiras and Cabeças Formations were determined for each well, a database was constructed by integrating publicly available well data provided by the ANP (National Petroleum Agency) with the interpreted log data. With the georeferenced thickness data for both formations at well locations, the kriging method was applied to estimate formation thicknesses at unsampled locations, resulting in a continuous surface representing the spatial variation in thickness across the study area. Kriging is a stochastic interpolation method that accounts for the spatial autocorrelation of the data, it assumes that the similarity between thickness values at two locations depends on the distance and direction separating them, a fundamental principle in geosciences (Yamamoto and Landim, 2013). The output of the kriging procedure is a spatial distribution model of the estimated thickness for the Pimenteiras Formation (represented using a green color palette) and the Cabeças Formation (represented using a yellow color palette).

Results and discussion

Based on the interpolation results, two maps were generated — one for each formation — highlighting the regions where outcrops of these formations occur, according to the SGB (Geological Survey of Brazil) database. In the easternmost portion of the map, where outcrops of the Serra Grande Group are expected, no data were represented, as, according to the stratigraphic framework, the Pimenteiras and Cabeças formations are no longer present in that region. In the interpolation map of the Pimenteiras Formation (Figure 1A), a greater thickness of shale layers is observed along a north-south axis. In both the western and eastern portions of the basin, the thickness of these shale layers tends to decrease — reaching values as low as 50 meters in the west and up to 100 meters in the east. In the interpolation map of the Cabeças Formation (Figure 1B), greater thicknesses are concentrated in the eastern part of the basin, with a progressive thinning toward the west.

In South America, Devonian deposits from shallow epicontinental seas influenced by wave action and transitional deltaic systems occur in the Pimenteiras Formation (Parnaíba, Pará-Maranhão, and Barreirinhas basins), the Barreirinha Formation (Amazon Basin), the Jandiatuba Formation (Solimões Basin), and the Ponta Grossa Formation (Paraná and Parecis basins). The deposition of Devonian black shales in the Parnaíba Basin is linked to global marine transgression events (Uveges et al., 2019).

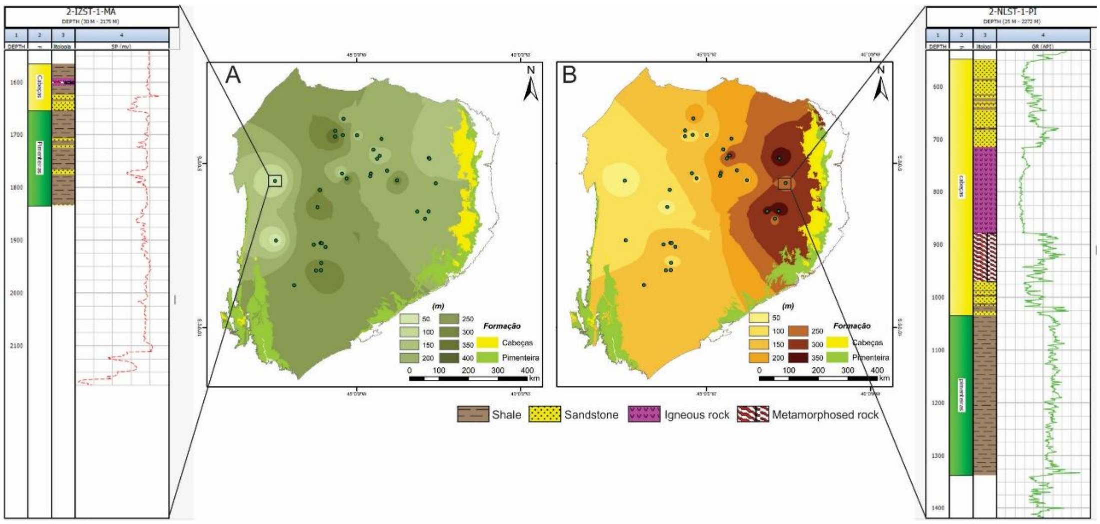

Figure 1: A) Interpolated map showing the spatial distribution of shale thickness in the Pimenteiras Formation; B) Interpolated map showing the spatial distribution of shale thickness in the Cabeças Formation.

During the Emsian, the Parnaíba Basin was located near the South Pole, but by the Famennian, it had shifted closer to it (Torsvik and Cocks, 2013; Trindade and Carvalho, 2018; Viccari et al., 2024). In the Emsian, marine incursions entered from the west, via the Solimões, Amazon, and Pará-Maranhão basins, reaching the Parnaíba Basin and partially flooding it, while also being strongly influenced by the Cabeças Formation delta (Figure 2C) (Torsvik and Cocks, 2013; Viccari et al., 2024). Later, during the Frasnian, a major marine transgression allowed seawater to enter the Parnaíba Basin from the west (through the Paraná and Parecis basins) and from the north (through the Solimões, Amazon, and Pará-Maranhão basins) (Figure 2D) (Torsvik and Cocks, 2013; Viccari et al., 2024).

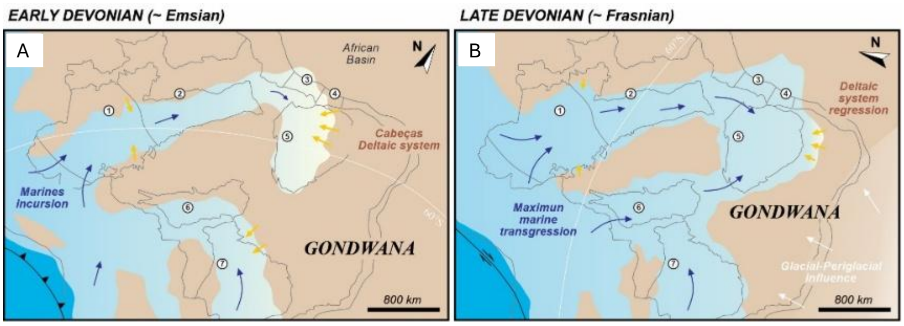

Figure 3: Paleogeografia do Gondwana durante o Devoniano Inferior-Médio. **Source** - Torsvik e Cocks (2013); Trindade e Carvalho (2018); e Viccari *et al.* (2024).

These major transgressive events, as well as the deltaic influence of the Cabeças Formation on the eastern margin of the basin, when compared with the interpolation maps, support the theories proposed by various authors regarding a marine incursion into Gondwana during the Devonian. This incursion flooded intracratonic sedimentary basins in present-day Brazil and supports the hypothesis that the source of the Cabeças Formation sandstones originated from the eastern part of the basin. The interpolation maps indicate areas where the shales are thicker, which suggests the depocenter of the basin has a north-south orientation. This observation may support the theory that the Parnaíba Basin was connected to the Paraná Basin and several offshore basins of the Brazilian Equatorial Margin (BEM) during the Devonian period.

Conclusions

The applied methodology proved to be consistent with the existing literature on the study area. The resulting map supports the proposed marine incursion model and suggests sediment input from the eastern margin of the Parnaíba Basin, playing a significant role in the sediment supply system of the basin. The integration of well log data with geostatistical methodology was important for the creation and reliability of the maps, which were supported by previous studies and literature on the Devonian paleoenvironment of the basin. Therefore, caution is advised when interpreting the interpolation maps. Supplementary data, such as bibliographic reviews and seismic analyses, should be incorporated to enhance the reliability of geological interpretations.

References

Andrade, C.L.N., Cardoso, T.R.M., Santos, R.R., Dino, R., Machado, A.J., 2020. Organic facies and palynology from the Middle to late Devonian of the Pimenteiras formation, Parnaíba Basin, Brazil. J. S. Am. Earth Sci. 99, 102481 https://doi.org/ 10.1016/j.jsames.2019.102481.

Caputo, M. V., R. Iannuzzi & V. M. M. Fonseca, 2005. Bacias sedimentares brasileiras: Bacia do Parnaíba. Phoenix (81): 1-6.

Carmichael, S.K., Waters, J.A., Konigshof, P., Suttner, T.J., Kido, E., 2019. Paleogeography and paleoenvironments of the late Devonian Kellwasser event: a review of its sedimentological and geochemical expression. Glob. Planet. Chang. 183 https://doi.org/10.1016/j.gloplacha.2019.102984.

Cunha, P. R., Gonçalves de Melo, J. H., da Silva, O. B., 2007. Bacia do Amazonas. Boletim de Geociências da PETROBRAS, 15, 227-251.

Milani, E. J., Rangel, H. D., Bueno, G. V., Stica, J. M., Winter, W. R., Caixeta, J. M., Neto, O. P., 2007. Bacias sedimentares brasileiras: cartas estratigráficas. Boletim de Geociencias da PETROBRAS, 15(2), 183-205.

Ponciano, L.C.M.O., Della Fávera J.C. 2009. Flood-dominated fluvio-deltaic system: a new depositional model for the Devonian Cabeças Formation, Parnaíba Basin, Piauí, Brazil. Anais da Academia Brasileira de Ciências, 81(4):769-780.

Torsvik, T. H., & Cocks, L. R. M. 2013. Gondwana from top to base in space and time. Gondwana Research, 24(3-4), 999-1030.

Trindade, V. S. F., de Araujo Carvalho, M., 2018. Paleoenvironment reconstruction of Parnaíba Basin (north, Brazil) using indicator species analysis (IndVal) of Devonian microphytoplankton. Marine Micropaleontology, 140, 69-80.

Uveges, B. T., Junium, C. K., Boyer, D. L., Cohen, P. A., Day, J. E., 2019. Biogeochemical controls on black shale deposition during the Frasnian-Famennian biotic crisis in the Illinois and Appalachian Basins, USA, inferred from stable isotopes of nitrogen and carbon. Palaeogeography, palaeoclimatology, palaeoecology, 531, 108787.

Vaz P.T., Rezende N.G.A.M., Filho J.R.W., Travassos W.A.S., 2007. Bacia do Parnaíba. Boletim de Geociências da Petrobras, Rio de Janeiro, Brazil, 15(2):253-263.

Viccari, J. M., Nascimento, S., Scomazzon, A. K., da Rosa, A. P., Mantilla, A. F. R., Dias, S. K. R., Souza, P.A., Lemos, V.B., Soffiatti, D.D.A & Caffroni, M. A. L. 2024. The record of marine ingression in western Gondwana from Devonian conodonts in the Amazonas and Solimões basins, Brazil. Marine Micropaleontology, 188, 102352.

Wanderley Filho, J. R., Eiras, J. F., & Vaz, P. T. (2007). Bacia do Solimões. Boletim de Geociências da PETROBRAS, 15(2), 217-225.

Yamamoto, J. K., & Landim, P. M. B. (2013). Geoestatística: Conceitos e Aplicações. Oficina de Textos.