Integrated Interpretation of Amplitude and Density Anomalies of Maracangalha Formation, Recôncavo Basin

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Abstract

Nowadays, the major exploratory challenges in Recôncavo Basin are the complex sandstone reservoirs of the Caruaçu Member that belong to Maracangalha Formation. The Maracangalha Formation, composed by Caruaçu and Pitanga Members, is formed by shales and low porosity sandstone bodies interpreted as complexes of mass flows. In this geological context, the recently drilled well P-8 aimed to test an opportunity where there was a strong correlation between seismic amplitude anomalies and density anomalies derived from gravity data.

The low quality of the seismic data in this area combined with the large lithological variability of the Caruaçu Member usually implies in amplitude anomaly maps showing disperse forms with reduced or even no geological meaning. However, the analysis of the seismic data allows the establishment of a correlation involving the anomalous seismic amplitudes and the thicknesses of the sandstones.

The analysis of the gravity data used to support seismic interpretation has applied several distinct procedures like basement estimate using non-linear inversion, stripping of the main geological unities, interpretation of the residual anomalies, and density estimate through linear inversion. With help from well and seismic data, the resulting anomalies were interpreted as density variations inside the sedimentary section. Thus, negative anomalies were assumed to be related to shale diapirs as well as to troughs filled with less dense sediments.

The seismic amplitude and density anomaly maps show great similarity in shape. The most remarkable feature in these maps is a large NE-SW channel located to the southeastern flank of the shale diapir. Such channel was the main target of the P-8 well, whose existence was confirmed by drilling. After the drilling of the P-8 well, it was possible to conclude that, when used as a lithological indicator, the use of an integrated interpretation of seismic amplitude and density anomalies may lead to the geological success of the prospect.

Introduction

In oil exploration, targets are usually delimitated by seismic interpretation because the seismic method provides higher resolving power than other geophysical methods. However, the complex geology of the mass flows of the Maracangalha Formation reduces the capability of seismic imaging (Fig. 1). Turbitides associated with slides, slumps and debris flows are practically invisible in seismic data. At the studied area only the main structures of the basin can be visualized. Internal variations on the major sequences caused by different lithologies are often not evaluated.

The difficulties found in the exploratory development of this section lie in the location of thick sand bodies of the Caruaçu Member as well as in their reservoir quality prediction. In classic exploratory models, the location of the larger sandstone thicknesses is conditioned by troughs usually located along the boundaries of shale diapirs, like in Massapê and Lamarão Fields, for instance. Some wells in the studied area show the presence of oil in the Caruaçu sandstones. Because only 15% of the sandstones combine the petrophysical characteristics necessary to be considered as reservoirs, the thickness of the sandstones is directly related to the chance of finding a commercial accumulation. Nowadays, there is only one producing oil/gas well, the P-7 well, among the 8 wells drilled in the study area (see Fig. 4 for location).

The lateral continuity of these sandstones is not evident in the seismic data due to the discontinuity of the reflections in the Caruaçu sequence. This problem can be minimized with the use of stratigraphic markers as auxiliary tools for seismic interpretation. However, no regional marker is available for Maracangalha Formation. We avoid this situation by using biostratigraphic units (biozones) to calibrate seismic interpretation. Such procedure has allowed us to locate these sandstones between biozones NRT004.3 / NRT 004.2. The average thickness of the NRT 004.3 Caruaçu sandstones is around 35 m.

In this paper we propose an approach that combines the high resolution of the seismic interpretation with a series of gravity procedures that includes 3D gravity inversion for basement relief constrained by both the seismic model and the available well log information; gravity stripping to remove the upper units, which are known and well defined by seismic; and 3D gravity inversion for density distribution to identify anomalous bodies. In addition to more reliable results and the consequent reduction of the exploration risk, we believe that the use of this multi-disciplinary approach promotes integration between different geophysical tools.

Method

The correlation between the seismic amplitude anomalies and the thickness of the Caruaçu sandstones is not always straightforward. For instance, well P-3 shows no amplitude anomaly even though it has drilled through a package of 40 m of sandstones (Fig. 2). In order to improve our knowledge about the area and to reduce exploratory risk we make use of some gravity techniques as a complement for seismic interpretation.

The goal of the 3D non-linear gravity inversion is to find a reliable model assumed to correctly represent the geometry of the basement. The inversion starts by discretizing the sedimentary section as a set of rectangular prisms of constant density, having the top at the surface, and whose height can be determined from the observed gravity data. The nonuniqueness of the inversion is minimized by incorporating *a priori* information, which in this case was composed by seismic data and wells. Seismic data is incorporated into the inversion as a reference model from which the solution must stay as close as possible.

Information from wells is introduced in two ways. First, the depth to basement is incorporated into the model where wells have reached the basement. In a second approach, the shallower depths that the basement can be placed are determined from the wells that although not reaching the basement, can provide information about where the basement is not present. The result of the 3D non-linear gravity inversion is an estimate of the basement that not only matches the observed gravity field, but also respects the existing available information, which makes it very robust.

Gravity data interpretation can produce new results based on the use of specific techniques that become available with the development of the exploration. This is the case of gravity stripping (Hammer, 1963); an interpretation technique specially designed for advanced exploration areas. The technique simplifies the interpretation of unknown features by calculating and subtracting the gravity effects of the known units whose structure and density become recognized in detail along the development. The remaining anomalies are then expected to indicate unknown density variations inside the sedimentary section. Assuming the remaining anomalies are the representation of unknown density variations inside the sedimentary section, it is possible to estimate such density distribution by using 3D linear gravity inversion.

The goal of linear gravity inversion is to recover the density distribution of a region from the observed data. The inversion is said linear because the data responds linearly to changes in the density distribution. Again, the procedure starts by discretizing the region of interest into a specific number of rectangular prisms of constant size, whose densities can be determined from the data. In this case, the nonuniqueness of the inversion is minimized by limiting the values the density can assume to a specific range obtained from the density logs of the wells.

Results

Although imaging the basement is a difficult task for seismic in Recôncavo Basin, in some restricted areas, the seismic interpreter is able to get a rough estimate of the basement. Fortunately, this study area is one of these regions and an existing basement map was provided to be used as a reference model for gravity inversion. The inversion was carried out to introduce modifications in the estimated seismic basement in order to fit the observed gravity data. So, by the end of inversion process, we end up with a more robust and reliable estimate for the basement.

In addition to the modified basement, the structural knowledge in the study area was composed by other two horizons: Marker L (ML) and the base of Maracangalha Fm. (bMF), which were also provided by seismic interpretation (Fig. 1). A 3D model was generated assuming that the geological framework of the area can be roughly represented by four units separated by the 3 provided horizons (Fig. 3). To complete the model, four average density values were estimate from the wells to represent the intervals between the top of the model and ML (2200 kg/m^3), ML and bMF (2300 kg/m^3), bMF and the basement (2400 kg/m^3), and between the basement and the base of the model (2700 kg/m^3). After the model was finished, gravity stripping was applied to compute and remove the effects of such known geology. Theoretically speaking, because the effect of the known constant density was removed, the resultant anomalies should represent lithologic related density anomalies inside the sedimentary sequence.

Linear inversion for density distribution was carried out over the residual anomalies after stripping. The result of the inversion is a density distribution where the different density values can be correlated with lithological changes in the analyzed region (Fig. 4). Several seismic amplitude maps were compared with this density anomalies and the one with highest correlation was selected.

In a try to generate a qualitative analysis, the seismic amplitude anomalies were classified into 5 categories, where category 1 represents the weaker anomaly while category 5 represents the stronger. Because the density of the sandstones are lower than the shales in the area (Fig. 5), the classification was inverted for the density distribution, with category 1 representing higher density values while category 5 represents lower values. The values in both category maps at the wells' locations were extracted and combined in a chart together with information about porosity and thickness of sandstones (Fig. 6).

Analysis of the correlation between the lithological parameters, the seismic amplitude anomalies and density anomalies shows a significant correlation between the sandstone thickness and the geophysical anomalies in this area. In order to emphasize the correlation we have introduced a new variable that is the combination of both geophysical anomalies. As expected, the correlation for this new variable is remarkable. Supported by such good correlation results between the geophysical anomalies and the sandstone thickness, the window used in the calculation of RMS amplitude map was adjusted producing a new map. The new map shows a geometrical form that seems to be a channel filled with sand (Fig. 7). The correlation between porosity and the geophysical anomalies was considered poor. Therefore, the proposed methodology, although capable of locating thick sandstones, is not able to address the quality of the reservoir.

Conclusions

We have developed and successfully tested a new methodology to locate expressive amount of sandstones in Caruaçu sequence, one of the members of the Maracangalha Formation, which is formed by shales and low porosity sandstones bodies interpreted as complexes of mass flows.

Because the correlation involving the anomalous seismic amplitude and the thickness of the sandstones is not straightforward, the proposed methodology incorporates gravity data to support and complement seismic interpretation. In this sense, density anomaly maps were produced and compared with the seismic anomaly maps. The comparison shows great similarity between anomaly shapes in both maps. The most remarkable feature, successfully tested by drilling, is a large NE-SW channel located to the southeastern flank of a shale diapir. The well found the larger thickness of sandstones among all the wells in the study area.

Qualitative analysis using lithological parameters from wells, seismic amplitude anomalies and density anomalies shows a good correlation between the sandstone thickness and the geophysical anomalies in this area. However, the methodology has fail in estimating the quality of the reservoir.

Despite geological and geophysical success, the lack of correlation for porosity has led to an economic failure, since well P-8 has found a thick but low-porosity sandstone. The prediction of the reservoir quality from the proposed methodology is still a subject that requires complex studies focusing in the development of more predictive geophysical models.

Acknowledgments

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Reference

Hammer S.,1963. Deep gravity interpretation by stripping. Geophysics, 28, 3, 369-378.

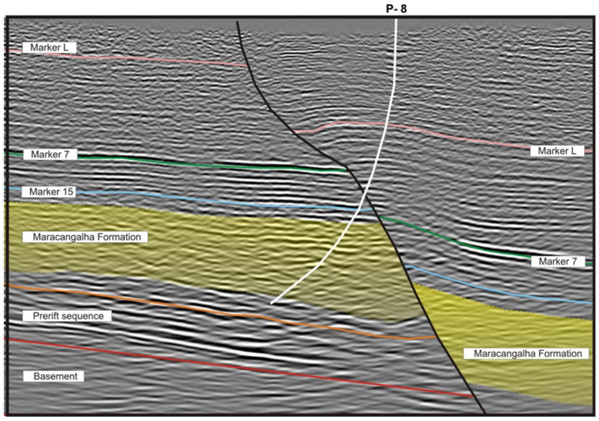

Fig. 1 – Seismic section crossing well P- 8 showing chaotic behavior of the reflections inside Maracangalha Formation. Major sequences were identified based on stratigraphic markers.

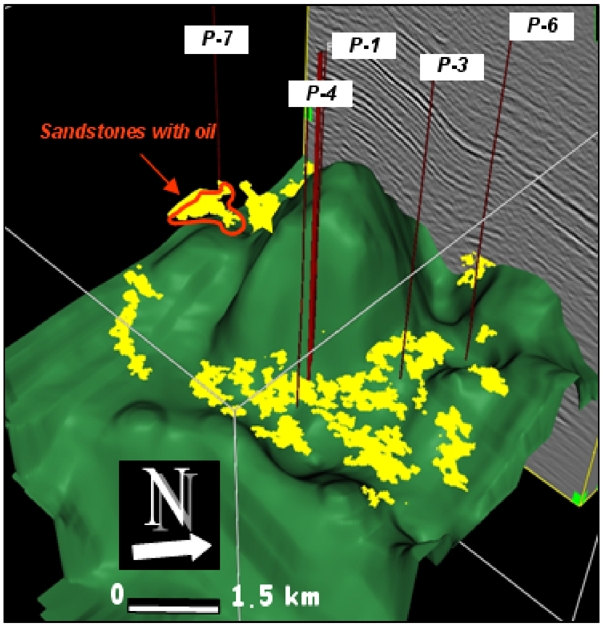

Fig. 2 – 3D visualization of the top of shale diapir (green) with superimposition of the amplitude anomalies (yellow) inside Maracangalha Formation.

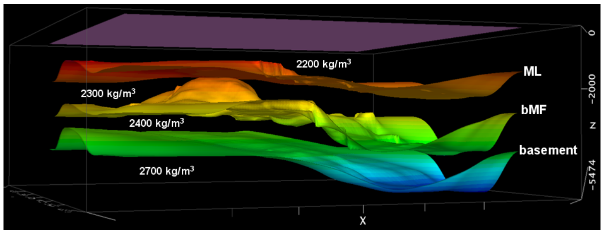

Fig. 3 – 3D model used for gravity stripping. The model is represented by four units separated by the 3 provided horizons: marker L (ML), base of Maracangalha Fm. (bMF) and basement). The selected density values are average densities computed from wells

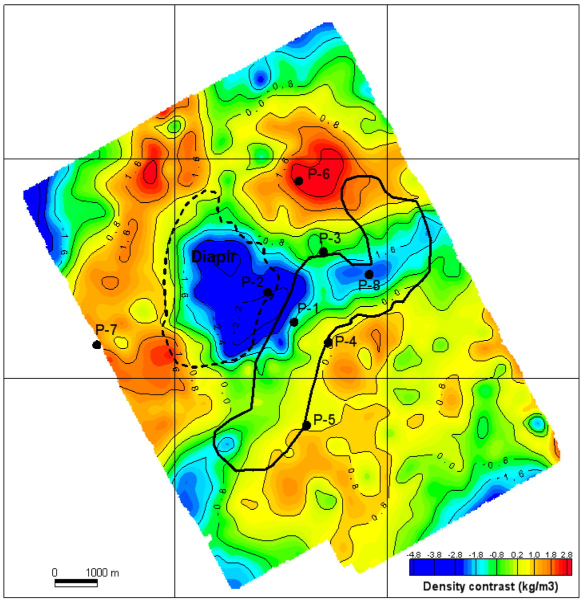

Fig. 4 – Density distribution at Caruaçu Member level after basement inversion and gravity stripping. The dashed line is the boundary of the shale diaper, while the continuous thick line is the limit of the seismic amplitude anomaly interpreted as a channel. Dots represent the wells from P-1 through P-7.

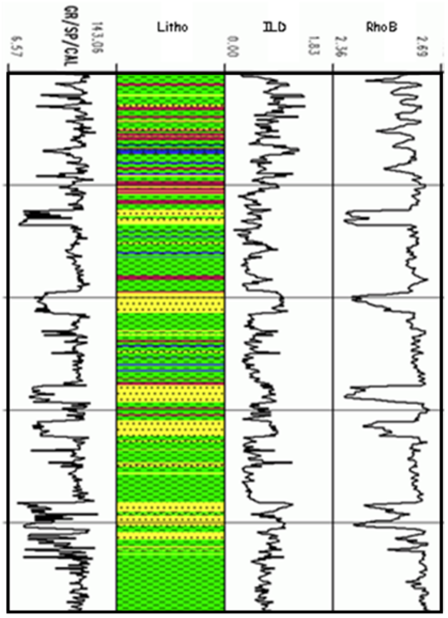

Fig. 5 – Well-log of P-7 at Caruaçu sequence. RhoB curve shows densities in shales greater than in sandstones.

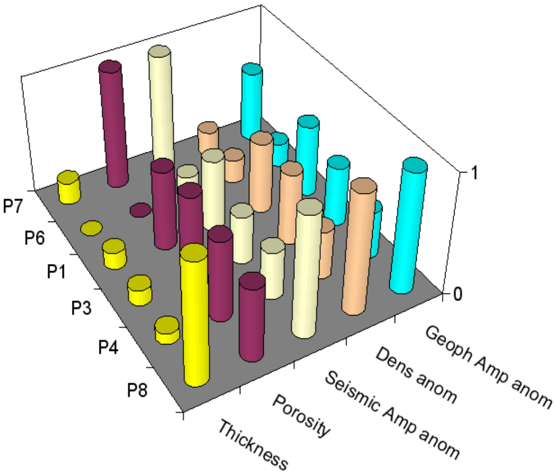

Fig. 6 – Plot of the correlation between lithological parameters and geophysical anomalies for each well. The overall correlation is good between the geophysical anomalies and the thickness of the sandstone, but poor for porosity. Values were normalized for comparison.

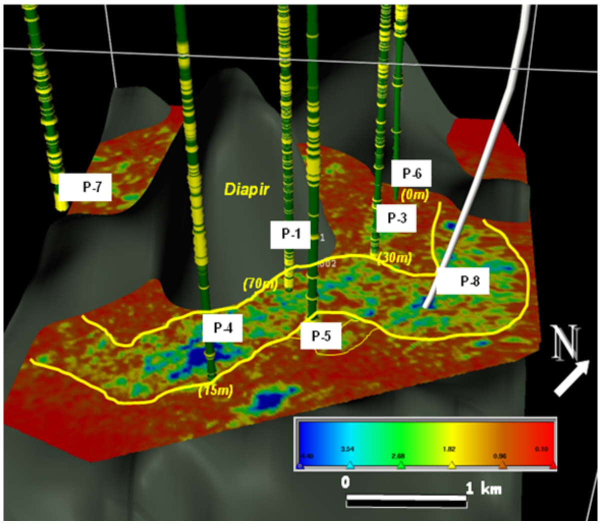

Fig. 7 – 3D view superposition of a channel delimited with seismic amplitude and density anomalies. The values written in yellow means the amount of sandstones at Caruaçu sequence.