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Using Seismic Attributes to Estimate Net Thickness in Pinch-Out Areas – Marlim Deep Water Turbidite Oilfield, Campos Basin

Rildo M. Oliveira, Nier M. da S. Ribeiro Júnior, Paulo R. Schroeder Johann (SPE), Luciano F.C. Júnior, Daniel E. Steagall, Paulo A. Kerber and Marimônica R. J. Carvalho Petrobras S.A.

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Abstract

The Marlim Field was discovered in 1985, about 100 km off the southeastern Brazilian coast, under water depths between 600 and 1,100 m. It is the largest producing oilfield in Brazil (average 500,000 bdp), containing an original oil-in-place volume of 6.4 billion STB and began to produce in 1991, through a pilot system. The field is exploited through 87 producing wells and 45 injectors connected to 7 production floatation units.

The Marlim reservoir is part of the lowstand systems tract of a third-order sratigraphic sequence, which is associated to an important eustatic, sea level fall of about 25 MMy. The turbidite lobes fill an intra-slope, wide depression developed by down slope gliding of underlying, Aptian evaporites. Reservoir facies comprise amalgamated graded beds of poorly consolidated, unstratified, medium to fine-grained sandstones with very low silt and clay contents. Porosities and permeabilities are relatively homogeneous. The Marlim turbidite system was subdivided into nine production zones, mostly on the basis of stratigraphic discontinuities recognized in well logs and cores.

The eastern margin of the field is fault-bounded with the rest of the field limits defined by sand pinch-out that determines the “zero line” of the reservoir. The pinch-out pattern of the sands depends on a series of geological factors, such as the topography of the substratum, the depositional system characteristics, and the intensity of erosive processes, among others. The way of modelling the pinch-out has an important influence in the oil volume since the pinch-out regions occur in a very extensive area of the Marlim Field. Also it has a significant impact in the success of location, navigation and productivity of horizontal wells positioned in the borders.

Considering that several projects of horizontal wells are expected to be drilled in pinch-out areas, the objective of this paper is to present the correlations between seismic attributes and reservoir properties used to improve the estimate of net thickness in pinch-out areas that are below the limit of seismic resolution.

Introduction

The initial development phase of Marlim Field has been recently concluded, where about 200 wells were drilled sucessfully, including 41 horizontal wells. The new phase of development is now in its early stages, involving more risk due to the fact of existing projects being infill-drilling wells with the risk of fast breakthrough or are wells located on the borders with the risk of productivity and navegation of horizontal wells because of the small net thickness. In order to minimize the risk of infill-drilling wells a new seismic acquisition with high resolution and 4D focus is being performed. For the wells on the borders, the correlations between seismic attributes and reservoir properties were analyzed to improve the estimation of net thickness in the pinch-out areas.

Principles of Seismic Attributes and Reservoir Properties Correlations

From seismic data we can infer realible geological information (Chambers and Yarus, 2002)[1], for example:

- Seismic velocity allows us to infer lithology, fluid content, abnormal pressure or temperature;
- Lateral amplitude changes permit the inferance of hydrocarbon locations, changes in porosity, lithology or thickness;
- Seismic trace morphologies or patterns allow us to infer depositional environments or faults and fractures;
- Changes in measurements direction permit the inferance of velocity anisotropy, or fracture orientation;
- Time-lapse measurements (4D seismic) allow us to infer the location of content movements in the reservoir.

This study analyses the correlations between seismic attributes (seismic amplitude anomaly of the reservoir top, average impedance and seismic composed amplitude anomaly equals the amplitude of the top less amplitude of the base) and reservoir properties at wells locations (isopach and net thickness). These properties have a great importance on the border areas considering that other properties, porosity for instance, are relatively homogeneous in the field.

A strong correlation was verified (Pearson correlation coefficient: "rho" = 0.96 in 144 well samples) between the time isopach (seismic data) and the reservoir isopach (in meters) verified in the drilled wells (Figure 1). This correlation is supported by solid physical means; in other words, thicker areas of the reservoir are directly related to longer travel times, since velocities remain reasonably consistent. As the Marlim reservoir is not so heterogeneous with a few shaly beds and cemented intervals (main heterogeneities) the Net to Gross (NTG) ratio is high with an average of around 0.85. This way the correlation between the reservoir isopach and net thickness at the wells with (rho) = 0.99 (Figure 2) are very good.

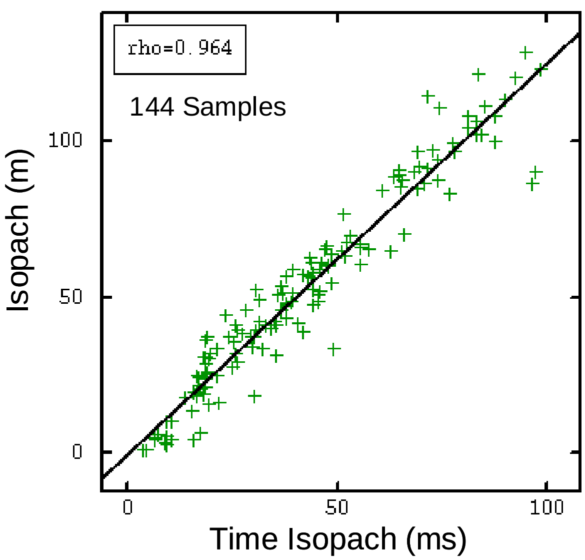

Figure 1 – Crossplot of time reservoir isopach versus isopach in meters from 144 samples.

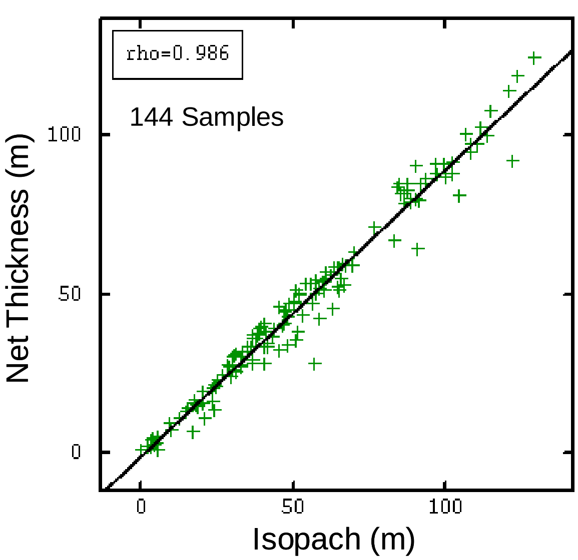

Figure 2 – Crossplot of reservoir Isopach versus net thickness.

Figure 3 shows the seismic amplitude anomaly map of the Marlim reservoir top and lateral variations are easily verified in the amplitude values. What are these changes due to? It is said that lateral variations of seismic amplitude anomaly could be due to fluid quality, changes in the porosity, lithology or thickness. In the Marlim Field significant changes aren't verified in the porosity values, facies and in types of fluids inside the reservoir. However, in the south portion of the field, there is a lighter oil and it is observed not only, in the seismic anomaly map but also, in the average impedance map of the Marlim reservoir (Figure 4). These values indicate better reservoir quality in the southern area. Further geological understanding of those variations needs more detailed studies.

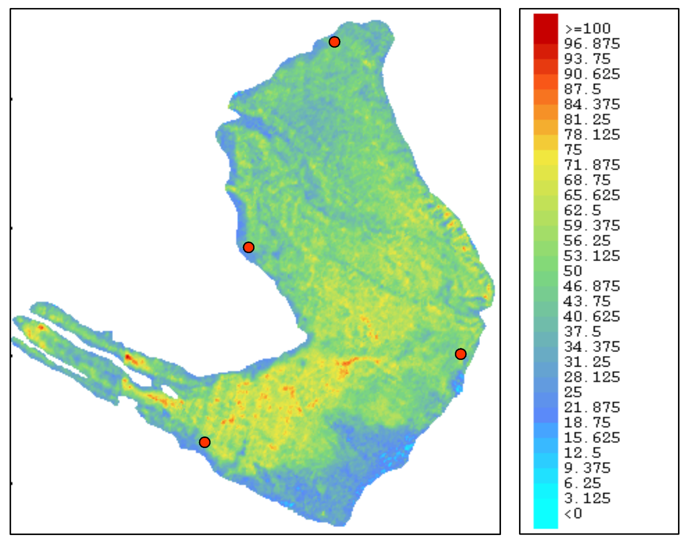

Figure 3 – Normalized seismic amplitude anomaly map of the Marlim reservoir top. Observe the best values in the south portion of the field.

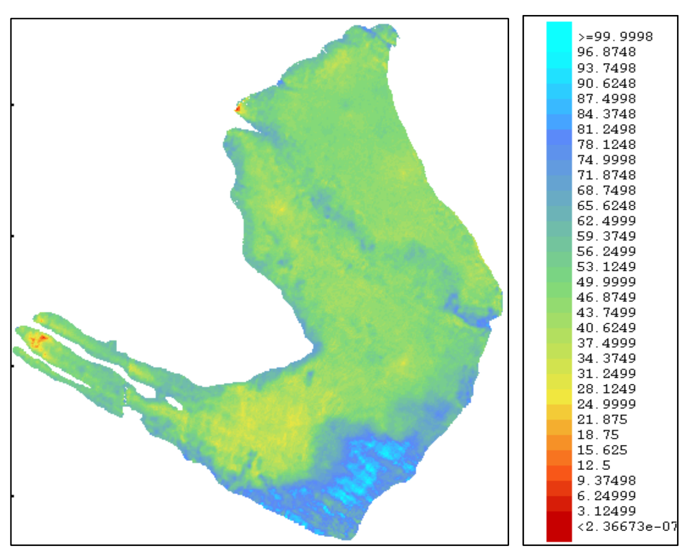

Figure 4 – Normalized average impedance map of Marlim reservoir. Observe the best values in the south portion of the field.

Figure 5 shows the plot of wells data between the seismic amplitude anomaly map of the reservoir top and the net thickness. The analysis of this plot allows us to conclude that a good coorelation is not observed, with a cloud of dispersed points. The seismic properties obtained in the wells were normalized and this normalization was done considering the maximum value of the property as a value of 100 (=100%) and the minimum of 0 (=0%). At the botton left corner of the plot a smaller dispersion of the amplitude values in smaller net thickness can be seen along with a lot of dispersion increases for intermediate thickness. In the center right of the plot the amplitudes tend to decrease in larger thickness. In this correlation the variable net thickness was used, but the variable isopach presents the same behavior, since these two variables present a very good correlation.

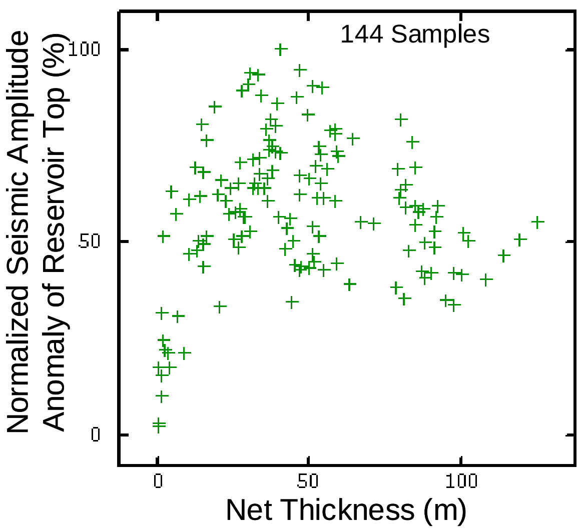

Figure 5 – Crossplot of net thickness versus normalized seismic amplitude anomaly of the reservoir top from Marlim wells.

Figure 6 represents a simulation of a wedge (pinch-out) built taking a layer with unitary coefficient reflection and reverse polarity in the top and base convoluted with a Ricker wavelet of dominant frequency of 25 Hz (Mundim *et. al*. 2004)[2].

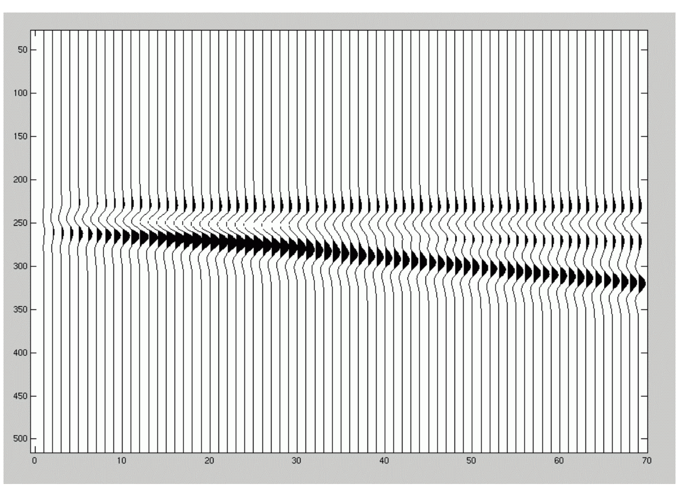

Figure 6 – Wedge (pinch-out) built to a layer. In this simulation the interval velocity inside the wedge is 2300 m/s and the maximum time isopach is 70 ms decreasing 1 ms to each trace.

In Figure 7 shows real thickness versus seismic amplitude anomaly of the reservoir top for the simulation done in Figure 6. For larger thickness there is no interference effect and the seismic amplitude is a function of the impedance contrast of the layers. While the thickness decreases the reflectors of the top and base come closer together there is an interference of the lateral lobes of the wavelet, causing an abnormal increase in amplitudes, that reaches a maximum value of $\lambda/4$ (λ = wavelength). From that point (tuning point) to the origin, the interferences have a destructive character and the thickness of the layer in seismic will be larger than the real thickness (Mundim *et. al*. 2004)[2]. Then, it can be said that below the tuning point, there is a relationship (almost linear) between reservoir thickness and seismic amplitude anomaly. The cloud of points in Figure 5 has similar behavior to the curve in Figure 7 or, in other words, it presents a linear relationship in the beginning, then reaching a maximum in an intermediate position, where the dispersion of points is high after stays almost constant in the end, where the dispersion decreases.

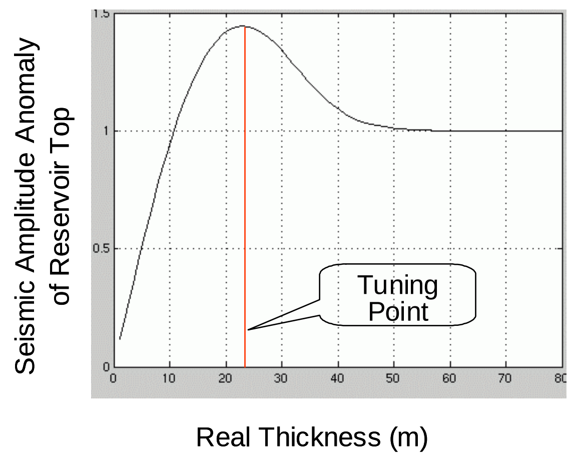

Figure 7 – Relationship between real thickness and seismic amplitude anomaly in a wedge (pinch-out) simulation.

In the Marlim Field the value of $\lambda/4$ is about 30 m, calculated using a velocity of 2600 m/s and a dominant frequency of 22 Hz. The interval velocity (P-wave) was calculated using the sonic log and the dominant frequency was estimated as being also the dominant frequency of the wavelet statistically extracted in a window of 300 ms around the reservoir level.

Figure 8 shows the points of time isopach versus normalized seismic amplitude of the Marlim reservoir. The analysis of this plot shows a similar behavior seen in the plot obtained from well data (Figure 5). Also the conditional expectation curve (black curve in Figure 8), that represents the curve of larger probability occurrence, is very similar to the curve obtained in the simulation of a pinch-out (Figure 7) with an almost linear behavior below the tuning point. It can also be observed that the dispersion around the conditional expectation curve is high in terms of seismic amplitude, even in the area below the tuning point. This can be one of the causes of the calculated errors in the estimates of net thickness from seismic properties.

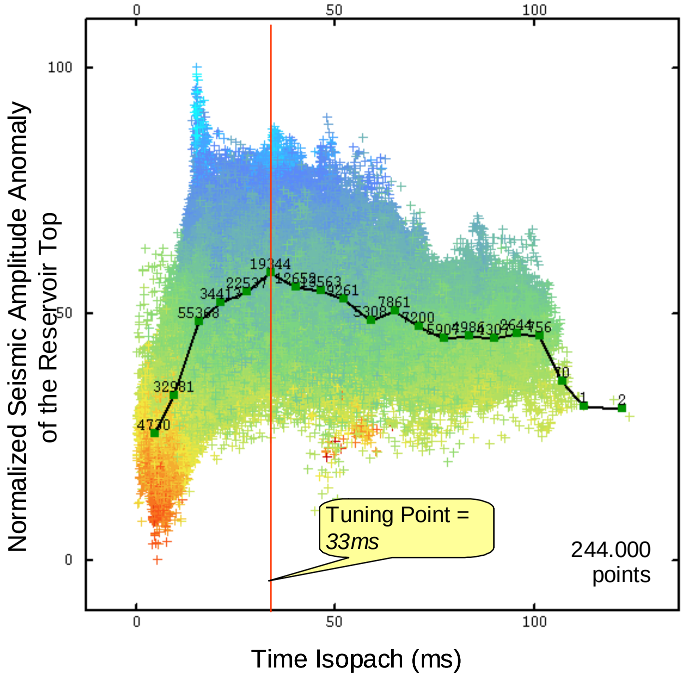

Figure 8 – Crossplot of time isopach versus normalized seismic amplitude anomaly of the reservoir top for all seismic data. Observe the conditional expectation curve (CEC) and the tuning point (maximum amplitude). Verify that the dispersion of the data around the CEC is high, even in the points below the tuning point. Colors of the points are related the scale of values of amplitude.

Figure 9 shows the maps of seismic time isopach and isopach in meters conditioned by well data. They are very similar, given the good correlation between these variables.

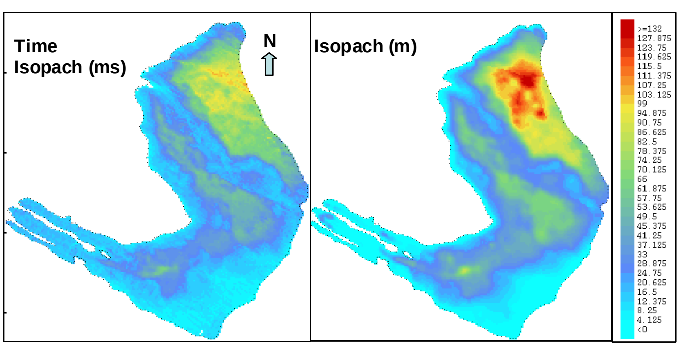

Figure 9 – Maps of time isopach and isopach in meters conditioned to well data.

The correlation between the seismic amplitude anomaly of the top and the net thickness for thickness less than 20 m, thickness below the tuning point were analysed. In the graph of Figure 10, considering only the points with thickness less than 20 m (points in green), a reasonable correlation is verified between these two variables. This correlation can be better seen in Figure 11 and it presents a correlation coefficient "rho" = 0.82. Three points were removed because of the different geological context of these wells located in RJS488 block.

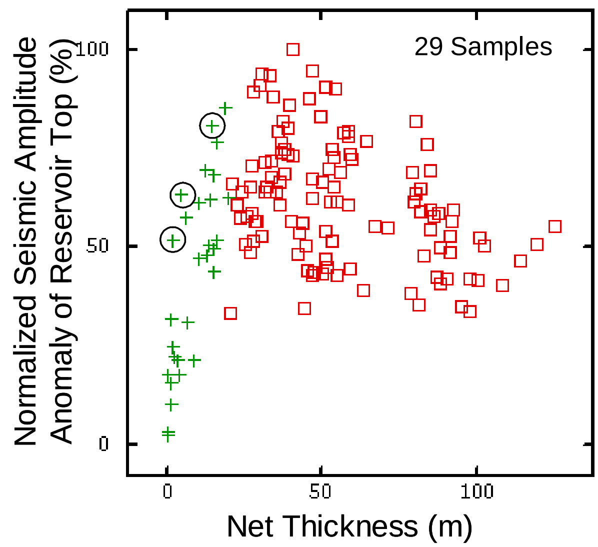

Figure 10 – Crossplot of net thickness versus normalized seismic amplitude anomaly of reservoir top. In red are the points with thickness greater than 20 m.

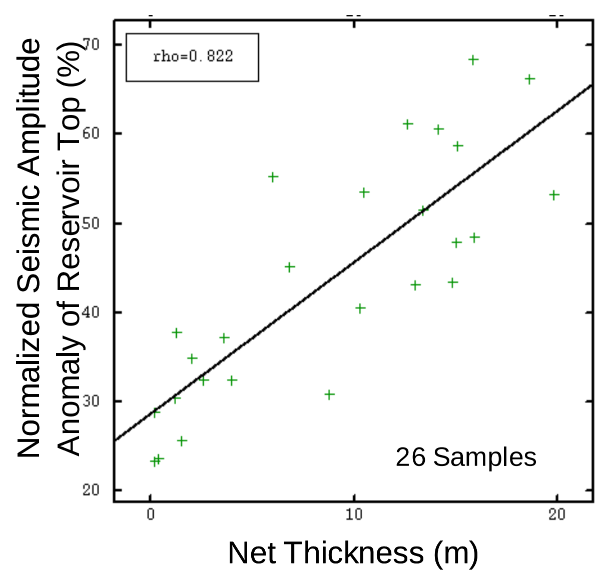

Figure 11 - Crossplot of net thickness versus normalized seismic amplitude anomaly of reservoir top for Marlim wells, removing the points with thickness greater than 20 m and three wells located in RJS488 block.

The physical meaning of the variables involved in the statistics correlations and the law results produced by those correlations are very important points to be observed and validate when applying this methodology. For instance, a high negative correlation between porosity and acoustic impedance has a physical meaning because the velocity has an inverse relationship with the porosity, in other words, when the velocity increases, the porosity typically decreases. Unfortunately a common practice exists of selecting attributes based only in the force of the statistical correlation observed in the measured properties at wells, but with little reflection given to the validity of the correlation, except that it seems good. In the case of the analyzed correlation there is physical relationship between the seismic amplitude anomaly and reservoir thickness for thickness below the tuning point. This correlation is not totally linear and according to the theoretical model the thickness obtained from the seismic data is smaller than the thickness verified at wells because the destructive character of the interferences. Romanelli Rosa (2001)[3] presents a methodology for correcting the thickness obtained from the anomaly of seismic amplitude maps in areas below the tuning point. In relation to impedance it is known that it is physically related to porosity, lithology and saturation. Therefore, the correlation of impedance with net thickness seems not to have a very good physical meaning but, on the other hand, in inversion process the average impedance reflects seismic amplitude anomaly greatly.

According Hirsche *et al*. (1998)[4] it is important to remember that correlation coefficient estimates have uncertainty associated with them and the smaller the sample size, the greater our uncertainty about the true correlation between the two variables. Unlike what happens in most of the fields where areas of low seismic amplitude anomaly and small thickness are typically not drilled, in Marlim there is a good sampling in these areas because the wells drilled in the Marlim south Field, whose reservoir occurs below the Marlim reservoir. Also in Marlim Field we have already drilled some wells located in pinch-out areas.

Figure 12 shows the correlation between net thickness and seismic composed anomaly of amplitude, computed by the difference between the top and base amplitude, for thickness less than 20 m. The correlation coefficient between these two variables is 0.89, a little better than the correlation of seismic amplitude anomaly of the top. Figure 13 shows the map of seismic composed amplitude anomaly.

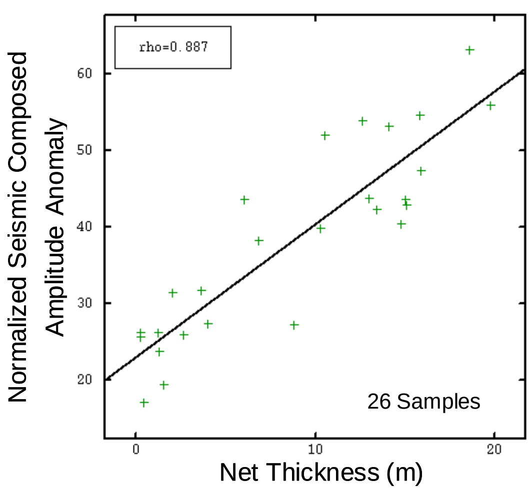

Figure 12 - Crossplot of net thickness versus normalized seismic composed amplitude anomaly for Marlim wells (top amplitude less base amplitude), removing the points with thickness greater than 20 m.

In the Figure 14 shows the crossplot of net thickness versus average impedance at wells for thickness less than 20 m. In spite of the absence of a clear physical sense in the relationship of those two variables we can see that the correlation is good, presenting a correlation coefficient "rho"= 0.87.

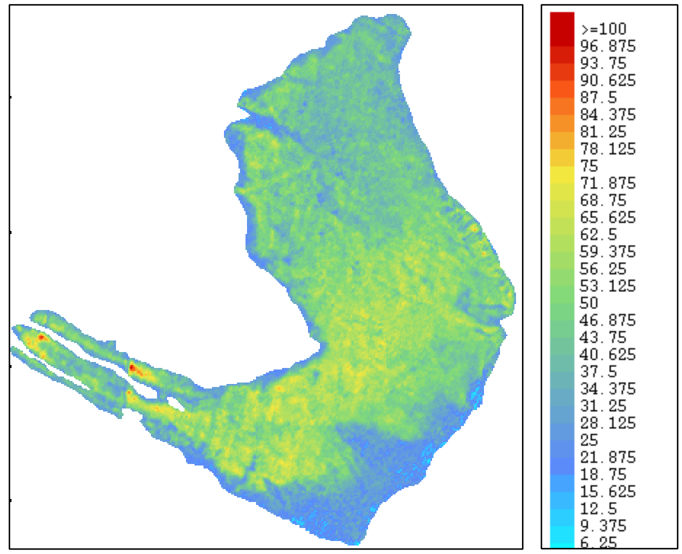

Figure 13 – Seismic composed amplitude anomaly map of Marlim reservoir. Observe the low values near the borders (blue).

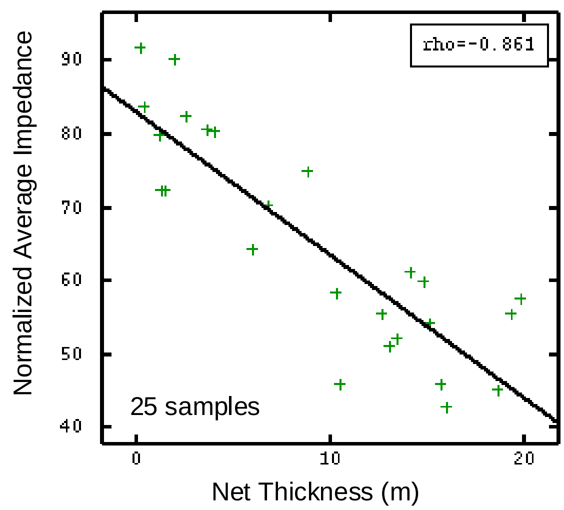

Figure 14 – Crossplot of net thickness versus normalized average impedance for Marlim wells, removing the points with thickness greater than 20 m.

To evaluate the uncertainty degree and obtain confidence in the correlations four wells drilled in the pinch-out region in different areas of the reservoir (see location in Figure 3) were removed from the data set. It was analyzed the net thickness forecast through lineal regression and net thickness verified in the wells. This data was summarized in Tables 1, 2 and 3.

Table 1 – Correlation between net thickness and normalized seismic amplitude anomaly of reservoir top.

			Thickness < 20 m - All the wells		Thickness < 20 m - Removing 4 wells	
Well	Top_Ampl	Verified Net Thickness (m)	Net Thick. from Regression (m)	Error (%)	Thickness from Regression (m)	Error (%)
A	53,46	10,5	13,1	25	12,6	20
B	68,25	15,8	19,3	22	18,6	18
C	47,78	15,0	10,7	29	10,3	31
D	48,29	15,9	11	31	10,5	34
			Average Error = 25		Average Error = 27	

Table 2 - Correlation between net thickness and seismic composed amplitude anomaly.

			Thickness < 20 m - All the wells		Thickness < 20 m - Removing 4 wells	
Well	Composed Amp	Verified Net Thickness (m)	Net Thick. from Regression (m)	Error (%)	Thickness from Regression (m)	Error (%)
A	51,77	10,5	15,2	45	14,9	42
B	54,44	15,8	16,5	4	16,1	2
C	43,38	15	11,3	25	11,0	26
D	47,25	15,9	13,1	18	12,8	19
			Average Error = 22		Average Error = 23	

Table 3 - Correlation between net thickness and seismic impedance.

			Thickness < 20 m - All the wells		Thickness < 20 m - Removing 4 wells	
Well	Impedance	Verified Net Thickness (m)	Net Thick. from Regression (m)	Error (%)	Thickness from Regression (m)	Error (%)
A	45,66	10,5	16,3	55	17,5	66
B	55,47	15,8	12,6	20	13,4	15
C	42,61	15	17,4	16	18,7	25
D	45,79	15,9	16,2	2	17,4	9
			Average Error = 23		Average Error = 29	

The analysis of the tables show that the average error between the forecast and verified net thickness in these four wells is about 23%. Also the equation obtained from correlation using all wells or removing four wells changes only a little (compare the columns of error in each table). The seismic impedance shows the largest error. Also it can be observed that the seismic composed anomaly of amplitude presented less error in the estimates as a consequence of the best correlation coefficient obtained. It is also verified that well A presented the largest error in the estimates using the variables that presented better correlation (seismic composed amplitude anomaly and impedance). Maybe this well is not very adjusted in the seismic data but this statement needs to be proven.

Perspectives

A new seismic data of reprocessing and new acquisition with new technology Q-marine will be obtained very shortly in the Marlim Field. This study will serve as a reference for other studies in order to quantify how much this reprocessing and new acquisition data will aid in the geological modelling and, consequently, in the drainage of the field. Besides, with the new data the seismic inversions will supply new impedance volumes (layer properties) which potentially should reduce the average errors quantified in this study.

Conclusions

Considering thickness below the tuning point, the analysis of the seismic and reservoir properties of the Marlim Field showed reasonable correlation between net thickness and seismic amplitude anomaly of the reservoir top and good correlation for seismic composed amplitude anomaly and average impedance. The seismic composed amplitude anomaly presented a better Pearson correlation coefficient, followed by the impedance. In the evaluation of the uncertainty degree of using seismic attribute correlations was verified that the obtained equation of the correlation using all the wells changed only a little compared to that obtained when four wells were removed in different pinch-out areas. The seismic impedance shows the largest error

Acknowledgments

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