ATUM Field: 4D QUALIFICATION OF 2 SEISMIC VINTAGES USING GEOSTATISTICS

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Abstract

Summary

4D spatial diagnostic and geostatistical filtering (factorial kriging) were applied to the 1987 and 2003 seismic vintages acquired on the PETROBRAS RN Atum field. The goal was to evaluate the suitability of these seismic data to highlight 4D production effects. A spatial analysis (controlled by frequency power spectrum) and factorial kriging were used to quantify and suppress the noises and acquisition artefacts in both data sets in order to improve the 4D repeatability. After spatial filtering, the measured coherency (both vertically and spatially) between the two cubes was largely improved but major amplitudes differences still remained due to the different acquisition parameters: streamer in 1987 and ocean bottom cable conventional in 2003. Consequently, the data were not qualified as such for a further 4D study: Instead, dedicated spatial filters controlled by geophysical frequency spectrum were derived to enable comparison and further amplitude equalization of the data sets. The filtered results are currently being used to increase the confidence level on structural interpretation of both seismic data sets.

Introduction

The 1987 and 2003 3D seismic surveys were recorded on the Petrobras ATUM oil (Rio Grande do Norte Brasil) using two different acquisition techniques (streamer 1987 and Ocean Bottom Cable 2003) as shown in **Figure 1**. The issue was then raised of reproducing the same structural interpretation on both seismic vintages and further continue a 4D study on the Atum field.

The Atum field is located in a shallow offshore environment and the seismic acquisition and processing are difficult. They result in noisy data with a large number of artefacts such as multiples occurring on both data sets. The reservoir interpretation of this heavily faulted field is also complicated by these acquisition and processing artefacts.

It was clear from the start of the work that the data quality was far from the well-established requirements for ensuring 4D repeatability. It was then decided to apply spatial filtering techniques to complement the geophysical processing and possible contribute to a more confident structural interpretation. Geostatistics provide suitable tools to perform a robust time-lapse coherency analysis: The initial spatial characterization part of the seismic data is called the 4D diagnostic step and it addresses the question: “Are the seismic data suitable for a 4D study?” The answer is negative when evidence of non-repeatability is exhibited. In that case, recommendations are issued to better equalize the amplitude data using dedicated spatial filters, in order to facilitate their structural and reservoir interpretation.

4D spatial diagnostic

The statistical and geostatistical tools used for the diagnostic on both surveys enable to compare the 2 seismic vintages.
The raw Atum 1987 and 2003 seismic cubes are scrutinized inside successive time windows and the results are summarized below for the 1600ms to 2300ms reservoir time window:

- **Figure 1**: The amplitudes are not equally recorded: there is a 1 to 4 ratio between the 1987 (3 mean 1104 std dev) and 2003 (7 mean 4015) amplitude values. The coefficient correlation is 0.27, preventing from any straightforward statistical comparison.
- **Figure 2**: The interpretation of the standardized time axis variograms (average auto correlation) is guided by the analysis of the frequency power spectrum: three dominant frequencies / periods (half periods are read from the variograms) show up that they are almost identical
    - High Frequency peak: T1 = 1987: 28 ms (36Hz) / 2003: 24 ms (40Hz)
    - Medium Frequency peak: T2 = 1987: 44ms 24Hz / 2003: 40ms (24Hz)
    - Low Frequency peak: T3 =1987: 100ms 10Hz / 2003: 80 ms (12Hz)
- The interpretation of horizontal directions of the variograms enable to associate apparent horizontal ranges (apparent because of the dip effect) to the time axis ranges:
    - High Frequency: 150 m apparent range
    - Medium Frequency: 300 m apparent range
    - Low Frequency: 750 m apparent range
- **Figure 3**: The frequency distribution is not the same between the two surveys:
    - The high 40 Hz frequency accounts respectively for 20% of the 1987 and 2003 total variability
    - The medium 24 Hz frequency accounts respectively for 35 % and 45 % of the 1987 and 2003 total variability
    - The low 10 Hz frequency accounts for 45 % and 35 % of the 1987 and 2003 total variability

The geophysical interpretation of these spatial ranges is not fully clear at this time:

- The high frequency is thought to be largely polluted by noise
- The medium frequency could be related to stratigraphical patterns
- The low frequency is being related to structural patterns

The conclusion of the 4D diagnostic is clear and based upon quantified evidence:

- Major differences in geophysical acquisition and processing processes between the 1987 and 2003 surveys do not allow for a direct input of the resulting amplitude cubes in a 4D study.
- Nevertheless, the same spatial patterns are identified on both surveys, in the spatial (variogram ranges) and frequency (power spectrum peaks) domains.
- The recommendation is to extract each of the 3 spatial ranges from the amplitudes cubes (spatial filtering) and to compare the two surveys at the similar resulting spatial scales.

Spatial decomposition of the 1987 and 2003 amplitude cubes using factorial kriging

The implemented geostatistical processing consists in separating each of the three identified spatial ranges by factorial kriging technique [Implemented by ERM.S SeisQuaRe]. This is done thanks to the variogram decomposition of the 3D seismic data into the three components corresponding to the interpretation of the variogram and power spectrum during the 4D diagnostic step.
1987: Variogram interpretation:
HF: 150m IL x 150m XL x 14mstwt half-period
MF: 300m IL x 300m XL x 22mstwt half-period
LF: 750m IL x 1450m XL x 50ms half-period
2003: Variogram interpretation:
HF: 150m IL x 260m XL x 12mstwt half-period
MF: 290m IL x 480m XL x 20mstwt half-period
LF: 750m IL x 1450m XL x 40ms half-period

Each 1987 and 2003 data-set is then filtered independently leading to 3 high mid and low frequency cubes (HF MF and LF). The result of this spatial decomposition is illustrated in **Figure 4** (1987) and Figure **5** (2003) on the same Inline 369 section.
Please note that such a spatial filtering (3D co-kriging estimation from the raw amplitude data of the HF, MF and LF spatial factors identified by their variogram component), is basically different from any geophysical filter applied in the frequency domain as it takes into account the 3D spatial consistency of the factor to be kriged. The power spectrum computed on the results of the spatial decomposition illustrate this major difference with the frequency filters as shown in **Figure 6.**

Contribution to the structural interpretation of the ATUM reservoir

The 4D spatial diagnostic highlighted that the large amount of spatial high frequency that could be related to processing noise didn't allow for a straightforward analysis of the difference between the two seismic cubes. Major time shifts between analogous traces were also recorded that made it hopeless to easily reproduce the available 1987 structural time interpretation on the 2003 vintage.
Thanks to the spatial decomposition, it appears that the filtering of the high spatial frequency removes a large part of the identified noise. When looking at the low frequency cubes that are interpreted as being related to reservoir structural position, it becomes much easier to see the consistency between the two acquisitions. **Figure 7** (left) displays the 1987 interpretation of 3 reservoir horizons on the raw and low frequency IL 370 sections (1987 and 2003). On the same figure (right) the 1987 interpretation is reproduced on the same IL 370 from the 2003 survey. No doubt it will greatly facilitate the interpretation of the 2003 cube.

Conclusions

This ATUM case study illustrates the benefit of using spatial processing when attempting to use differently acquired seismic vintages for 4D reservoir interpretation. A streamer and an ocean bottom cable acquisition have been compared in term of spatial frequency content. Although it is very hard to correlate the raw data for reservoir interpretation, the spatial decomposition of the amplitude controlled by a frequency analysis and the extraction of similar low spatial frequency on both cubes greatly improves the interpretation environment.
The current limitation of the decomposition technique lies in the interpretation and modeling of the horizontal variograms that are largely affected by the structural dipping. These limitations should be soon overcome and major operational filtering improvements are expected in the near future.

References

(1) Sandjivy L. – 1987 – Analyse krigeante des données de prospection géochimique – PhD Thesis Centre de Géostatistique de Fontainebleau.

(2) F. Jugla, M. Rapin, S. Legeron, C. Magneron' L. Livingstone – 2004 - Improving seismic repeatability using factorial kriging - EAGE PARIS 2004

Acknowledgments

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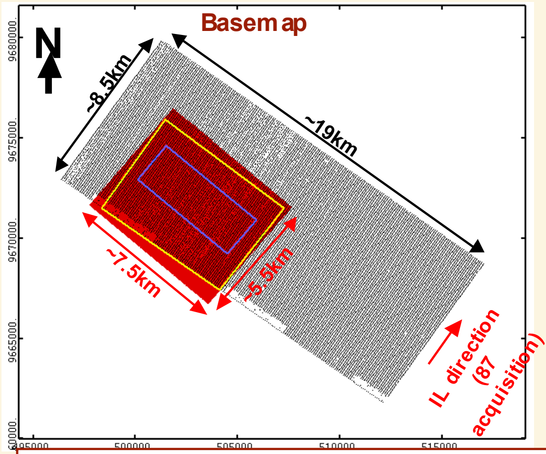
ATUM Field : Basemap and statistics of 1987 and 2003 surveys



In black : 1987 streamer acquisition
In red : 2003 OBC acquisition
In blue : target limits
In yellow : studied area

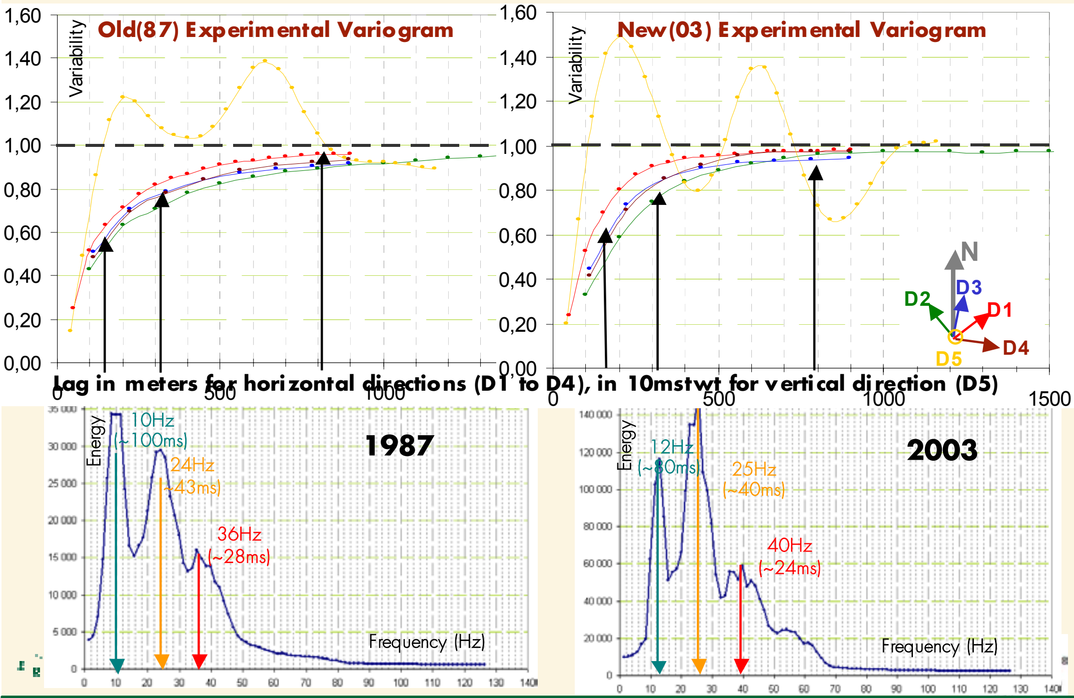
	1987	2003
Number of samples	1 259 652	1 381 189
Minimum	-7466	-29464
Maximum	8075	28332
Mean	-3	-7
Mean (absolute values)	839	3140
Standard Deviation	1105	4015

1987/2003

Correlation Coefficient **0,27**

SeisQuaRe® – April 2005 – **SBGf Salvador** 4D qualification of 2 seismic vintages on the ATUM field **FIGURE 1**

Standardized variograms and Power spectrum



SeisQuaRe® – April 2005 – **SBGf Salvador** 4D qualification of 2 seismic vintages on the ATUM field **FIGURE 2**

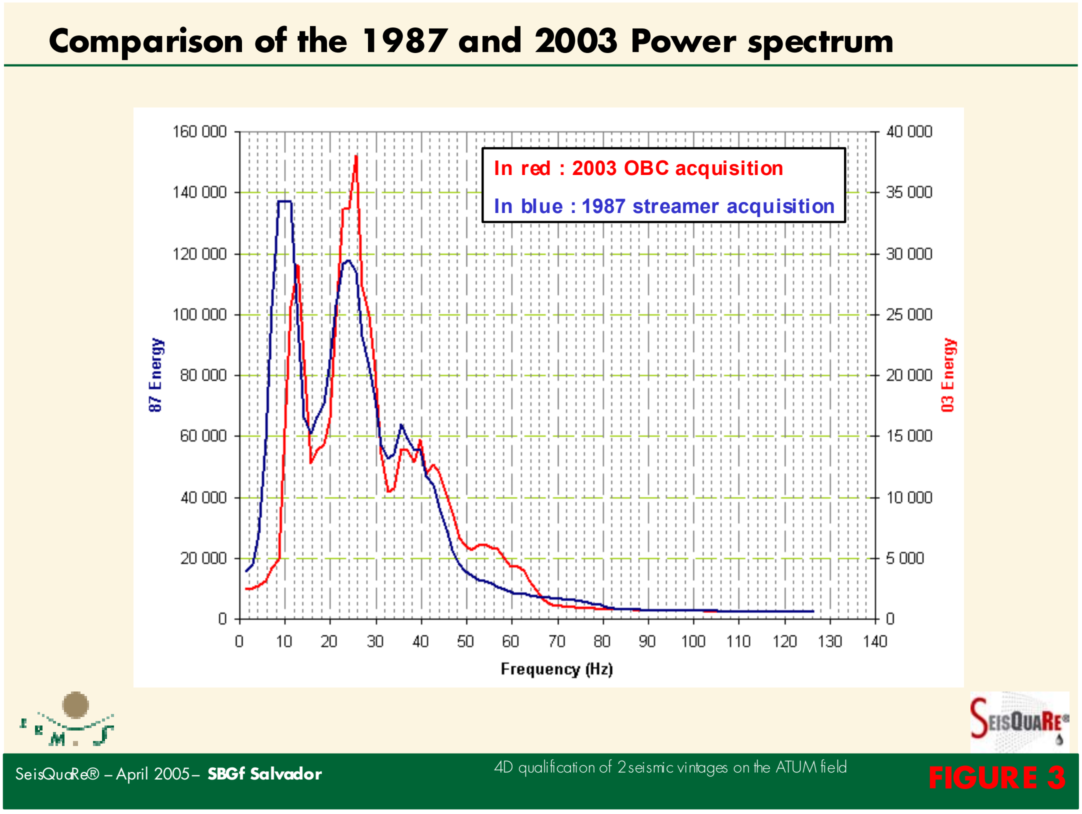


FIGURE 3

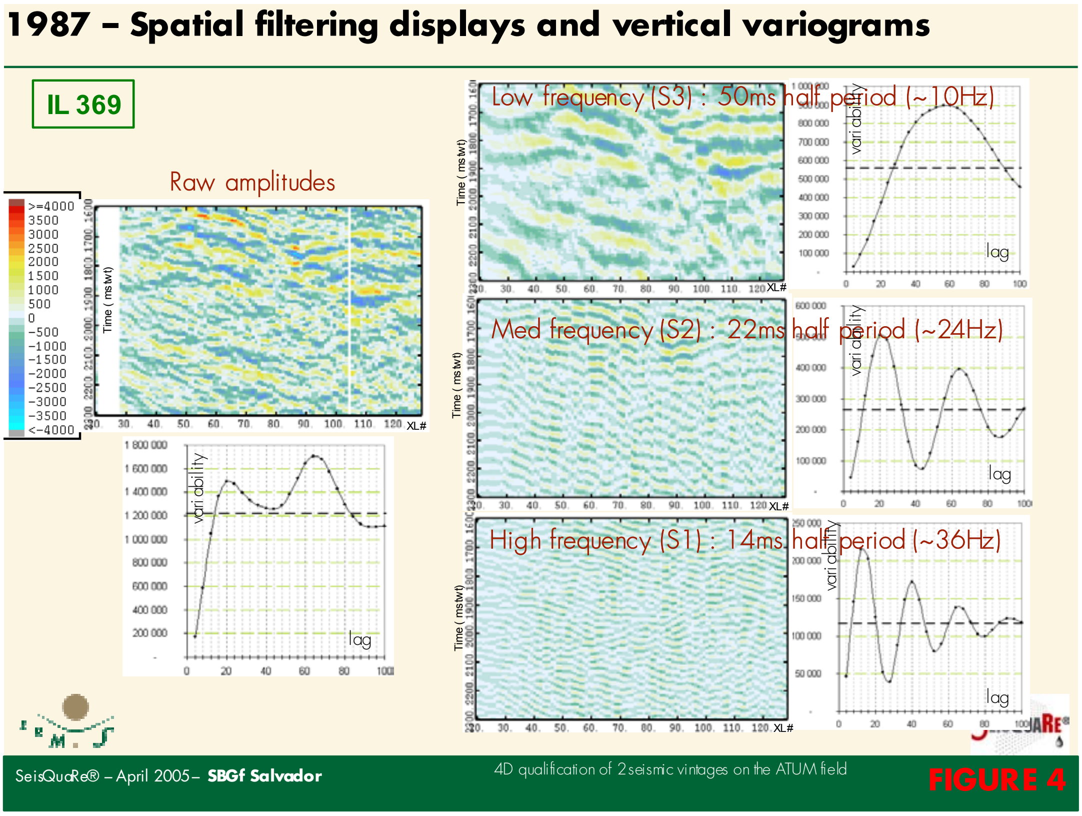


FIGURE 4

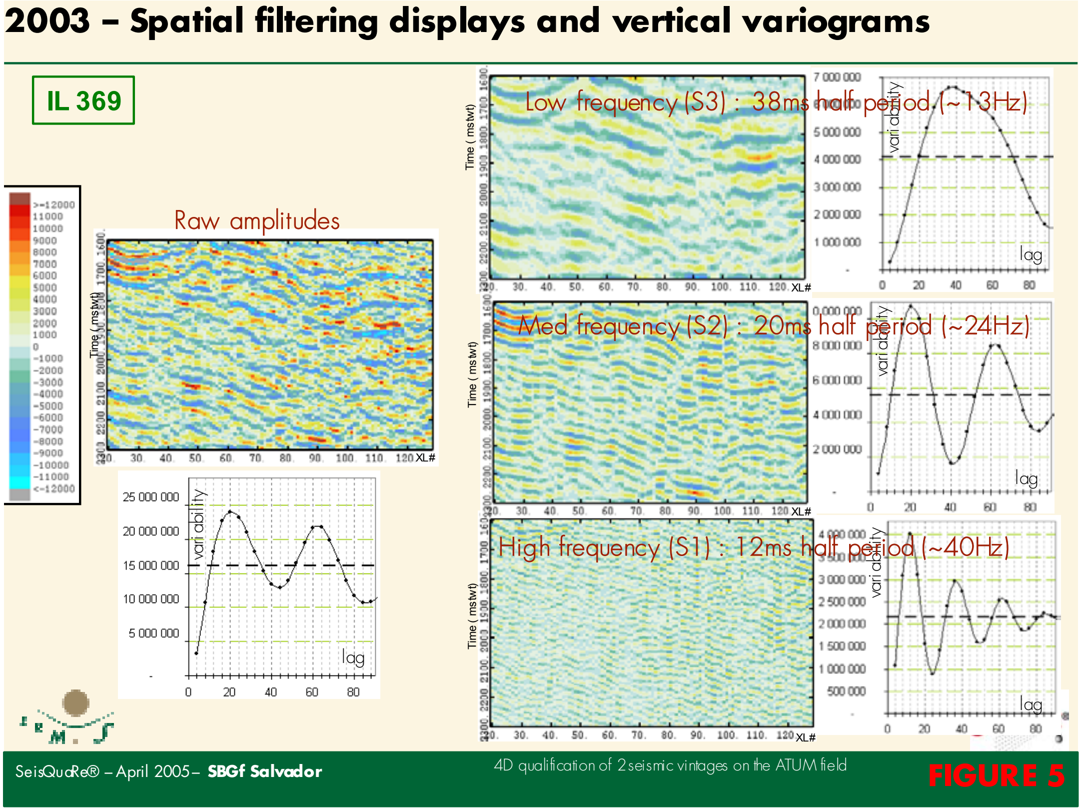


FIGURE 5

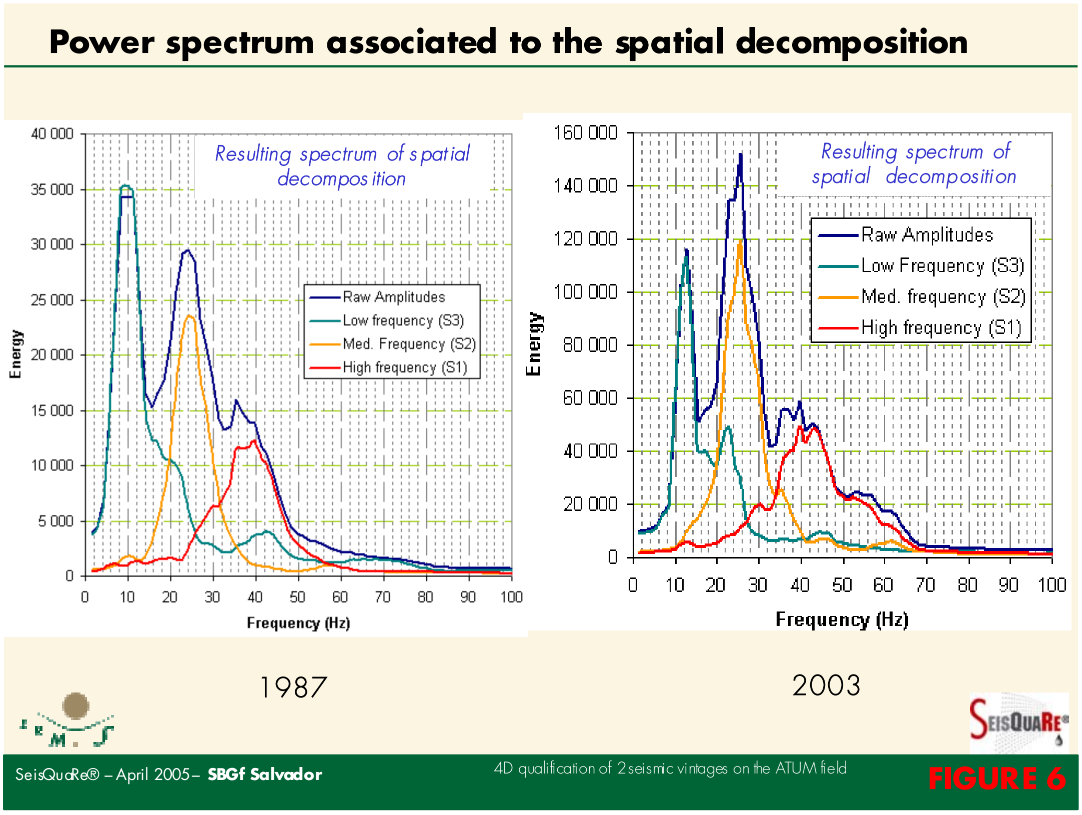


FIGURE 6

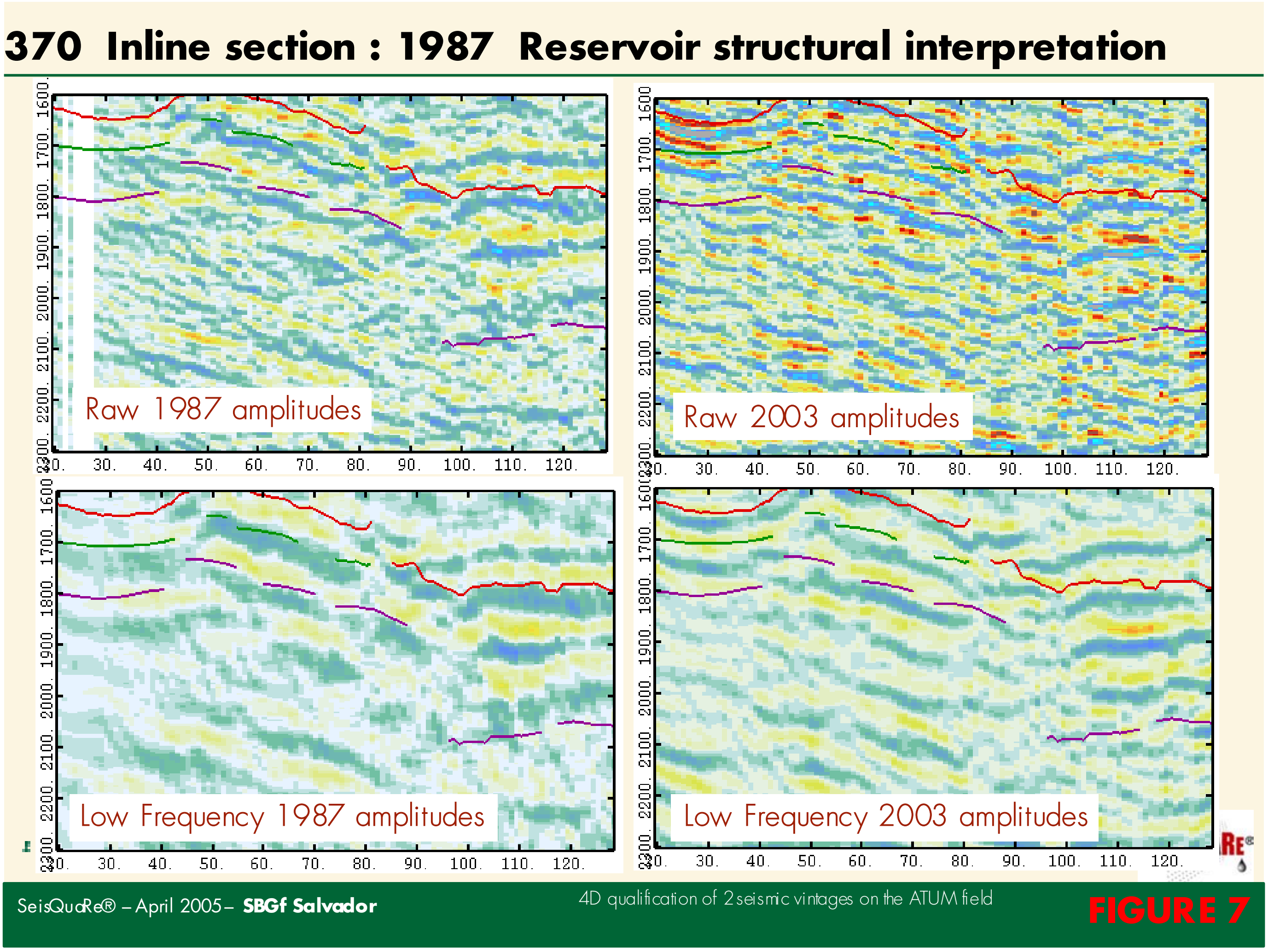

370 Inline section : 1987 Reservoir structural interpretation
Raw 1987 amplitudes
Raw 2003 amplitudes
Low Frequency 1987 amplitudes
Low Frequency 2003 amplitudes
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FIGURE 7