Geophysical Anomaly: A Novel Contribution to Integrated Geophysical Interpretation*

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Search and Discovery Article #42337 (2018)**
Posted December 31, 2018

*Adapted from oral presentation given at 2018 International Conference and Exhibition, Cape Town, South Africa, November 4-7, 2018
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Abstract

In different geophysical methods, the physical responses derived from a specific type of geological target show very distinct characteristics. Such responses represent different rock properties with specific physical units, which in most of the times differ within several orders of magnitude. Therefore, geophysical data combination and integrated interpretation are not simple straightforward processes and cannot be satisfactorily performed by visual inspection only. The proposed Geophysical Anomaly is a data fusion solution for multiphysics data that is under development by Petrobras’ Multiphysics Team. It consists in a spatial representation of the correlation between anomalous regions detected by different geophysical methods, designed to improve the integrated interpretation of multimodal geophysical data.

In the geophysical anomaly approach, maps from several types of seismic attributes as well as gravity, magnetics, and resistivity anomaly maps are mathematically treated to allow reliable combinations. Anomalous regions interpreted from each geophysical methodology, as resulting from the same geological source, are mathematically highlighted because they represent areas with great probability for target occurrence. Resulting highlighted anomaly maps are mathematically combined in such a way that anomalies showing spatial superposition will be stressed while remaining anomalies tend to be diminished. The final result is a new anomaly map named Geophysical Anomaly Map. This novel solution bounds regions where individual interpretations of different geophysical methods correlate, bringing confidence to the interpretation.

We illustrate the effectiveness of the geophysical anomaly approach by showing results from the application of the proposed methodology to three real data examples from Brazil: offshore Campos Basin where the results correlate with volcanic rocks
thickness; offshore Sergipe-Alagoas Basin where we were able to identify an oil-bearing channel; and onshore Reconcavo Basin where the results were related to the thickness of a sand channel. The variety of results described in these examples make clear the flexibility of the geophysical anomaly as a qualitative interpretation tool for a wide range of geological problems.

References Cited


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Summary:

- Motivation
- Methodology
  - Geophysical anomaly
  - Logistic function
- Examples
  - Recôncavo Basin example
  - Campos Basin example
  - Sergipe-Alagoas Basin example
- Conclusions
- Acknowledgments
Motivation:

• The understanding of the subsurface geology requires the combination of different geophysical data since a single method may have limited or even no response to a particular rock property.

• Rock properties may differ within several orders of magnitude making the geophysical data combination a not simple straightforward process.

• The interpretation process requires more than ordinary visual inspection of single geophysical maps to adequately reduce uncertainties.

• Data fusion techniques can simplify such processes by providing a total or partial synthesis of the different geophysical data.
Data combination techniques in geophysics:

- **Composite color images:**
  - Combination of gravity, magnetic and radiometric data to assist geological mapping - Duval (1983) and Broome (1990).

- **Image processing techniques:**

- **Machine learning algorithms:**

- **First approach to GA tool:**
  - Seismic amplitude and density anomaly combination in a oil discovery in Recôncavo Basin, Brazil - Ramos et al. (2011).
Data fusion solution that blends non-linearly normalized data.

- It mathematically combines selected anomalous regions from different methods.
- Anomalies showing spatial superposition will be highlighted.
- Anomalies with no spatial superposition will be downgraded.

Geophysical anomaly
Logistic function:

A logistic function is a non-linear mathematical function showing a typical sigmoid shape curve used in statistics for studies of growth models and machine learning techniques like neural networks and learning algorithms to introduce nonlinearity into the models.

The generic form of the logistic function $\sigma$ is:

$$\sigma(x) = \frac{L}{1 + e^{-kS(x-x_0)}}$$

where $e$ is the natural logarithm base, $x_0$ is the $x$-value of the sigmoid inflection point, $L$ is the curve maximum value, $k$ is the steepness of the curve, and $s$ is a scaling factor that fits the data domain into the chosen function domain.
Why logistic functions? The asymptotic characteristic of the logistic function seems more suitable for normalization.
Logistic function as penalty function: values greater than threshold will be favored, smaller values will be penalized.

**Sigmoid function**

- **Example**
  - LA LA GA
  - $0.9 \times 0.9 = 0.81$
  - $0.9 \times 0.4 = 0.36$
  - $0.4 \times 0.4 = 0.16$

**GA function**

- **Example**
  - LA LA GA
  - $1.8 \times 1.8 = 3.24$
  - $1.8 \times 0.8 = 1.44$
  - $0.8 \times 0.8 = 0.64$
Recôncavo Basin example
Recôncavo Basin example

RMS amplitude map

Logistic seismic anomaly map
Recôncavo Basin example

Density contrast map

Logistic density anomaly map
Geophysical anomaly map - Recôncavo Basin example
Campos Basin example
Campos Basin example

Seismic discontinuity attribute map

Logistic seismic map
Campos Basin example

Gravity residual anomaly map

Logistic gravity map
Campos Basin example

Analytic signal amplitude map of magnetic data

Logistic magnetic map
Geophysical anomaly map – Campos Basin example
Sergipe-Alagoas Basin example
Sergipe-Alagoas Basin example

Vp/Vs attribute map

Logistic Vp/Vs anomaly map
Sergipe-Alagoas Basin example

Ip-Is attribute map

Logistic Ip-Is anomaly map
Sergipe-Alagoas Basin example

Resistivity anomaly map

Logistic resistivity anomaly map
Geophysical anomaly map – Sergipe-Alagoas Basin example
Conclusions:

• We have developed a powerful and flexible strategy for integrating multisensor geophysical data into a unique dataset.

• The proposed methodology preserves the main characteristics of each geophysical datum and identifies regions of high correlation between anomalous values.

• Our choice for logistic function has played an important role in the success of all tested examples and may be used as a starting point for different data combinations.

• The integration with structural and stratigraphic features should amplify its use as an interpretation tool and contribute to the expansion of its multimodal nature.
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Altundas, Y. B., and N. Chugunov, 2018, Multiphysics fluid monitoring: towards targeted monitoring design under uncertainty: Interpretation, 6, 1-44.


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ACKNOWLEDGMENTS

- The authors would like to thank the colleagues João Maurício Ramos, Celso Moura Jardim and Ana Patrícia Santana for providing the seismic data used in this study and for many useful discussions.

- The authors also thank Petrobras for the permission and support to present this work.