Geophysical Anomaly: A Novel Contribution to Integrated Geophysical Interpretation*

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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.

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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.

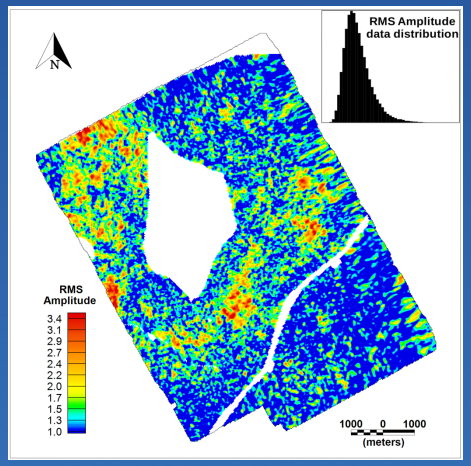
- The interpretation process requires more than ordinary visual inspection of single geophysical maps to adequately reduce uncertainties.

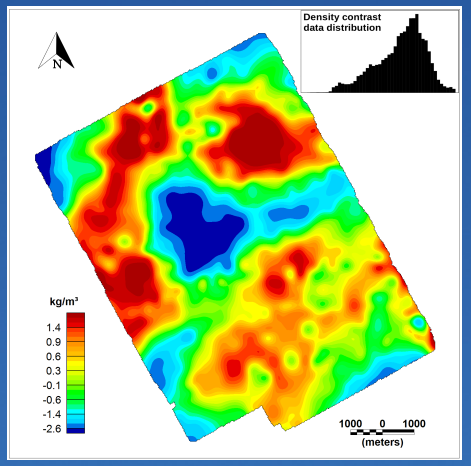
- Data fusion techniques can simplify such processes by providing a total or partial synthesis of the different geophysical data.

Data combination techniques in geophysics:

- **Composite color images:**
  - **Combination of gravity, magnetic and radiometric data to assist geological mapping - Duval (1983) and Broome (1990).**
  - **Spectral decomposition analysis of 3D seismic - Hall & Trouillot (2004), Henderson et al. (2007), McArdle & Ackers (2012) and in Cooke et al. (2014).**
- **Image processing techniques:**
  - **Geophysical data integration - Tilbury & Bush (1991), Cowan & Cooper (2009), Carneiro et al. (2012), Altundas & Chugunov (2018).**
- **Machine learning algorithms:**
  - **Explore relationships among multiple datasets - Velasco et al. (2018).**
- **First approach to GA tool:**
  - **Seismic amplitude and density anomaly combination in a oil discovery in Recôncavo Basin, Brazil - Ramos et al. (2011).**

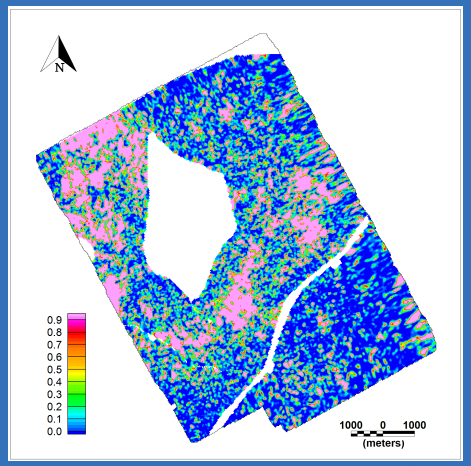
Geophysical anomaly





- 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.

Logistic function normalization



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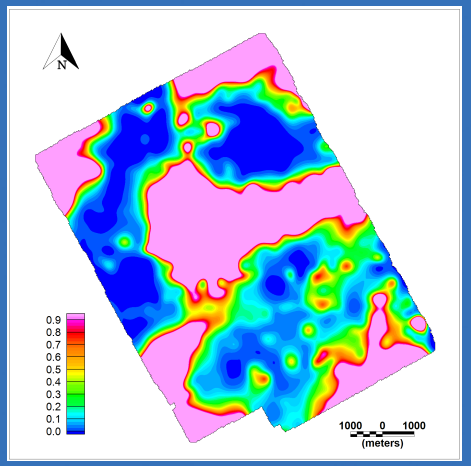

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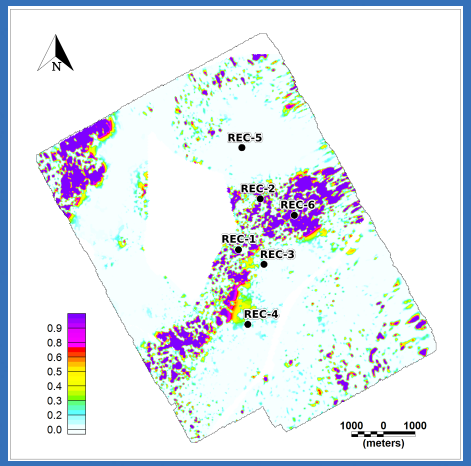
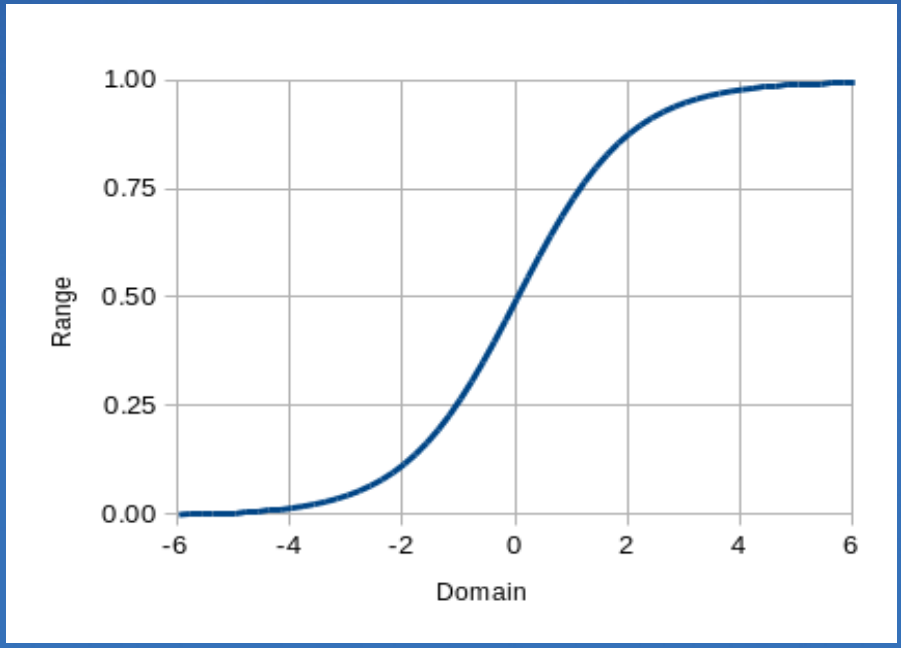


Logistic function:

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.

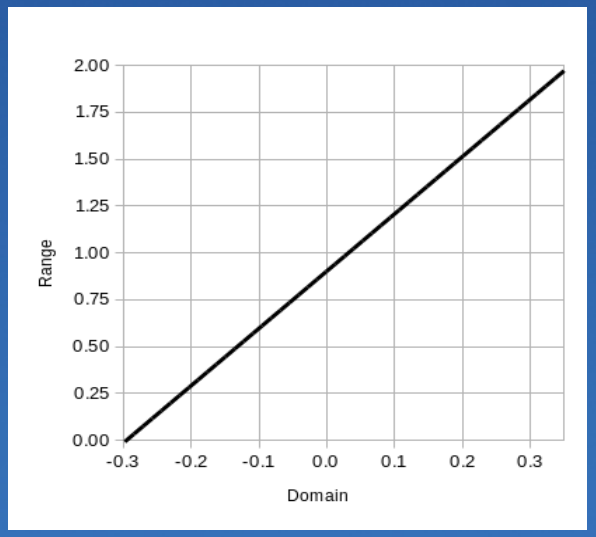
The generic form of the logistic function σ is:

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

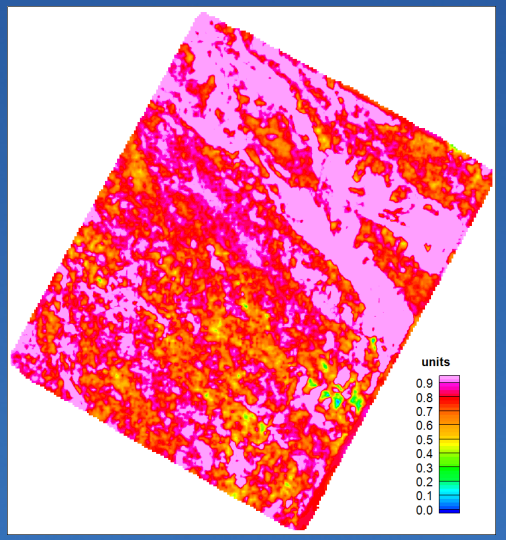


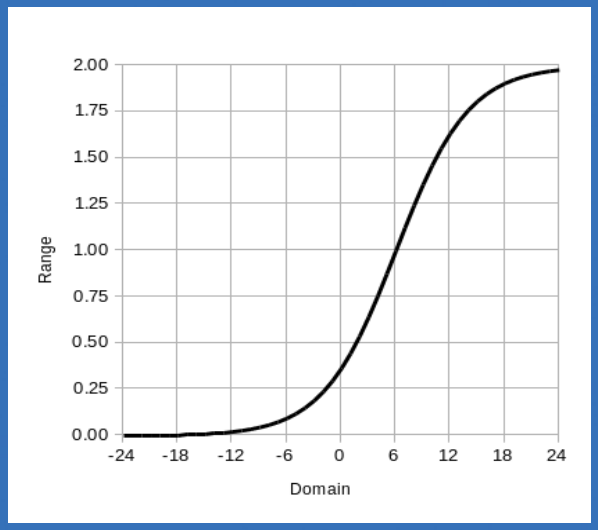
where *e* is the natural logarithm base, x_0 is the *x*-value of the sigmoid inflection point, *L* is the curve maximum value, *k* is the steepness of the curve, and *s* is a scaling factor that fits the data domain into the chosen function domain.

Why logistic functions? The asymptotic characteristic of the logistic function seems more suitable for normalization.

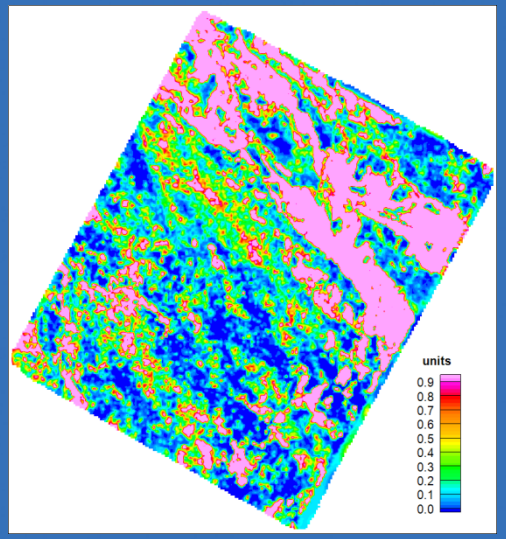


Linear function

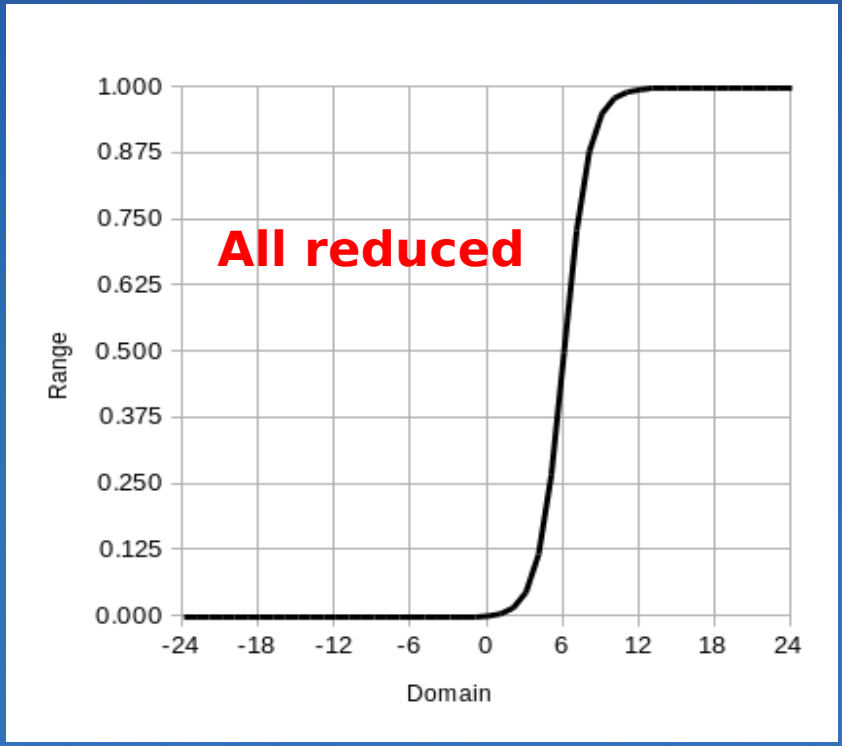


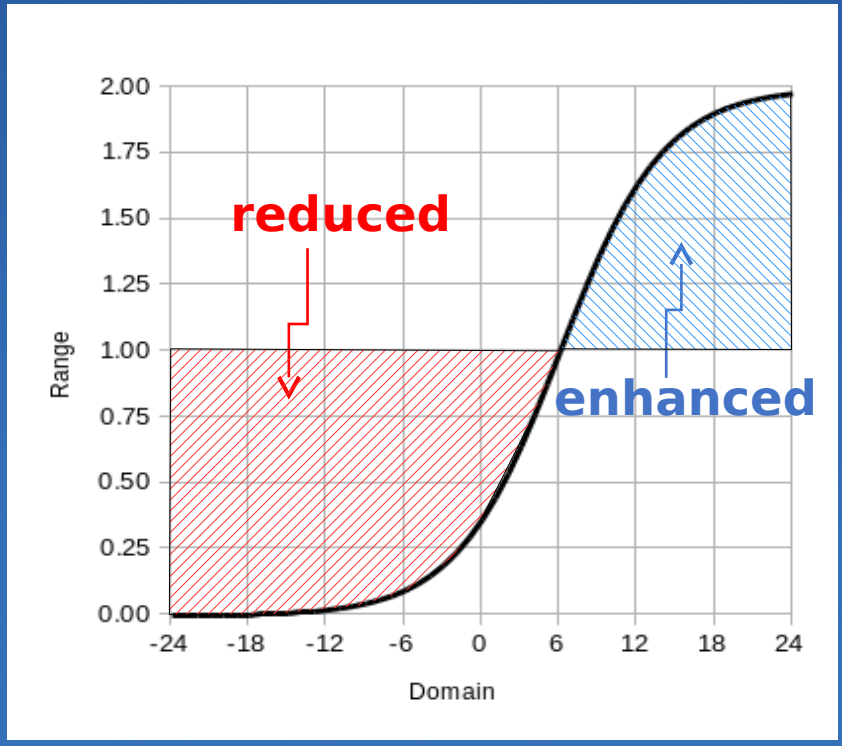


Logistic function



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	X	0.9	=	0.81
0.9	X	0.4	=	0.36
0.4	X	0.4	=	0.16

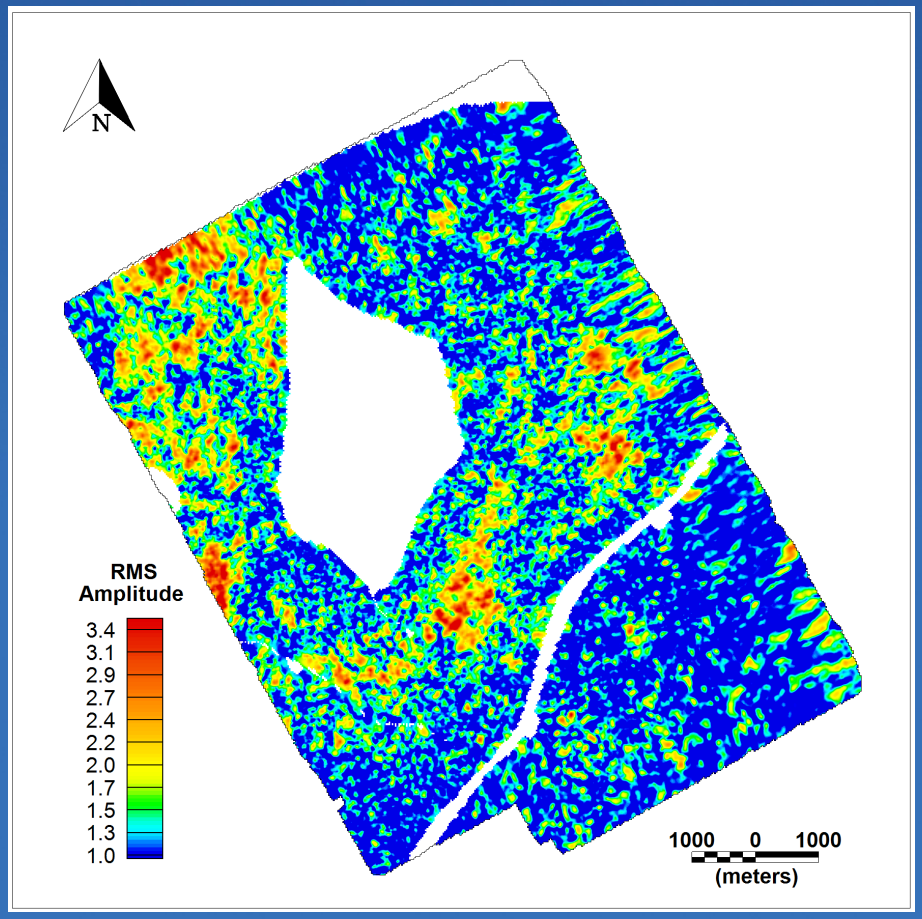
GA function

Example

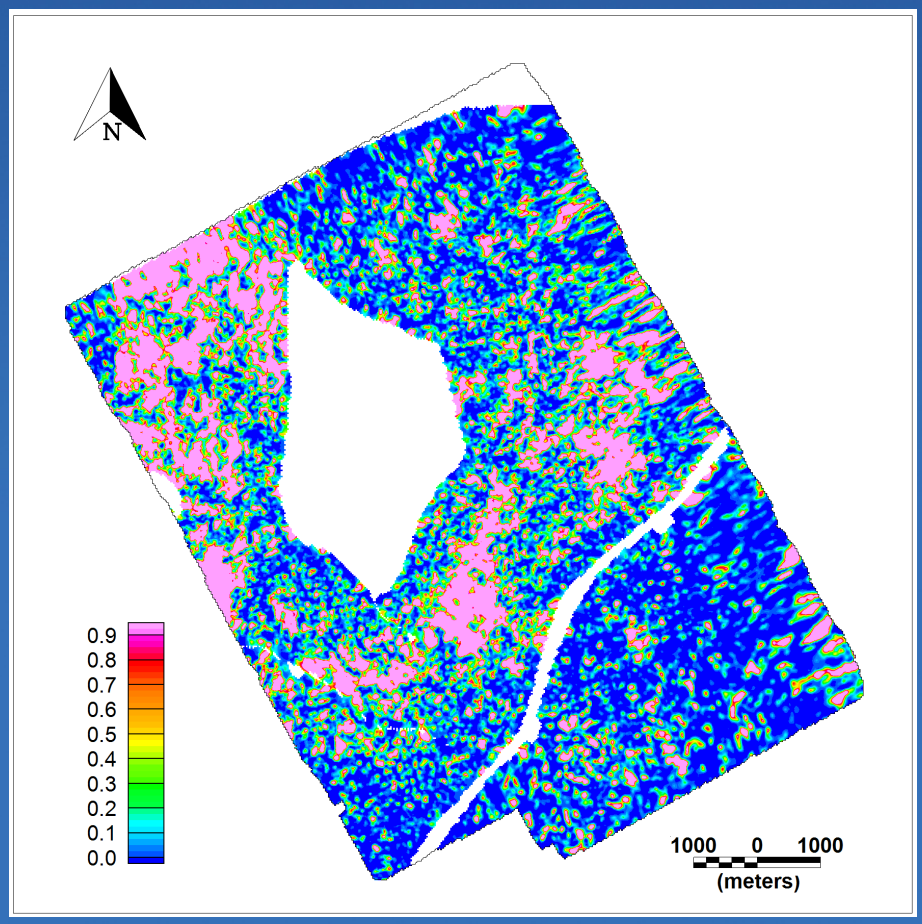
LA		LA		GA
1.8	X	1.8	=	3.24
1.8	X	0.8	=	1.44
0.8	X	0.8	=	0.64

Recôncavo Basin example

Recôncavo Basin example

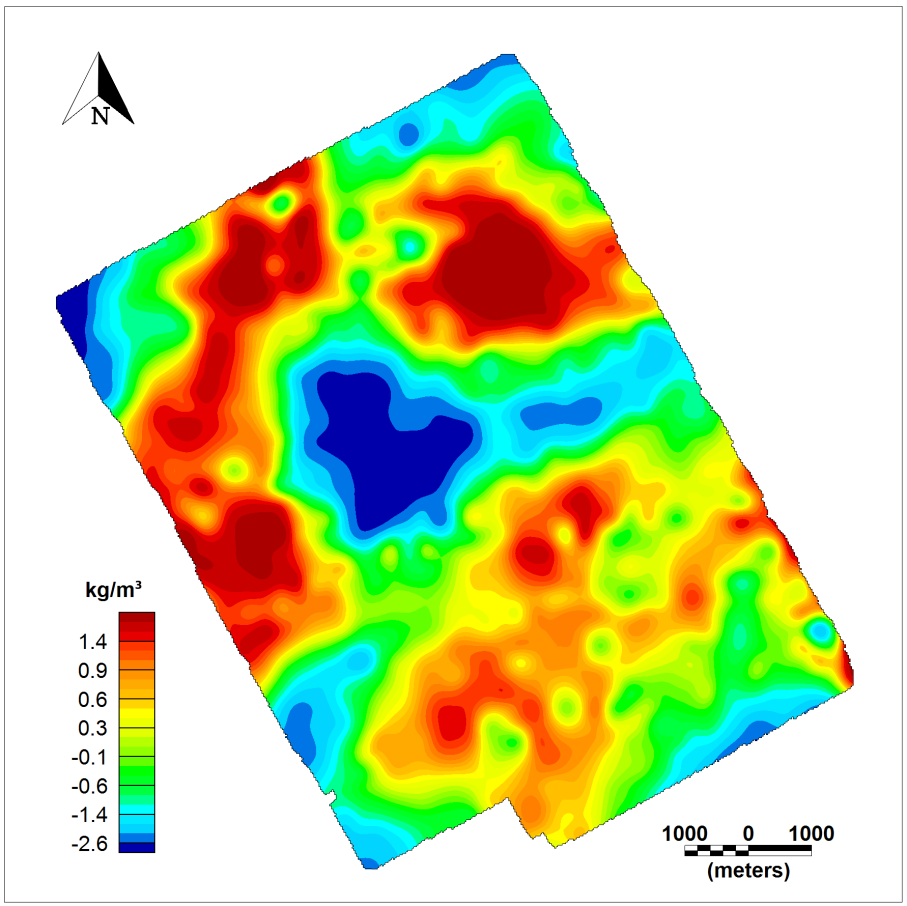


RMS amplitude map

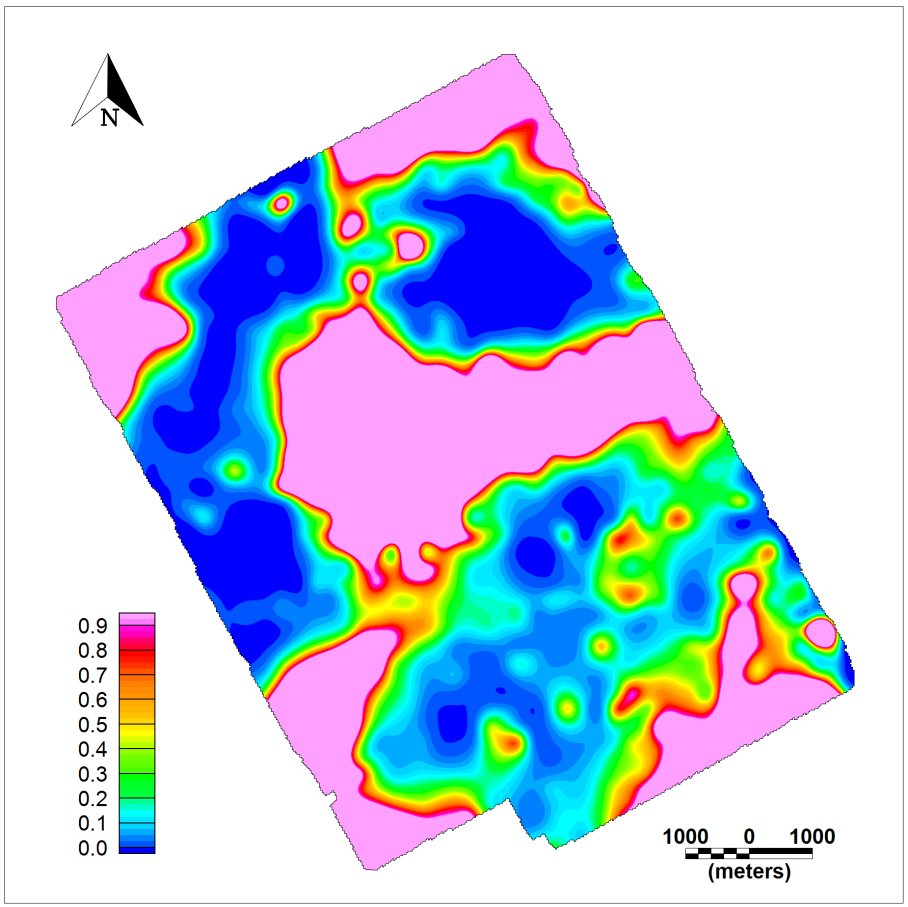


Logistic seismic anomaly map

Recôncavo Basin example

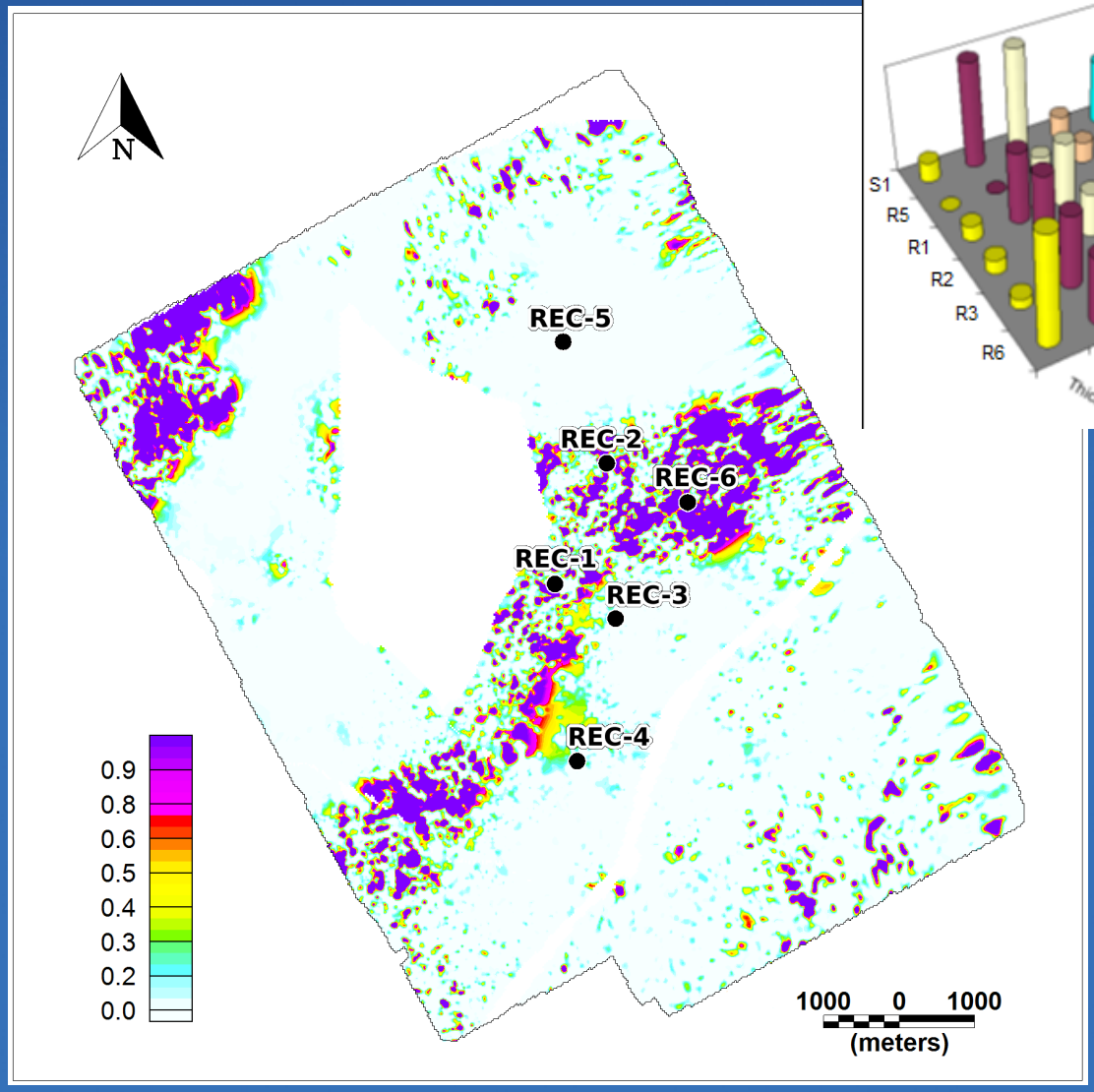


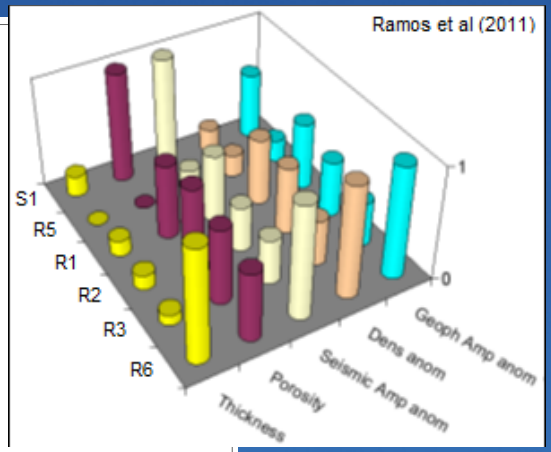
Density contrast map



Logistic density anomaly map

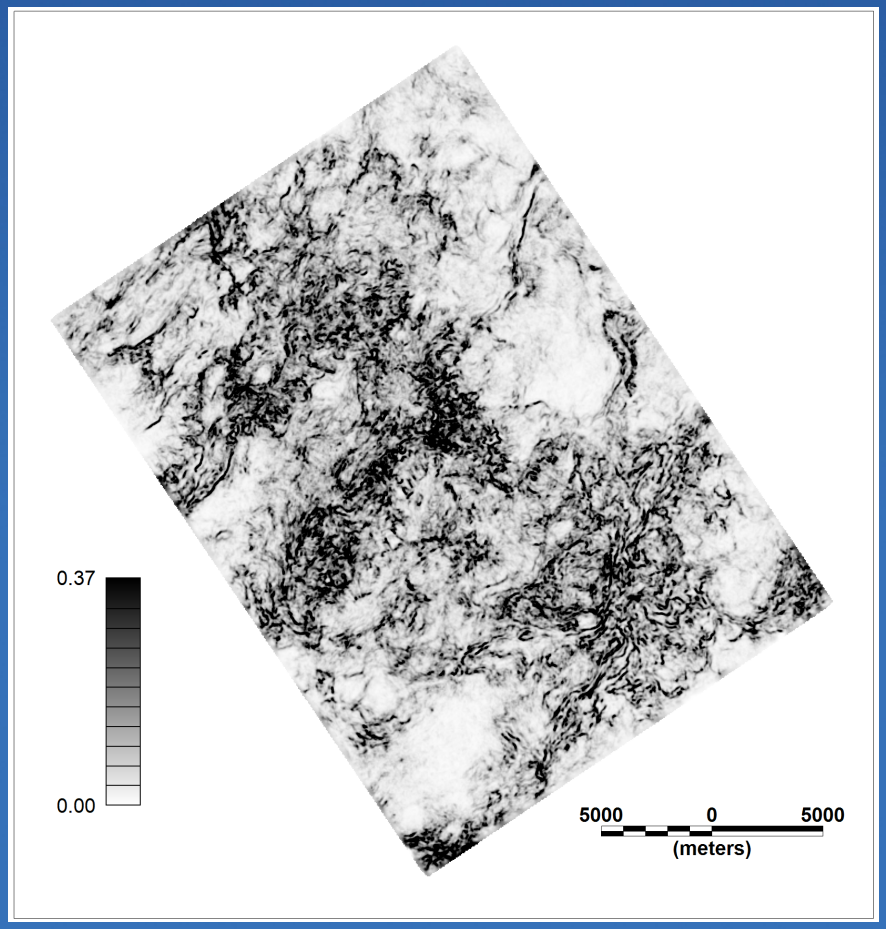
Geophysical anomaly map – Recôncavo Basin example



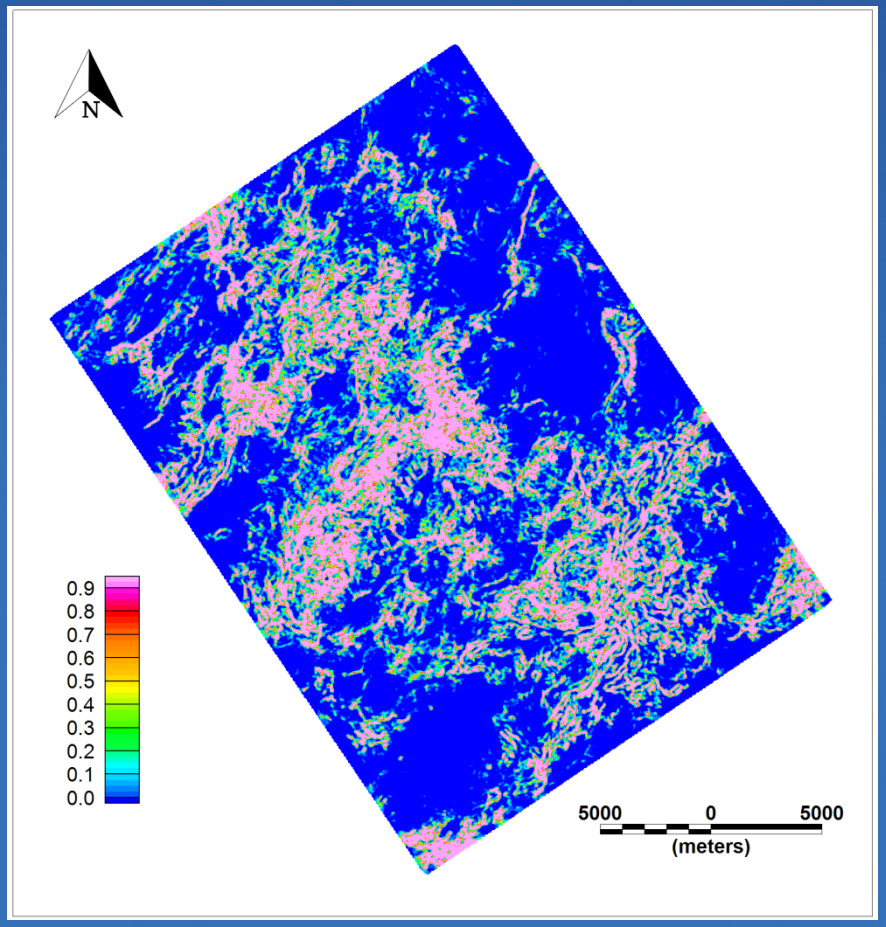


Campos Basin example

Campos Basin example

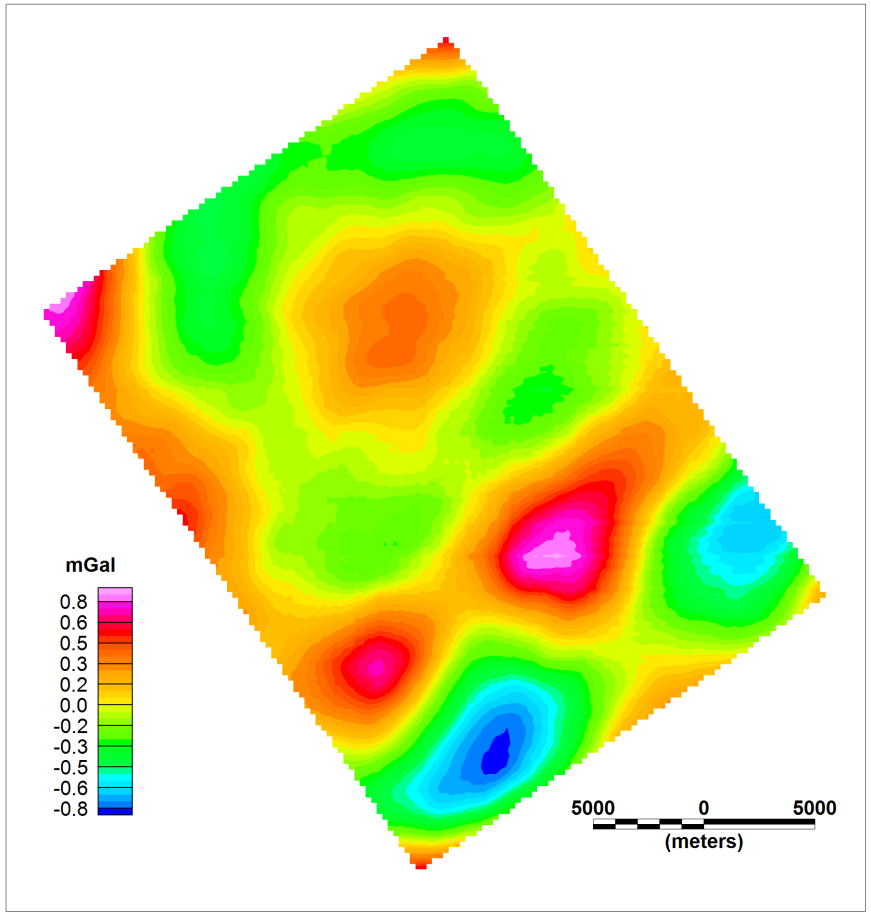


Seismic discontinuity attribute map

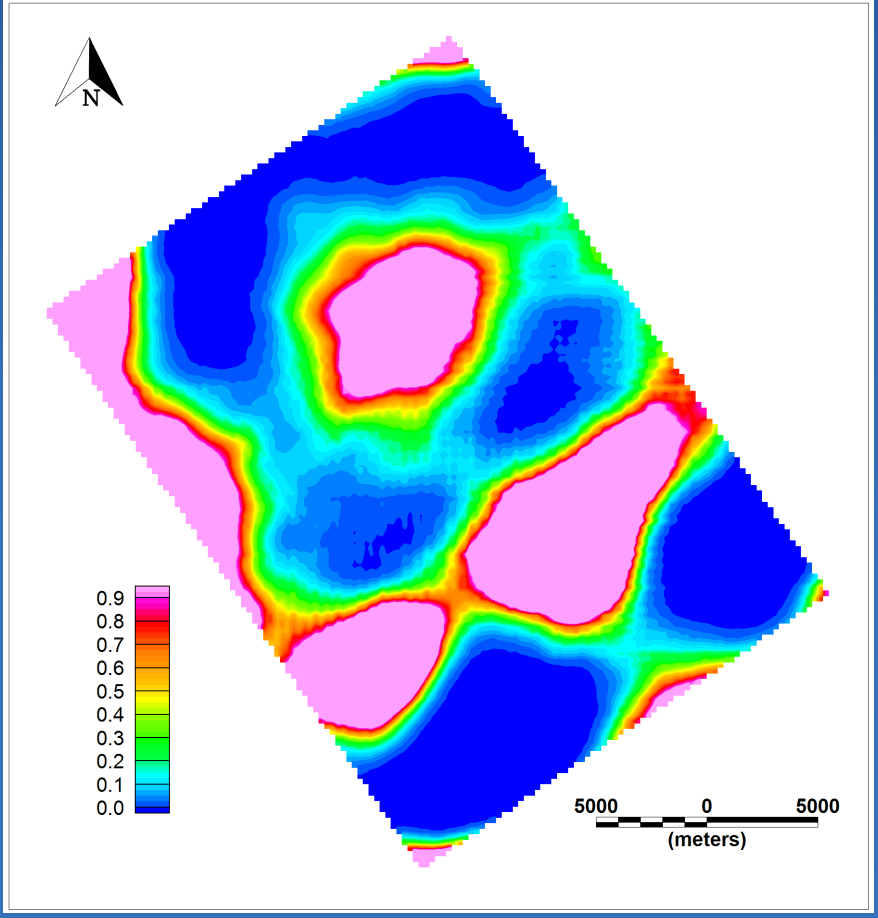


Logistic seismic map

Campos Basin example

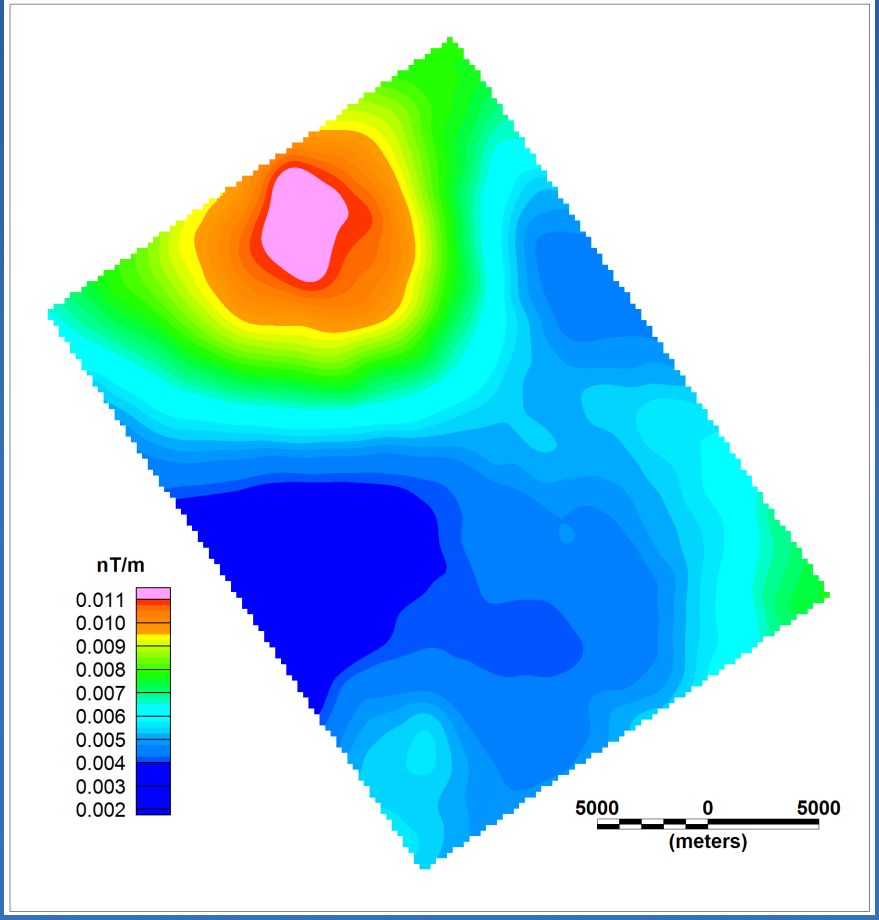


Gravity residual anomaly map

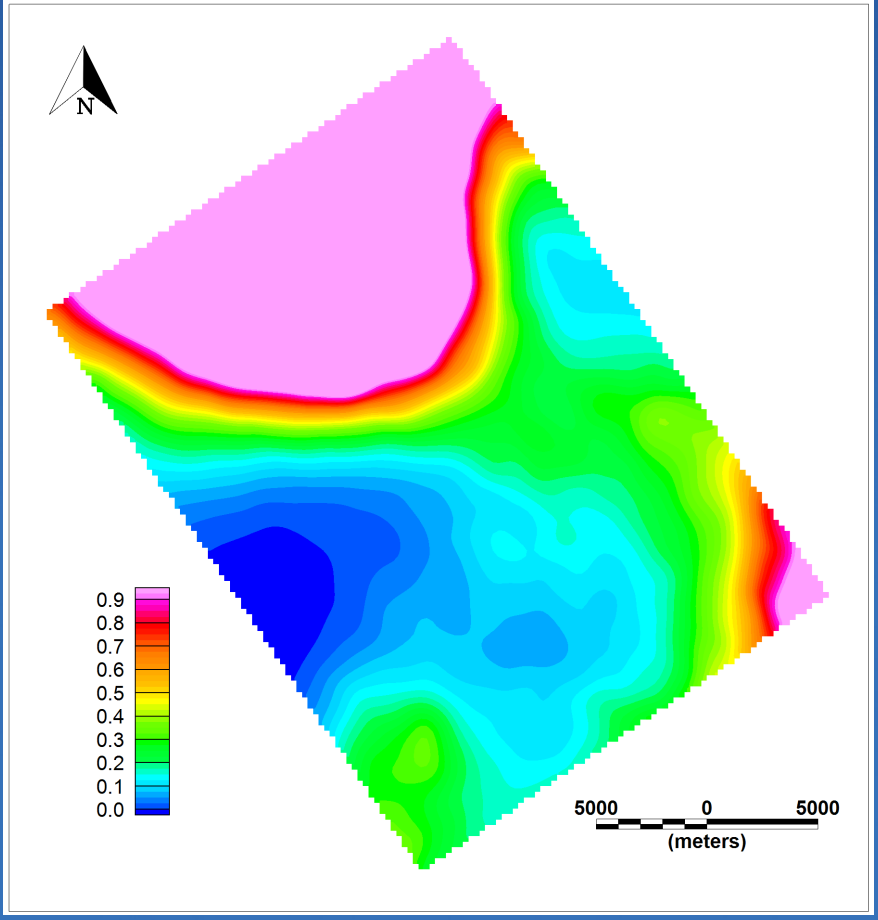


Logistic gravity map

Campos Basin example

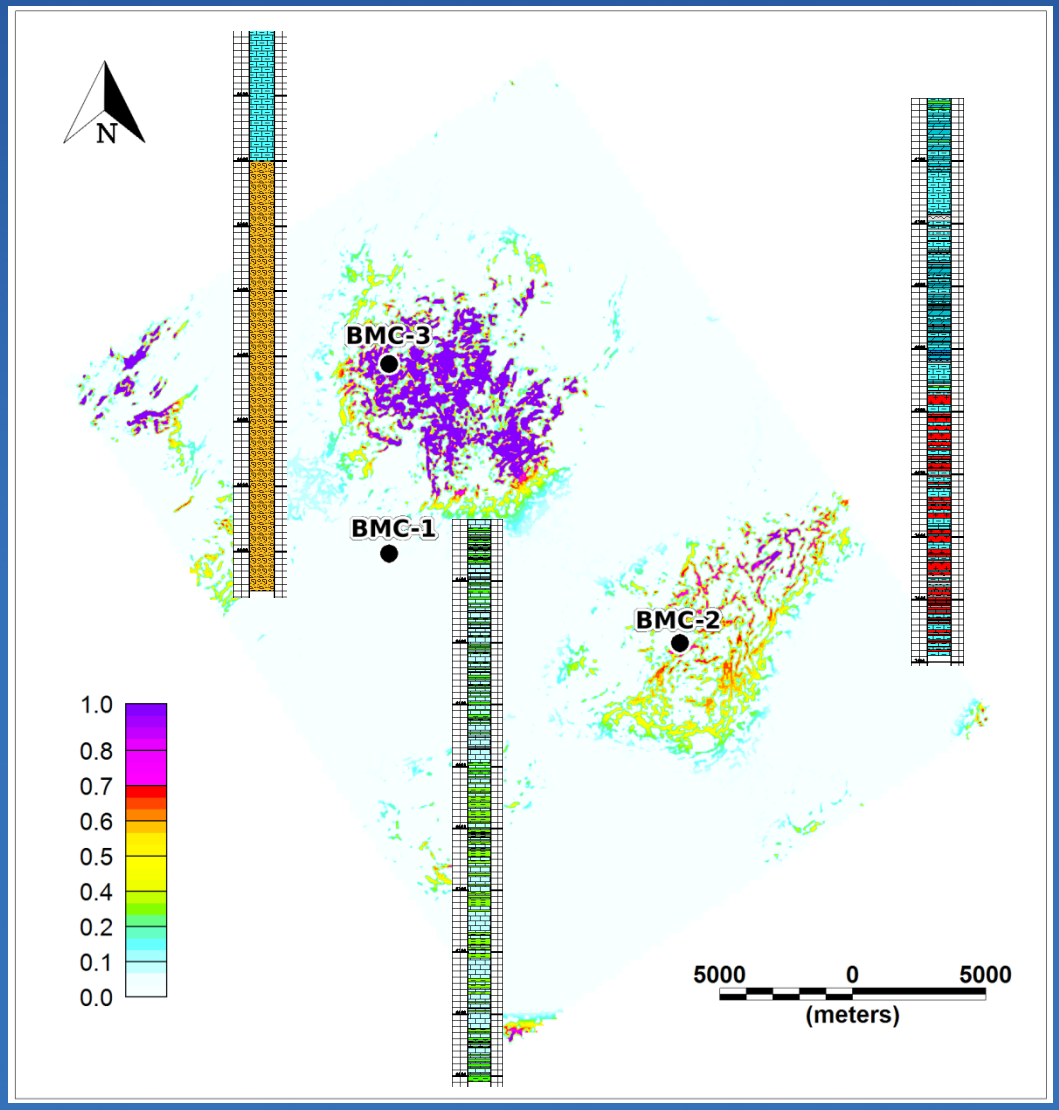


Analytic signal amplitude map of magnetic data



Logistic magnetic map

Geophysical anomaly map – Campos Basin example



Sergipe-Alagoas Basin example

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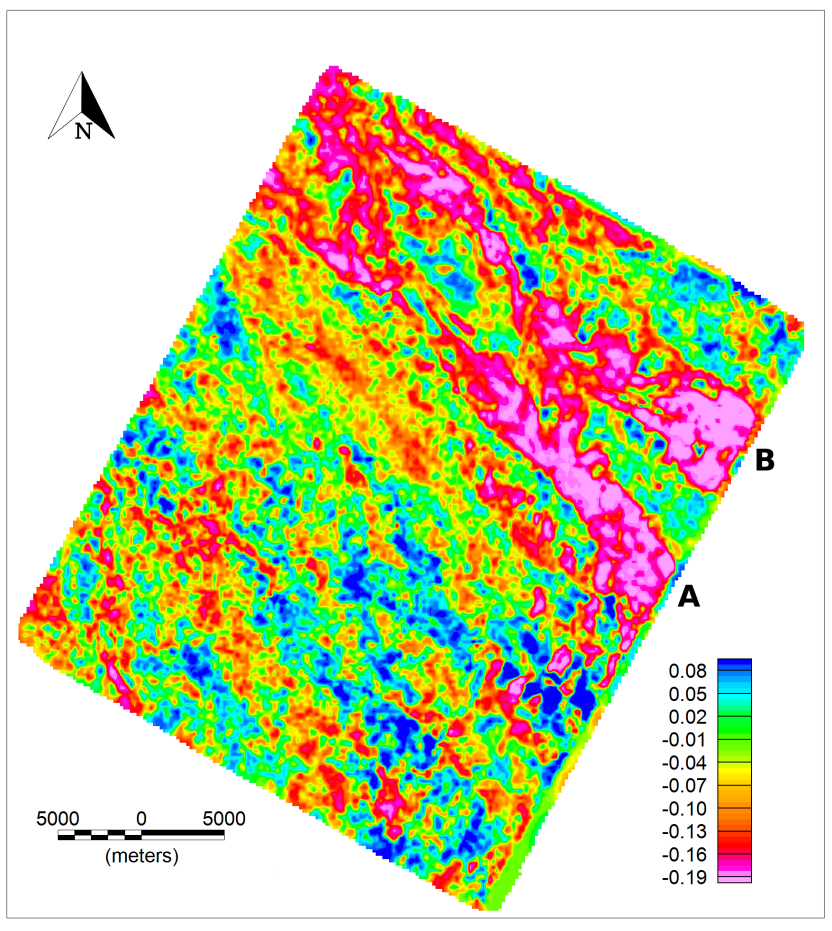
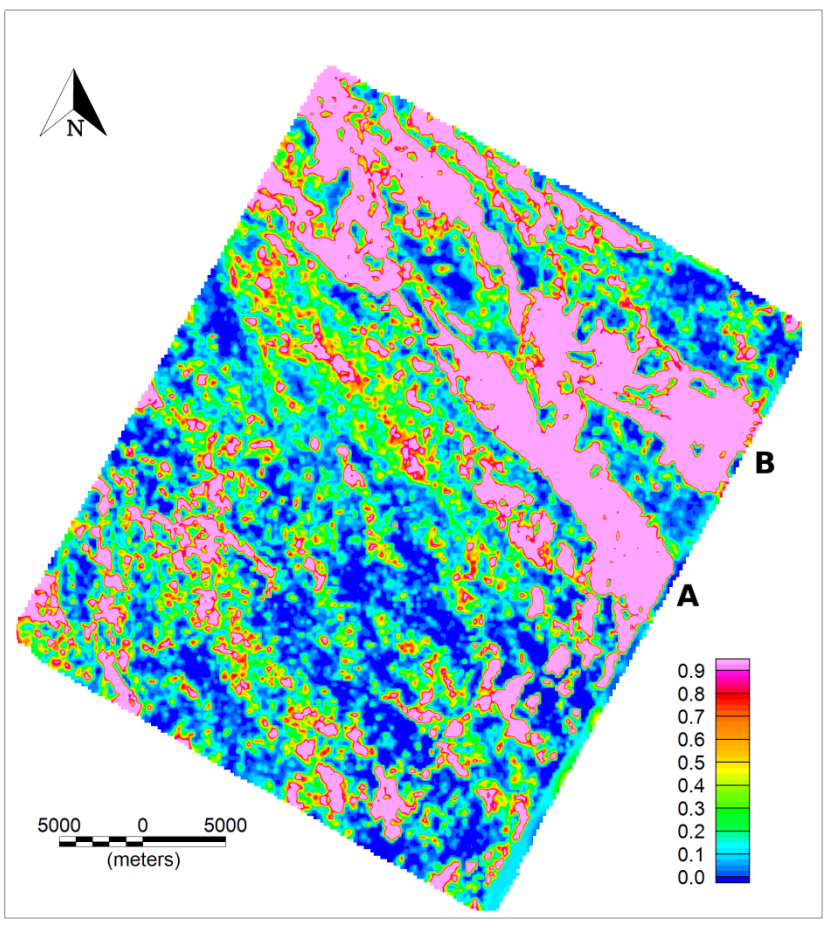
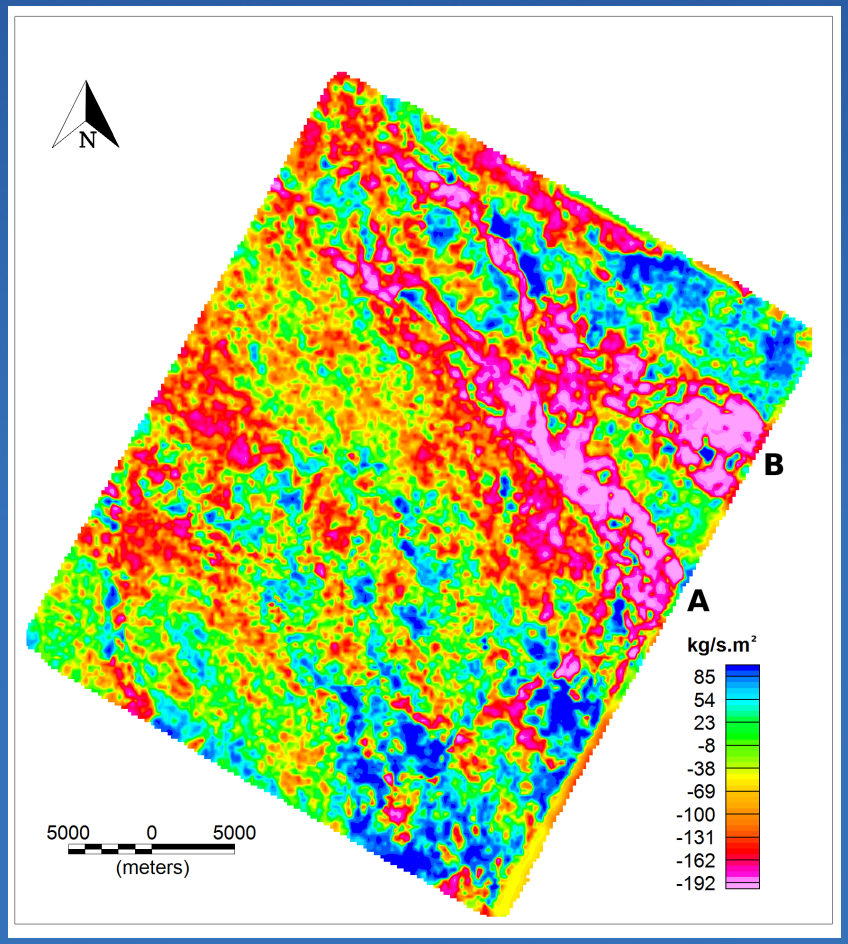


Vp/Vs attribute map

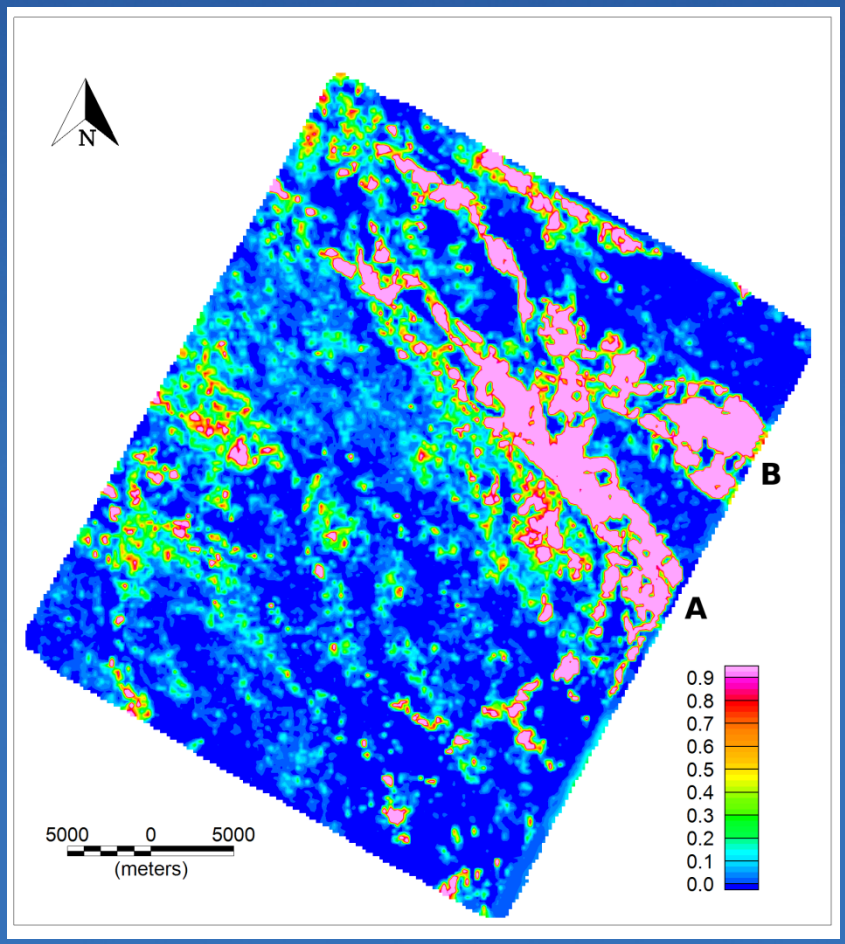


Logistic Vp/Vs anomaly map

Sergipe-Alagoas Basin example

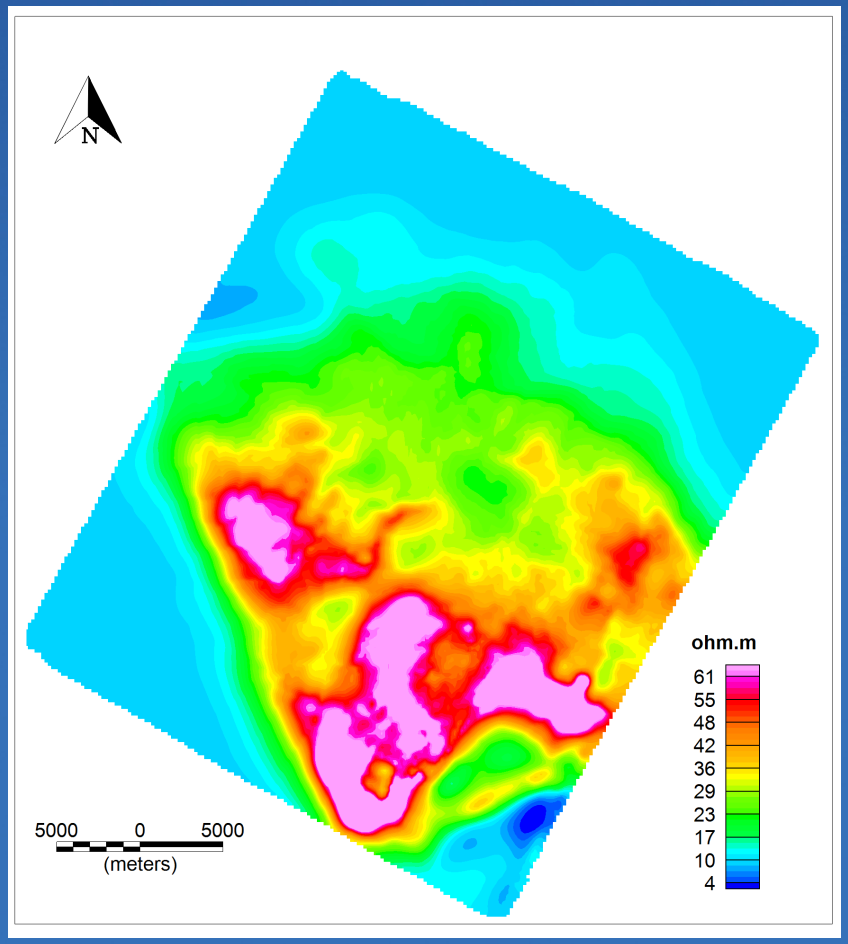


Ip-Is attribute map

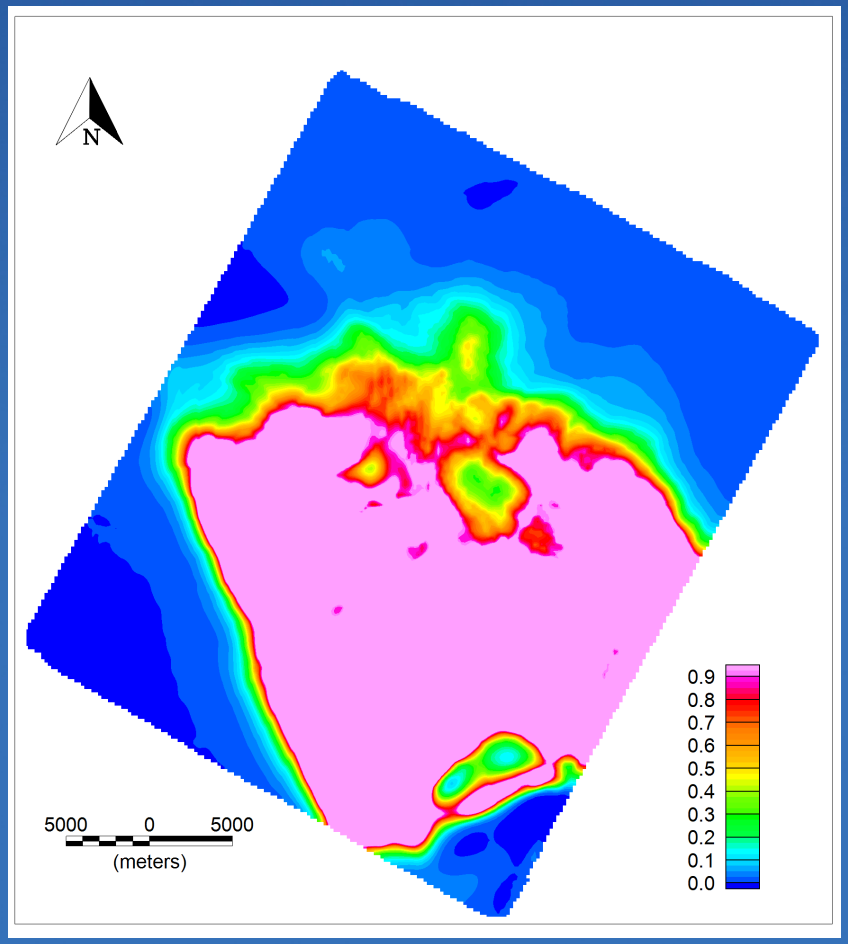


Logistic Ip-Is anomaly map

Sergipe-Alagoas Basin example

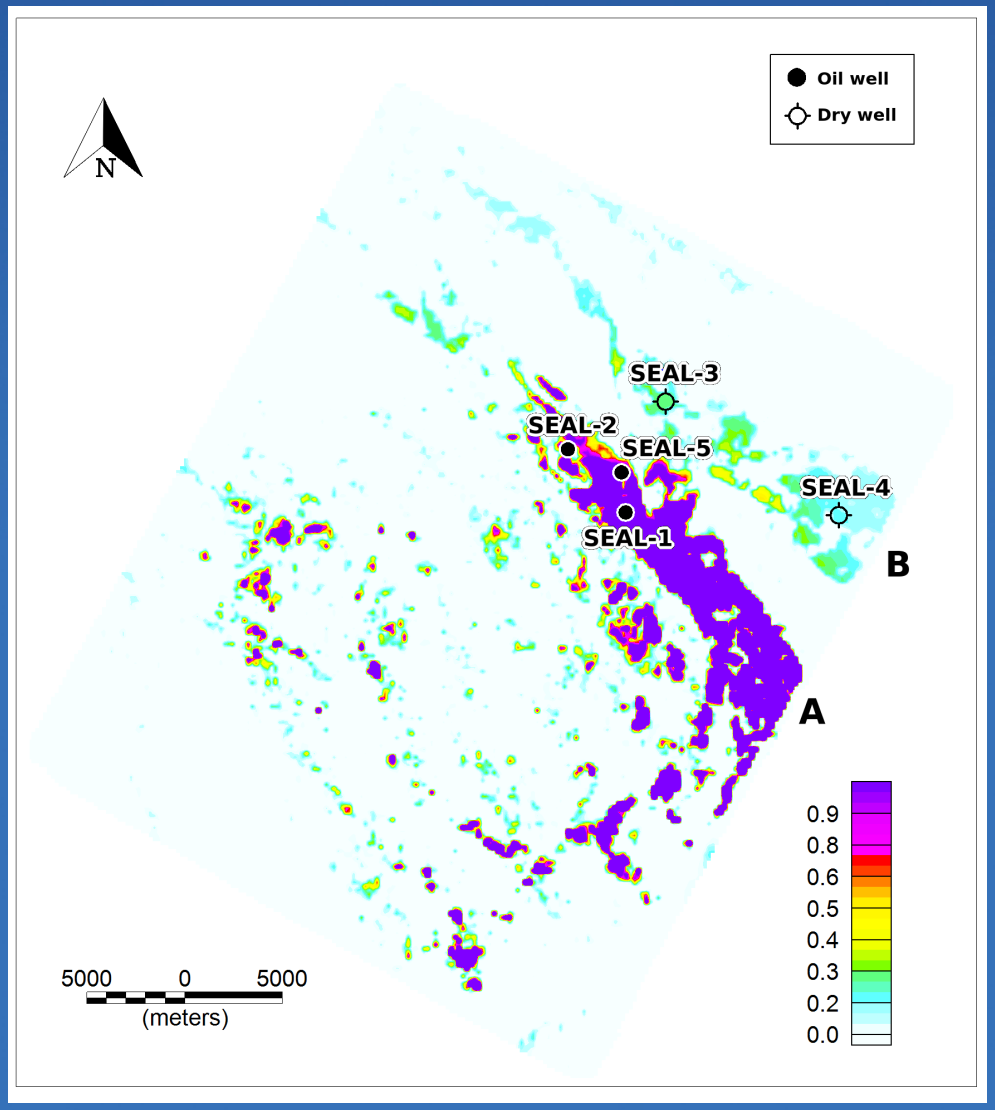


Resistivity anomaly map



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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