Advances in Depth to Basement Spectral Inversion of Gravity and Magnetic Data with Applications to Mexico and the Greater Gulf of Mexico.

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Abstract

This paper presents the techniques and results of a depth to basement inversion effort over Mexico and the greater Gulf of Mexico and an analysis of the quality of the inversion. The spectral method was applied to magnetic and gravity data. New high resolution data sets for gravity and magnetic data have been merged and now cover all of these areas. The data used were derived from a variety of sources, and leveled and merged using techniques specially developed for large data sets.

This paper presents a brief description of the development of a program to invert gravity and magnetic data using the spectral technique. The results of these developments are applied to determining the depth to basement and sediment thickness over These areas.

To better understand the quality of the inversions three measures were used to try and quantify the possible errors in the inversions. The inversion utilize the Tau-P spectrum of the the radial spectrum in the inversion. Thus the Tau value, the semblance and an enhanced semblance were used in the error evaluation. Processed values of the parameters appear to indicate, but not give a quantative estimate of, the quality of the inversions. Examples from the inversion over Mexico and the greater Gulf of Mexico (MexGG) show the results of this investigation

Results for South America and western Africa will be shown in the presentation.

Introduction

The method used in the inversions was described in some detail by Odegard (2011). The method is summarized here.

The spectral method is based on the shape of the power spectrum for buried bodies with a density contrast. Odegard and Berg (1965) showed for simple bodies, and Bhattacharyya and Leu (1975) showed for complex shaped bodies that the depth to the center of mass of the body is easily found from the power spectrum of the gravity field. If the spectrum is displayed in a semi-log plot, then the negative of the slope of the spectrum is equal to the depth to the center of mass of the body.. Extremely complex shapes and layering can, however, complicate the spectrum. . For magnetic bodies the results are more complex in the sense that, although the same equations apply, in practice, the spectrum gives information primarily about the location of the top and bottom of a magnetic layer (Blakely, 1995, Section 11.4.1 - 2.)

Since the gravity and magnetic fields of the earth are linear systems, this can be applied to inverting for the depth to a surface containing a distribution of complex shapes. The assumption is that the density basement is composed of an aerially distributed number of structures which produce individual spectra. Then the ensemble average of the spectra is equivalent to that for a single body at the same depth. (c.f., Papoulis, 1965, Chapters 10 and 11.) . This process has also been described for magnetic data by Spector and Grant (1970).

The spectral method has been extended using a variation of the Tau-P method to make the process automatic. The Tau-P method or Radon transform has been described and used by several authors (c.f. Estill and Odegard, 1979).

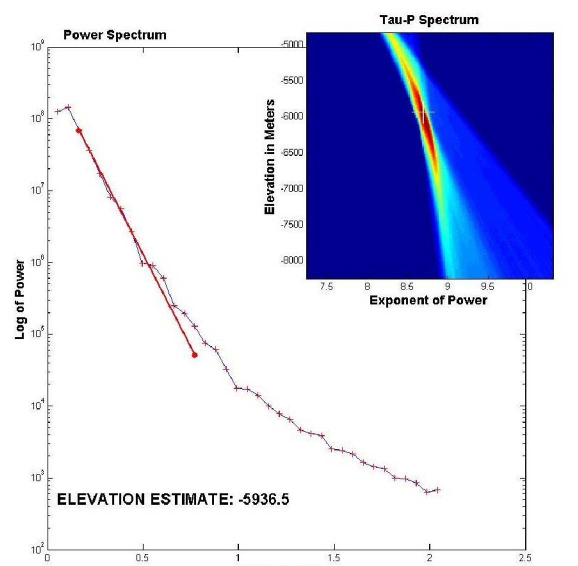

Figure 1: Spectrum and Tau-P spectrum of a 40 by 40 kilometer window of magnetic data over the Santos Basin. After Odegard (2011).

The process of mapping the depth to basement first involves calculating the average radial power spectrum over a rectangular window on a magnetic or gravity grid. After the average radial power spectrum is calculated, it is displayed in a semi-log figure of spectral power versus spatial wave number. This is illustrated in Figure 1. A straight line is then fit to the power spectrum, usually in the higher amplitude, lower wave number area. For gravity and magnetic data the negative of slope of this line is equal to twice the depth to the center of mass of the bodies producing the gravity or magnetic field. When used in a semi-automatic mode the line fit to the data can be edited by moving the end points.

This method produces very accurate results when applied to isolated bodies or to surfaces with a broadly consistent spatial distribution. It has problems when the distribution or the type of geological structures varies rapidly in a spatial sense. The spectral method also produces better results over surveys with significant noise than many other methods. This is because the data are spatially averaged over a window.

Data Merging and Leveling

Data for these projects are a combination of data from all available sources. These include data from the US National Geophysical Data Center (NGDC), other government sources, global compilations, and data digitized from published sources

Methods developed to level and merge large data sets (Odegard, 2009) were used to produce the grids of gravity, magnetic and bathymetry data at a resolution of 30 arc-seconds or about 900 meters. Images of the resultant free air gravity and total magnetic intensity grids over the MexGG are shown in Figures 2, and 3.

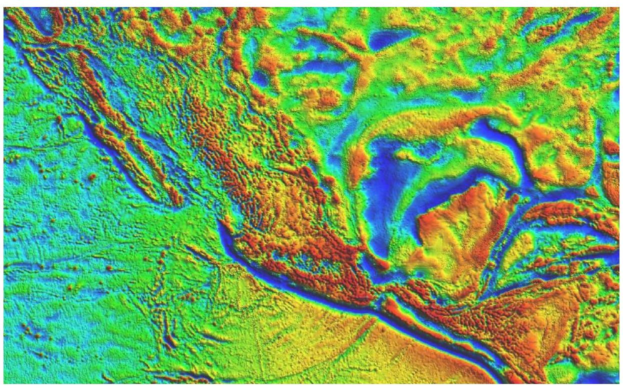

Figure 2: Free air gravity for Mexico and the greater Gulf of Mexico (MexGG).

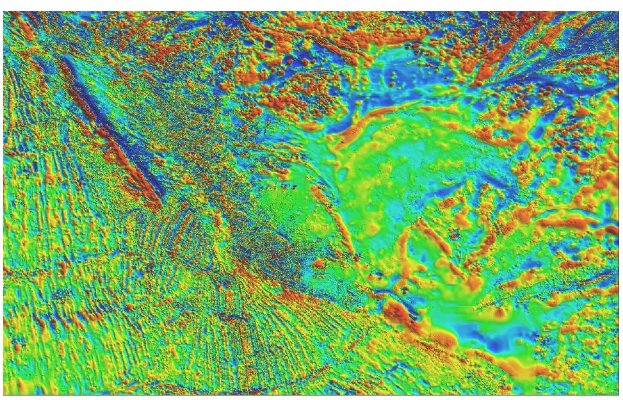

Figure 3: MexGG total magnetic intensity (TMI).

The Process

The process of mapping the depth to basement by inverting a grid of data involves calculating the average radial power spectrum over a rectangular window on a magnetic or gravity grid

A 40x40 kilometer window is useful for basement depths encountered in hydrocarbon exploration, however for shallower basement a 20 by 20 kilometer window, and for deeper basement 60 by 60 or 80 by 80 kilometer windows are used.

After the depth has been calculated over one window a new calculation is made over a next window. In our semi-automated application we usually step the window horizontally or vertically by one half the width of the window, but for higher resolution a 5 or 10 kilometer step can be used. The MexGG area is partitioned into overlapping tiles. Each tile has a differnet projections centered on that tile. An Albers equal area conic is generally used.

Implementation

For each window the data are processed and a Tau-P spectrum is calculated. The maximum of the semblance is taken as the best fit of a line to the original spectrum. This pick is shown as a white cross in the Tau-P spectrum window in Figure 4. The semblance can be weighted to emphasize shallow or deep solutions and is called the enhanced semblance. In Figure 4 the Tau is the exponent of the power in the power spectrum and P is the elevation.

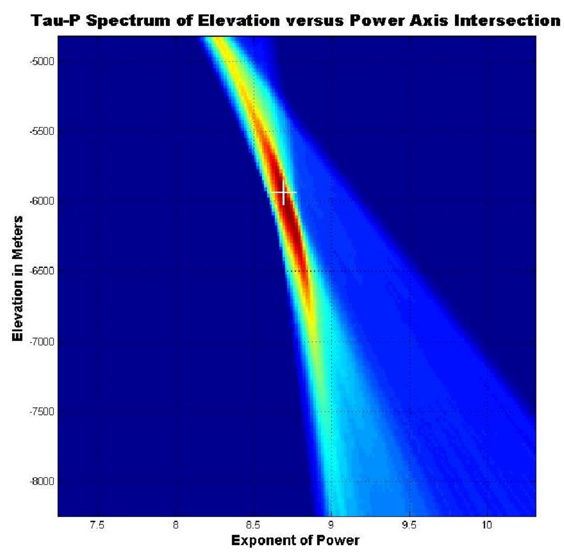

Figure 4. Final Tau-P spectrum of straight line fits to the power spectrum in Figure 1. The white cross shows the maximum semblance in the spectrum. After Odegard (2011).

For each solution the location of the center of the window, the depth below the sensor, the Tau/exponent of the power, the semblance, and the enhance semblance are output. The data are projected back into geographic coordinates and gridded. The grids are processed with a median filter to reduce outliers and then smoothed with a low pass filter. The resulting spatial resolution is about 30 kilometers for a 40 by 40 kilometer window with a 20 kilometer step.

Results

The free air gravity and total magnetic intensity data over the MexGG area were inverted for depth to basement. The resulting inversions were merged, generally selecting the deepest solutions, but using constraining data. Sediment thickness can then be calculated using the sensor elevation, and the topographic and bathymetric elevations. The result is shown in Figure 5.

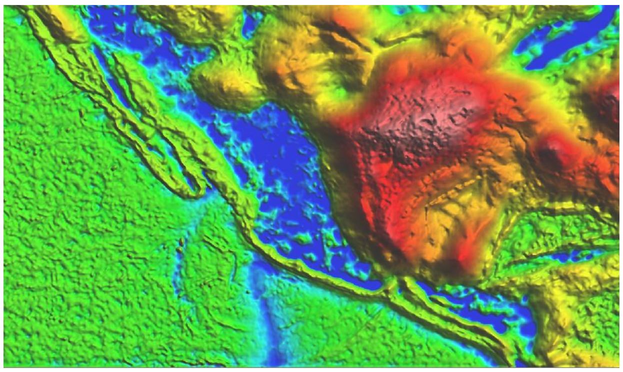

Figure 5: The sediment isochore derived from the depth to merged basement over the MexGG. Reds are thick and blues are thin areas.

The Tau, semblance and enhanced semblance were also gridded and processed. The Tau grid is shown in Figure 6.

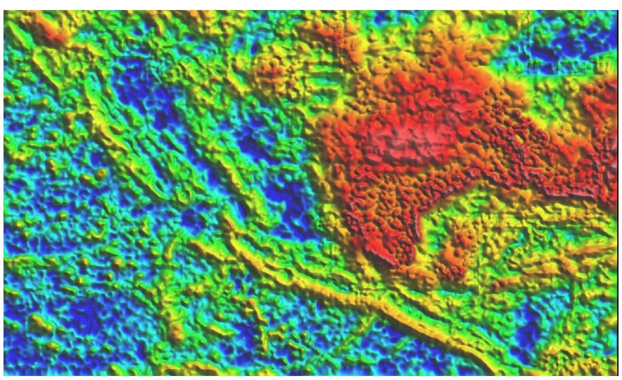

Figure 6: The Tau/exponent of power over the MexGG. Reds are large and blues are small areas.

This shows that the Tau value is largest for the deeper basement areas as expected. To mitigate this Tau can be divided by the depth to basement. The result is shown in Figure 7. The blank areas are for depth to basement less than 1000 meters. These areas were not inverted because the process should not be valid at these shallow depths for this size of window.

An interesting feature in Figure 6 is the low values over the deeper Gulf of Mexico. This is actually not surprising as the amplitude variation of the magnetic data in this area is quite small. The gravity variation related to the basement is also small. Thus this figure may be a good indication of relative accuracy.

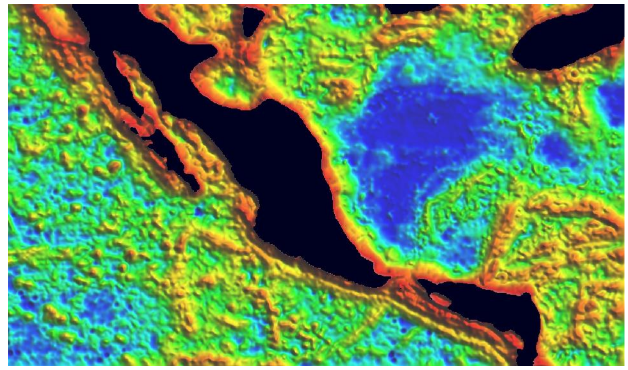

Figure 7: The Tau/exponent of power over the MexGG area divided by the depth to basement. Reds are large and blues are small areas. Blank areas are where the depth to basement is less than 1000 meters.

The semblance grid is shown in Figure 8 and the enhanced semblance plotted with a linear amplitude scale is shown in Figure 9. The linear plot of enhanced semblance is not useful in investigating the quality of the inversion except for the small "glitches" in the grid. Taking the log of the enhanced semblance provides a more useful grid for quality estimation. This grid is shown in Figure 10.

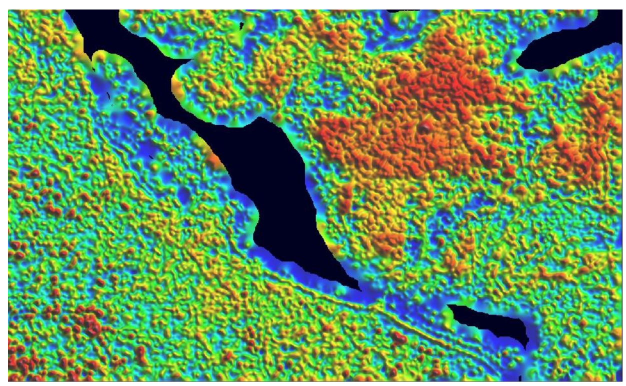

Figure 8: The semblance over the MexGG area. Reds are large and blues are small areas. Blank areas are where the depth to basement is less than 1000 meters.

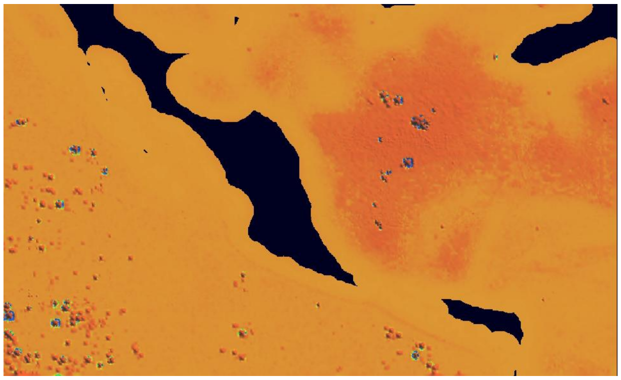

Figure 9: The enhanced semblance over the MexGG area. Reds are large and blues are small areas. Blank areas are where the depth to basement is less than 1000 meters.

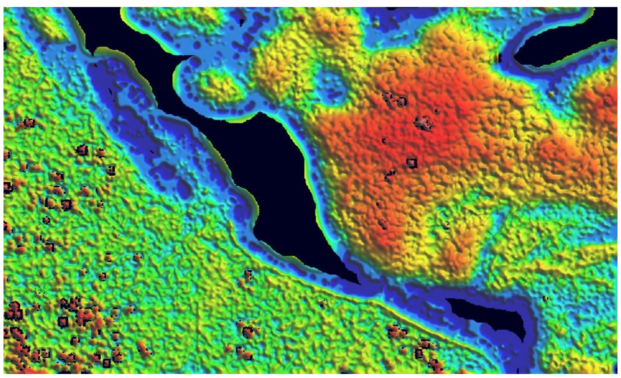

Figure 10: The log base 10 of the enhanced semblance over the MexGG area. Reds are large and blues are small areas. Blank areas are where the depth to basement is less than 1000 meters.

The semblance and log of the enhanced semblance both indicate that the inversion is of higher quality over the deeper Gulf of Mexico. This is in seeming conflict with the indications from the Tau grid. However the two may indicate two things. 1) The data used in the inversions are of lower amplitude and perhaps quality. 2) The data are more consistent with better adherence to the requirement of spatial stationarity over the broadly varying Gulf of Mexico.

The “glitches” in the enhanced semblance possibly indicate non-stationarity at those locations. However the data in these areas do not indicate anything unusual. A more detailed investigation of these areas is left for the future with a possible statistical analysis for stationarity.

Conclusions

The use of the Tau/exponent of power, semblance and enhanced semblance grids appear to indicate areas of higher quality in the inversion results. The deeper Gulf of Mexico area appears to give mixed results. One indicates poor data quality and the other indicates a high quality inversion. Where all three indicate good or poor data and inversion quality, the results should be considered very good or possibly unusable in these areas respectively.

Acknowledgments

This research and these projects are supported by funds derived from sales of speculative projects to clients by the author and other consultants that he works with. We thank our many clients for their interest and support.

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