Mapping regional sedimentary horizons in the onshore Baram Delta, Sarawak, from magnetic and gravity data using Energy Spectral Analysis

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Abstract **Aeromagnetic and airborne gravity data acquired over part of the Baram Basin, Sarawak, Malaysia, was used to estimate depth to economic basement that is the Top Cretaceous (Horizon-1), and depth to three intra-sedimentary horizons: Top and Base of Carbonates (Horizon-2 and Horizon-3), and the top of an additional shallower interface (Horizon-4). Depths to these horizons were calculated through the analysis of energy spectra of the observed magnetic and gravity fields, while faults and magnetic lineaments were derived through the application of an automatic curve matching (ACM) method based on the Naudy technique.**

The project involved the application of a new spectral technique, termed the *Multi-Window-Test (MWT).* The application of the MWT allowed quick estimation of depth to multiple horizons (skeleton maps) and also provided a set of optimal window sizes used for detailed mapping. The potential field derived results correlate well with both seismic and well data. Spectral methods have been successfully applied in the Baram Basin, and the MWT has proved itself a valuable tool in producing a robust interpretation of potential field data.

Introduction

Archimedes undertook a study of potential field data covering the onshore Baram Delta for JX Nippon Oil & Gas Exploration Corporation to map the economic basement, and three sedimentary horizons (Top and Base Carbonates, and an additional shallower sedimentary horizon) and to determine the regional structural trends of the basin. The objectives were achieved by the use of Energy Spectral Analysis *'Multi Window Test'* and *'Moving Window'* (ESA-MWT and ESA-MW) techniques.

A study of aeromagnetic data was performed (Figure 1a), with the aim of mapping two horizons: Base Carbonates (Horizon-2), and the top of a shallower horizon (Horizon-4). In addition, the MWT procedure was applied to gravity data (Figure 1b) to determine the depth to the economic Basement (Horizon-1), Top Carbonates (Horizon-3), and the top of a shallower horizon (Horizon-4).

The primary tool employed in this project was Energy Spectral Analysis (ESA). A new refinement of the spectral analysis technique was conducted in two stages:

- First, to identify magnetic or gravity interfaces, the ESA-MWT was run at stations located on a 4km by 4km mesh over the whole project area. MWT was used to compute the average depths to the targeted horizons and to construct the horizon skeleton maps. MWT was instrumental in overcoming some of the limitations of the spectral method as traditionally employed, by detecting the optimal window sizes required for detailed mapping at every MWT station.

- The second stage, the detailed horizon mapping involved an application of the ESA-MW technique. The spectra are computed and interpreted for the optimal window size determined from the MWT *'depth-plateaus'* over a dense mesh 1.4km by 1.4km for each mapped horizon.

ACM was used along profiles to define major faults and lineaments, and forward modeling undertaken to confirm the interpretations.

Method

Energy Spectrum Analysis

ESA is a well established technique for estimating the depth to a (magnetic/gravity) horizon, originally based on the work of Bhattacharyya (1966). Following Spector and Grant (1970), a magnetic/gravity interface is modeled by a statistical layer of magnetized multi-prisms. The logarithm of the radial average spectrum plotted vs. radial frequency produces a curve that has a slope proportional to the depth. In order to obtain an estimate of depth in a localized area, ESA is applied to a windowed sub-region of the potential field data. By performing ESA-MW procedure at multiple locations, a depth map of the interface can be produced (Kivior et al. 1993).

ESA Window Size

The most important factor for applying the ESA-MWT procedure is determining the correct window size. If the window is too small, it will not incorporate enough of the data for successful imaging of the horizon; if it is too large, the low frequency spectral decay will be dominated by deeper magnetic/gravity sources. The MWT estimates the depth over a span of window sizes centered over a point of interest (MWT station); estimates that are not sensitive to window size correspond heuristically to magnetic susceptibility or density interfaces.

The MWT procedure consists of calculating energy spectra over a series of increasingly larger windows (Figure 2), all centered over a point of interest. Ranges of window size where the derived depth value is nearly constant, *"Depth-Plateaus"*, indicate both a suitable window size for performing ESA-MW in the neighborhood and the approximate depth to the causative magnetic/gravity interface. Coupled with fast, automatic spectral decay estimation, the MWT can be applied along a profile or over a whole survey area on a regular mesh (Figure3a), to quickly map both depth estimates and stable window sizes for ESA-MW. It is quite possible for each station to have multiple depth-plateaus, and these can often be successfully identified with distinct magnetic susceptibility or density interfaces. At any station, the MWT may identify from the depth-plateau the approximate depth to the mapped horizon and estimate the corresponding optimal window size. Plotting all depth-plateaus along a profile can simultaneously image multiple horizons. Depth-plateaus identified as the same interface, form a coarse image of the detected horizon, called a *'horizon skeleton map'* (Figure 3a).

Geological Setting

Block SK333 covers the onshore Baram Delta located in Sarawak, Malaysia. The tectonic evolution of this region is dominated by the interaction between the Eurasian continental plate, the oceanic Indian and continental Australian plates and the oceanic Pacific plate. The interactions between these plates make the region geologically complex with two tectonic models, which show either an extension or subduction of the South China Sea. The major tectonic events that affected the region are the Eocene Sarawak Orogeny and the Eocene-Early Oligocene Sabah Orogeny. The Baram Delta overlies two different structural blocks, in the south it overlies the relatively stable Luconia Block and to the north of the West Baram Line it overlies the more active subsiding West Baram Delta. The top of the economic basement corresponds with the Deep Regional Unconformity (DRU), below which lies the Mesozoic Ragang Group, a highly deformed mélange of deeply buried sediments. This accretionary complex is overlain by the Eocene sand-rich West Crocker Formation and the Belait Formation sandstones.

Results

Horizon Mapping in the Baram Basin

We applied the ESA-MWT to magnetic and gravity data sets across the study area at the stations located at 4km by 4km mesh. MWT was used to estimate spectral decay, in order to detect depth-plateaus to obtain an average estimate of the depth to the targeted horizons and to identify optimal window sizes for more detailed horizon mapping (ESA-MW).

Figure 2 shows an example of the MWT graph at one station computed from the gravity data, where the depth-plateaus are showing the stability of the depth solution with respect to window-size. Each depth-plateau represents a density contrast related to the following horizons, economic Basement (Horizon-1), Top Carbonate (Horizon-3) and an additional shallower sedimentary horizon (Horizon-4). Similar procedures have been repeated for each station all over the area. Depth-plateaus were identified and approximate average depths from the plateaus were used to construct a skeleton map of Horizon-1, Horizon-3 and Horizon-4 from gravity data. The magnetic data was analyzed in a similar manner. The MWT stations were repeated on the same regular mesh over the whole area. The plateaus were identified and skeleton maps were constructed based on approximate average depths for Horizon-2 and Horizon-4. An example of the skeleton map for Horizon-1 is shown in Figure 3a. For both data sets, for each single station, for each separate horizon the optimal window size was determined from the depth-plateaus and used to perform detailed horizon mapping.

The detailed mapping was undertaken using the ESA-MW technique. For each horizon and each data set, spectra of different window sizes were computed at a very dense mesh of 1.4km by 1.4km. The detailed maps of the following horizons were produced: from gravity, economic Basement (Horizon-1), Top Carbonate (Horizon-3), the shallower intra-sedimentary horizon (Horizon-4). From magnetics, Base Carbonate (Horizon-2), and the shallower intra-sedimentary horizon (Horizon-4) from both data sets. As we analyse potential field data representing different rock properties, the same horizons cannot necessarily be imaged from both magnetic and gravity datasets.

In Figure 3 there is a comparison between the basement skeleton map and the high resolution detailed map. It is clearly visible that detailed mapping highlights many small features and structures which could be of great importance for petroleum exploration. Detailed mapping outlines high resolution details that are not visible on the skeleton maps. Both, the skeleton maps and final detailed horizon maps were QC'ed by comparison with well, seismic data and forward modeling of the magnetic and gravity data using the generated surfaces. As shown in Figure 4, there is a very good correspondence between horizons detected from magnetic and gravity with those derived from seismic.

Conclusions

We can conclude that in the Baram Basin the analysis of magnetic and gravity data can provide very good estimates of depths to magnetic susceptibility and density interfaces. The MWT technique identifies magnetic susceptibility and density contrasts which can be mapped as continuous surfaces. Further, the ESA-MW technique is a valuable tool for producing detailed images of the sedimentary horizons.

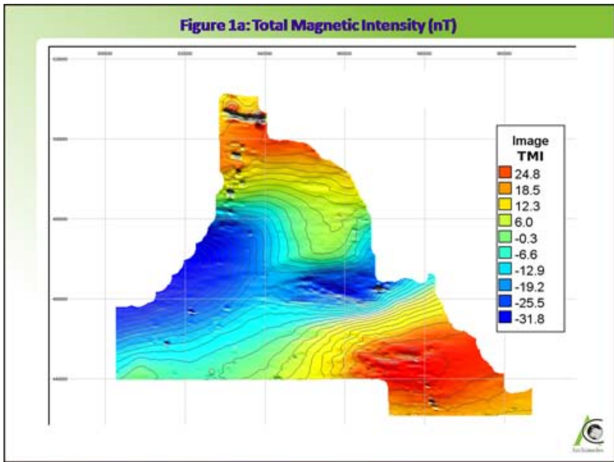

Figure 1a: Total Magnetic Intensity (nT)

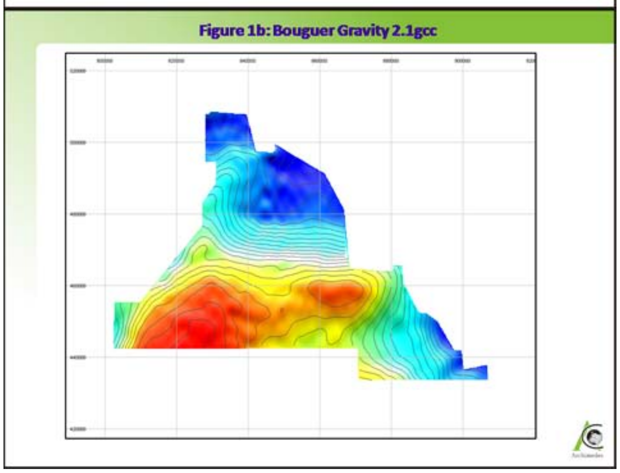

Figure 1b: Bouguer Gravity 2.1gcc

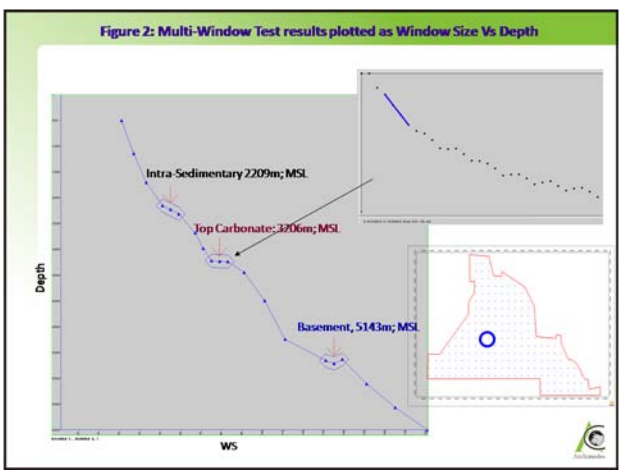

Figure 2: Multi-Window Test results plotted as Window Size Vs Depth

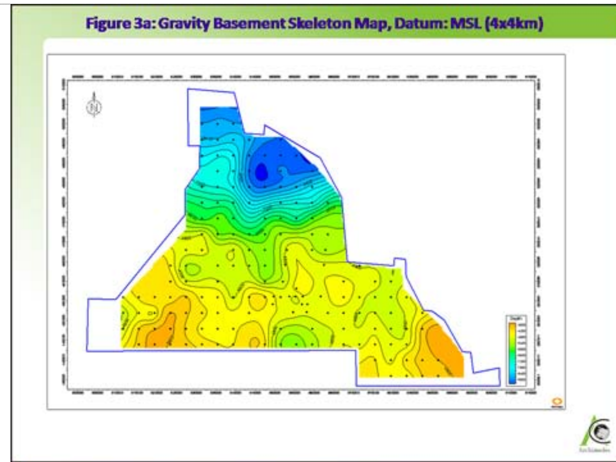

Figure 3a: Gravity Basement Skeleton Map, Datum: MSL (4x4km)

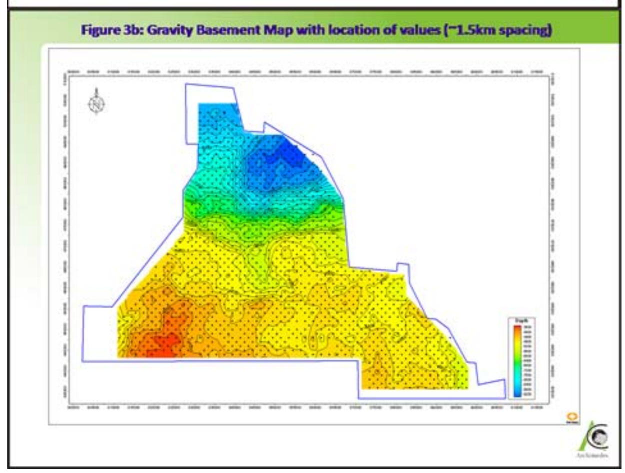

Figure 3b: Gravity Basement Map with location of values (~1.5km spacing)

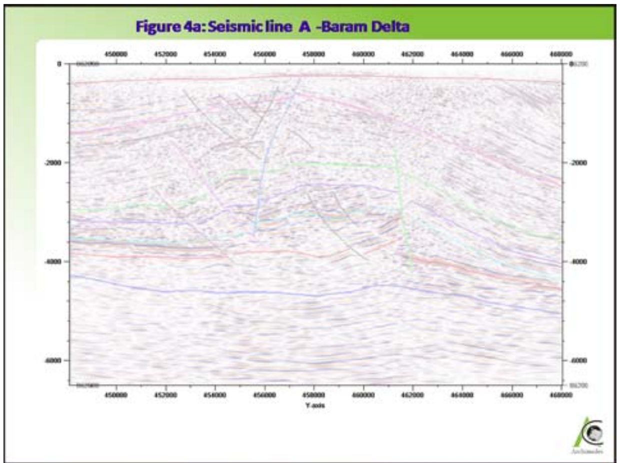

Figure 4a: Seismic line A -Baram Delta

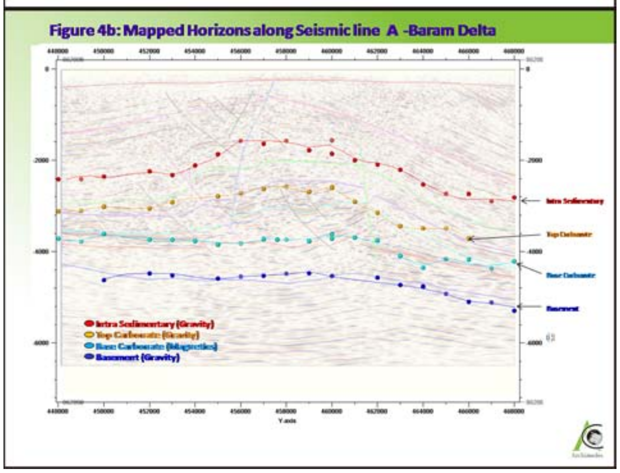

Figure 4b: Mapped Horizons along Seismic line A -Baram Delta

Acknowledgments

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