1346373 Regional Mapping of Basement and Sedimentary Interfaces in the Deep Waters of the Andaman Sea Basin using Marine Magnetic and Gravity Data

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Summary

This paper presents the results of a magnetic and gravity study, which aimed to map the top of crystalline basement and other detectable sedimentary interfaces as well as associated structures (magnetic lineaments) over an area of about 15,000 km^2 in the deep water part of the Andaman Sea basin, in offshore Myanmar, with water depth ranging from 1100m to 2900m.

Marine magnetic and gravity data acquired in 2010 simultaneously with a regional 2D seismic survey, over part of the deep water Andaman Sea basin, was interpreted using an in-house Energy Spectral Analysis technique - the Multi- Window Test (ESA-MWT) technique - to map magnetic and density interfaces, which were subsequently correlated to the tops of Pre-Tertiary crystalline and economic basement and a Tertiary inter-sedimentary erosional surface. The Automatic Curve Matching (ACM) technique was applied for the interpretation of magnetic lineaments. The magnetic and gravity study shows that sediment thickness within the study area may reach up to 12km.

Application of the Multi-Window Test (MWT) technique to energy spectra computed from magnetic or gravity data allows detection of magnetic or density contrasts, which often correspond to sedimentary interfaces. The potential field results correspond well with seismic interpretation.

The Multi-Window Test technique has been successfully applied in the Andaman Sea basin and proved to be a valuable tool in producing a robust interpretation of the potential field data.

Introduction

The Andaman Sea basin is one of the active back-arc basins of the world, where an oblique subduction of the oceanic Indian plate beneath part of the continental Southeast Asian plate and related extension and rifting has resulted in the formation of the back-arc Andaman Sea basin. With regard to petroleum exploration and related studies, much of the Andaman Sea basin in general and the studied part of the basin in particular is still considered frontier area.

A magnetic and gravity study, aimed at mapping the top of crystalline basement and other detectable sedimentary interfaces as well as associated structures (magnetic lineaments) was conducted over part of the Andaman Sea basin, in offshore Myanmar. The study area extends between latitudes 11º N to 13º N and longitudes 95º 30'E to 96º 30'E, covering a total area of about 15,000 km^2 in the deep waters of the Andaman Sea, with water depth ranging from 1100 to 2900m.

Horizon mapping was conducted in a process, which involved first computation of energy spectra from gridded magnetic and gravity data and then applying an in-house Energy Spectral Analysis technique – the Multi-Window Test (ESA-MWT) Technique. The ESA-MWT technique enables detection of magnetic or density interfaces as depth-plateaus. Detected depth-plateaus are correlated laterally to map a particular horizon. Magnetic lineaments were mapped at various crustal levels using the Automatic Curve Matching (ACM) technique, to help reveal the structural fabric of the area and to aid in horizon mapping.

Regional Geological Setting

The study area is situated in the tectonically active Andaman-Sumatra subduction margin (Figure 1), which displays complex regional tectonics including a subduction trench (the Andaman-Sumatra Trench), major regional faults onshore and offshore, shoreline delta regions supplying large quantities of fluvial sediments, an active back-arc spreading centre, island arcs and seamounts.

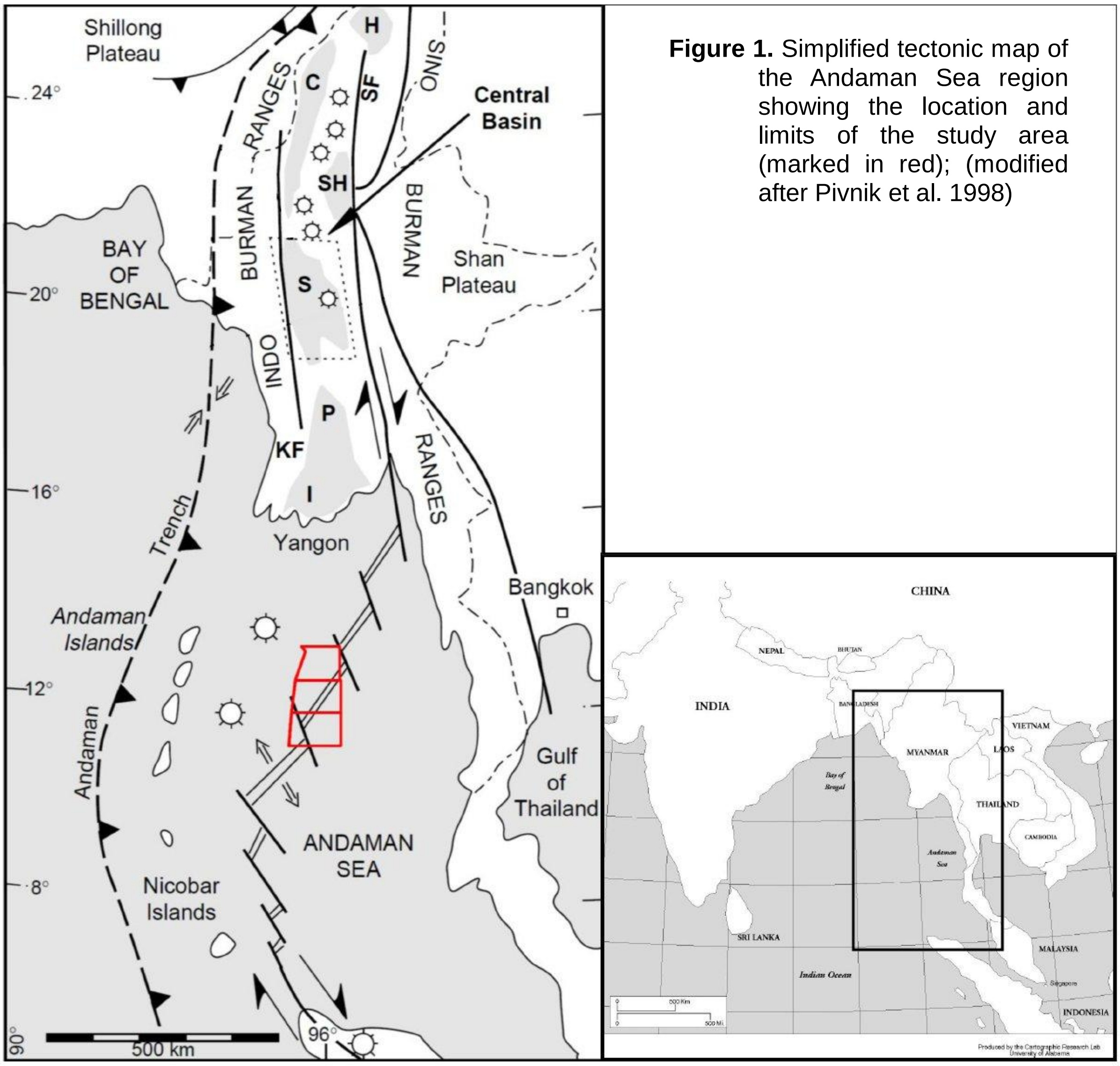

Figure 1. Simplified tectonic map of the Andaman Sea region showing the location and limits of the study area (marked in red); (modified after Pivnik et al. 1998)

The formation of the Andaman Sea basin is believed to have occurred due to back-arc extension and spreading within the central Andaman trough (Chakraborty and Khan 2009) relating to the oblique convergence subduction of the Indian plate beneath part of the continental Southeast Asian plate.

Basin formation is believed to have occurred in two phases: an early (~11 Ma) stretching and rifting, followed by active spreading since 4–5 Ma (Chakraborty and Khan 2009). An oceanic crust basement made up of back-arc volcanics forms the western part of the study area, while the eastern part is thought to be floored by a transitional attenuated continental crust of Pre-Tertiary granitic and metamorphic basement. The basement is overlain by a sedimentary succession of clastics and carbonates ranging in age from Late Eocene to Recent.

Data Description

The marine magnetic and gravity data used in this study was acquired in 2010 during regional 2D seismic survey, with a gravimeter located in the seismic office at the nominal waterline, and a magnetometer towed behind the ship below the water surface. The survey had a shiptrack spacing of 4km (EW in the northern half of the survey and WNW to ESE in the southern half), and tie line spacing of 12km in NS and NNE to SSW directions respectively (Figure 2).

Bathymetry data was acquired using an echo sounder system. The Free-Air and Bouguer gravity data as well as the Total Magnetic Intensity (TMI) data were gridded with an 800x800m mesh (Figures 3, 4 and 5 respectively).

The Total Field Intensity is 42,015nT. The inclination and declination of the centre of the area are 10º 6' and -0º 50' respectively. The low magnetic latitude of the survey means that magnetic anomalies may not overlap with their causative source bodies. In the present study, the most important effect on the TMI data is that the centres of the magnetic source bodies have a magnetic low close to them rather than a magnetic high.

The standard practice is for the TMI data to be Reduced to the Pole (RTP), as this transformation shifts the centre of a magnetic anomaly over the centre of the body generating the anomaly. At these low magnetic latitudes, however, the standard transformation selectively amplifies anomalies and noise in the direction of the magnetic declination. Hence, the Reduction To the Equator (RTE) transformation rather than RTP was applied. The RTE transformation, however, produces a magnetic low over the centre of magnetic bodies, so a 180º phase reversal was applied to the RTE data (Figure 6) to place magnetic highs over the source bodies, enabling direct comparison with the Bouguer gravity data. The Energy Spectral Analysis method is not affected by this, as it analyses spatial frequencies in the data rather than amplitudes of anomalies.

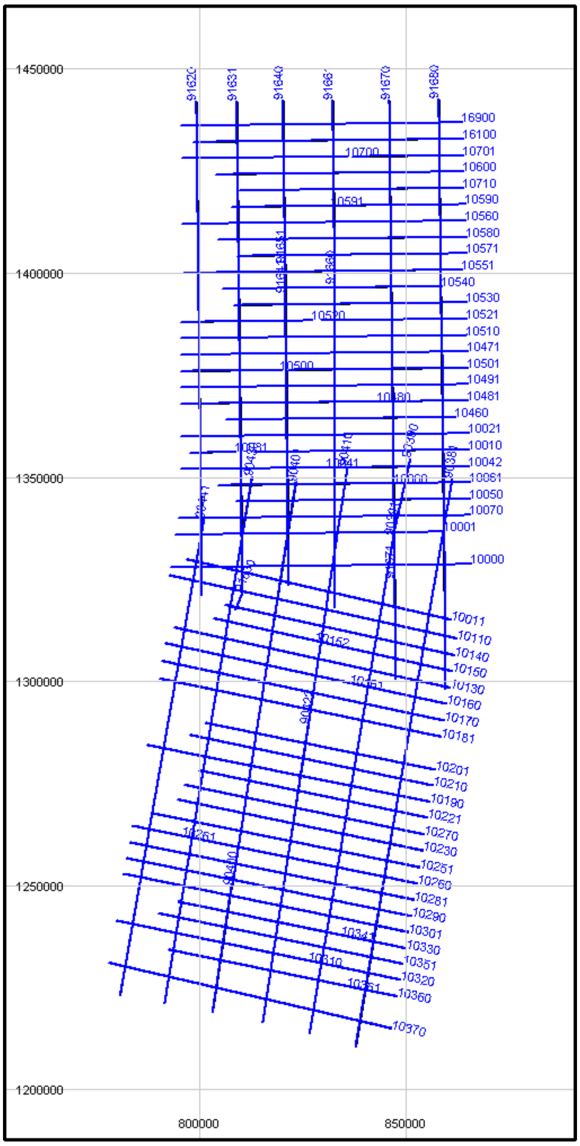

Figure 2. Magnetic and gravity survey, traverse and tie lines

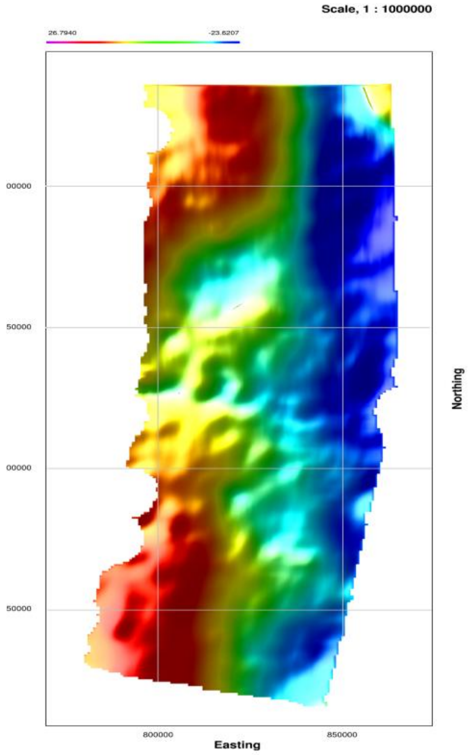

Figure 3. Free Air Gravity

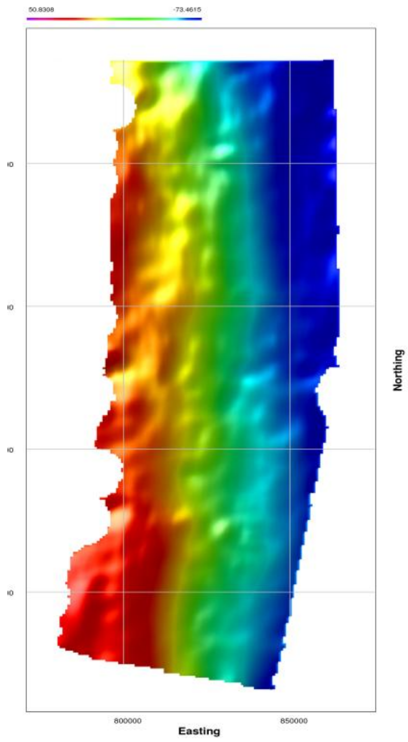

Figure 4. Bouguer Gravity

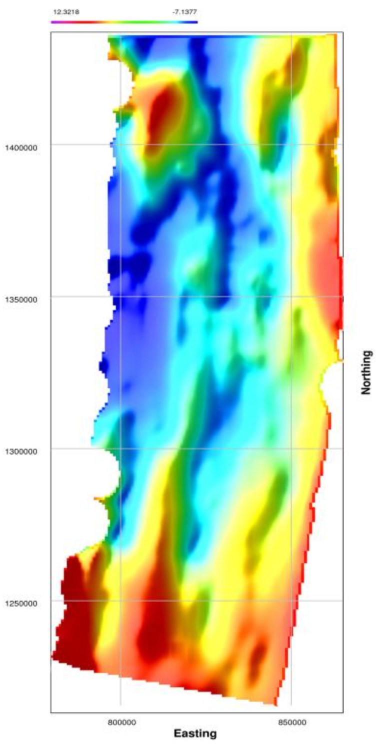

Figure 5. Total Magnetic Intensity

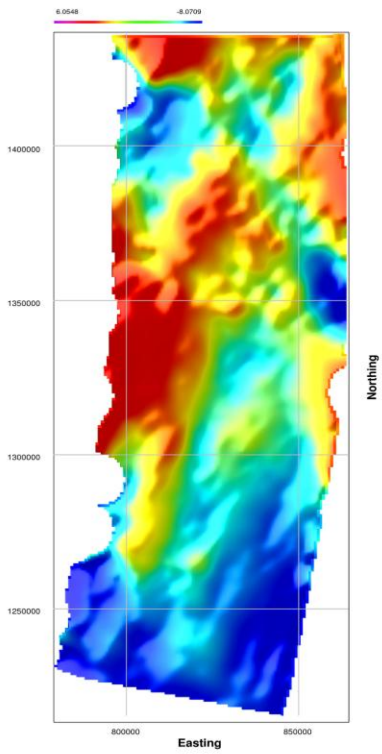

Figure 6. Reduced To Equator

Methodology

Energy Spectral Analysis (ESA) is a well established technique for estimating the depth to a magnetic/density interface, originally based on the work of Bhattacharyya (1966). Following Spector and Grant (1970), a magnetic/density interface is modelled by a statistical layer of multiprisms with uniform susceptibility or density. The logarithm of the radially averaged spectrum plotted against radial frequency produces a function where slopes tangent to the decay of the function are proportional to the depth to source(s) (Figure 9D). 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 the ESA-Moving Window (ESA-MW) procedure at multiple locations on a regular mesh or along profiles (Figure 8), a depth map of the interface can be produced (Kivior et al. 1993).

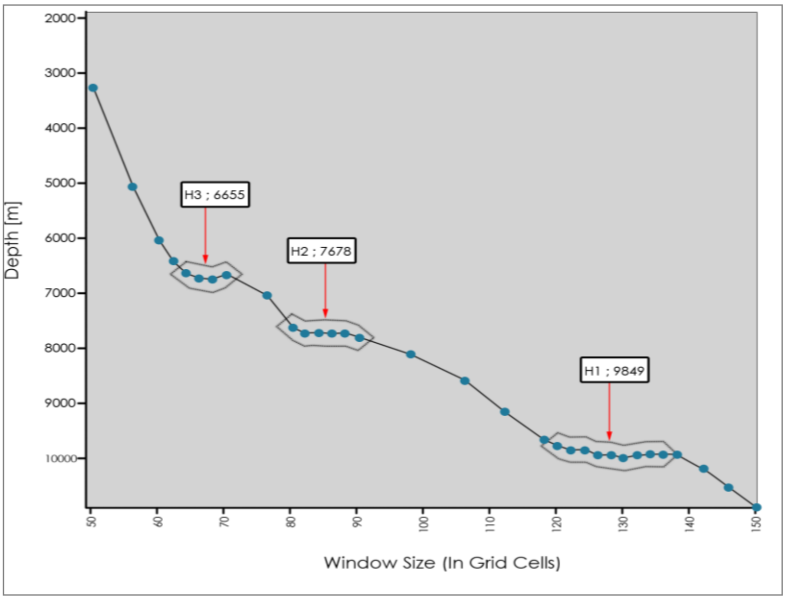

Figure 7. An example window size versus depth plot showing 3 depth-plateaus corresponding to the 3 mapped horizons

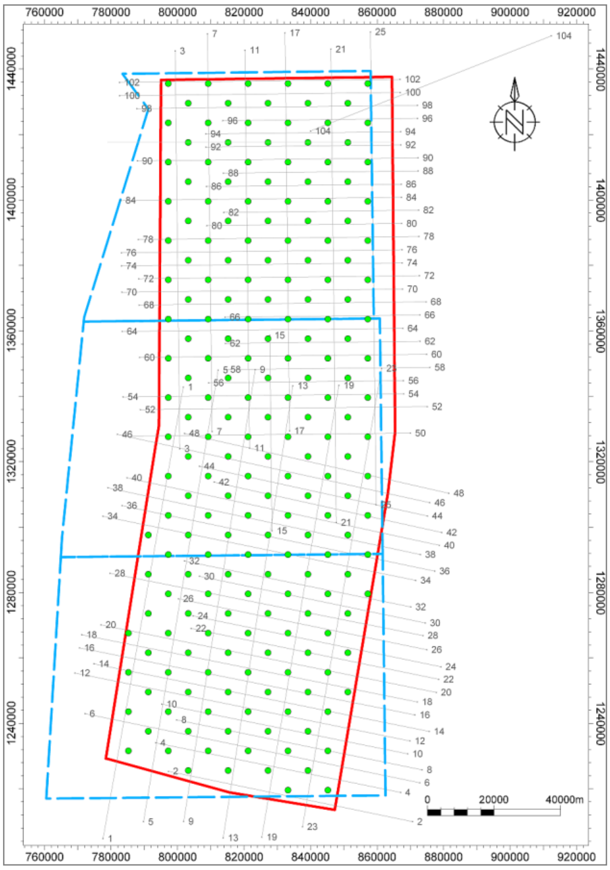

Figure 8. Location of ESA-MWT test stations (green circles) and survey lines

The most important factor for applying the ESA-MW procedure is determining the correct window size. A small window would not include enough data to successfully image the horizon; while a window that is too large will be dominated by deeper sources. The Multi-Window Test (MWT) procedure estimates the depth over a series of increasingly larger window sizes centred over a point of interest, MWT station (Figure 9C). Ranges of window sizes where the estimated depth value is nearly constant, "depth-plateaus", indicate the approximate depth to magnetic/ density interfaces. These also indicate a suitable window size for detailed mapping (ESA-MW) in the vicinity of the station (Figure 9E). At each MWT station, multiple depth-plateaus may be detected, and these can often be successfully identified as distinct magnetic susceptibility or density interfaces (Figure 7).

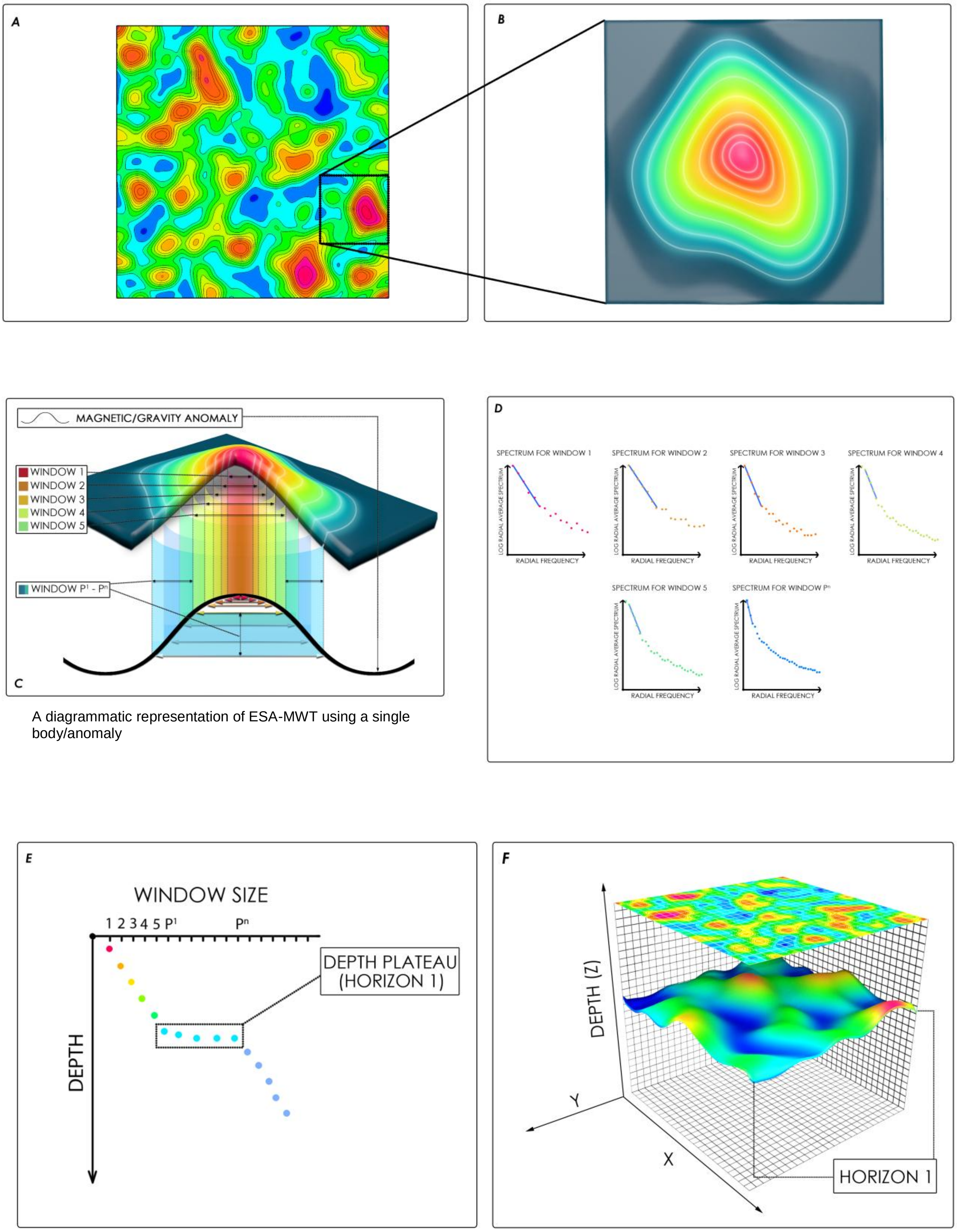

Figure 9. A simplified representation of the ESA-MWT horizon mapping procedure; beginning with a magnetic/gravity anomaly map (A & B), over a statistical layer of an ensemble of multi-prisms (C), ESA-MWT, applied through interpretation of spectra computed from windows of increasing size (D), identifies a depth-plateau (E); analysis of depth-plateaus detected over a coarse mesh of ESA-MWT stations covering the study area produces a skeleton map of a magnetic/gravity horizon (F).

Horizon Mapping in the Andaman Sea Basin

The ESA-MWT method was applied on both the magnetic and gravity data sets to detect and map magnetic and density interfaces which were subsequently correlated to the tops of crystalline and economic basement and an inter-sedimentary erosional event. Mapping of each of these horizons was carried out in a staged approach commencing with the build-up of a coarse mesh skeleton (framework) map followed by a relatively denser mesh detailed mapping.

The skeleton map of a horizon is generated by applying ESA-MWT over a coarse mesh of stations with the aim of identifying a depth-plateau corresponding to the particular horizon of interest. While identification of such a depth-plateau from a set of candidate depth-plateaus is an interpretive process, it is conducted based on consideration of several factors such as window-size and frequency interval continuity, and in tandem with information from anomaly separation filters and structural ACM interpretation. Further, where available, various geological information such as well and seismic data are used to constrain the interpretation.

In the present study, ESA-MWT skeleton mapping tests were conducted over a coarse grid of 12km by 12km + 5^{th} (centre) point mesh of stations (Figure 8). Analysis of the multiple depth-plateaus detected at each station allowed the progressive build-up of skeleton maps of 3 horizons, herein referred to as H1, H2 and H3. Final detailed mapping of these horizons was carried out on a 6km x 6km mesh.

The interpretation defines, in all the mapped horizons, two distinct structural elements: a platform (shelf) area in the eastern part of the study area and a basin area in the west. These structural features are divided by an approximately N-S trending central escarpment area. The central escarpment area shows highest westward dip on H1 and has relatively gentler slope on H2 and H3 horizons.

Integration with seismic and other available data

On the basis of the spectral and other related characteristics of the depth-plateaus used to define the horizon, the deepest mapped horizon H1 is interpreted as the top of the crystalline basement. Depth to the interpreted crystalline basement (H1) within the study area varies from about 7.5km below sea level in the southeastern extremity of the study area to about 12km near the southwestern edge of the study area (Figure 10). These depth estimates compare well with total sediment thickness estimates from previous studies conducted in the Andaman Sea region. For instance, Mukhopadhyay and Krishna (1991), based on gravity modelling, estimated maximum sediment thickness of the order of 10-12km at the area they refer to as the “Andaman-Burmese subduction zone”, an area that roughly coincides with the back-arc basin that this magnetic and gravity study area is part of. Morley (2009) put a figure of about 12km as the total sediment thickness accommodated in the adjacent Central Basin, a Tertiary sedimentary basin which forms the northern extension of this study area.

The interpreted H2 horizon was defined by the next continuous set of depth-plateaus above the H1 horizon. The depth to H2 horizon within the study area ranges from about 5.5km to about 10km below sea level (Figure 11). This depth range was found to have good correlation with depth estimates of seismic (acoustic) basement, which in this region coincides with economic basement. Stratigraphic information from the more explored adjacent region south of the study area indicate that Pre-Tertiary and younger meta-sediments, for instance the Eocene Tampur Formation carbonates in the Mergui-North Sumatra basin, form the economic basement (Carnell and Wilson, 2004). Crystalline basement may be significantly deeper than seismic (acoustic) basement, where the latter coincides with economic basement.

The interpreted H3 horizon was the shallowest mappable horizon detected from the magnetic and gravity interpretation ranging in depth from 4.5 km to 8.9km below sea level (Figure 12). Comparison with seismic interpretation carried out along some seismic profiles indicates that the horizon shows broad correlation with a Tertiary erosional surface event picked on seismic.

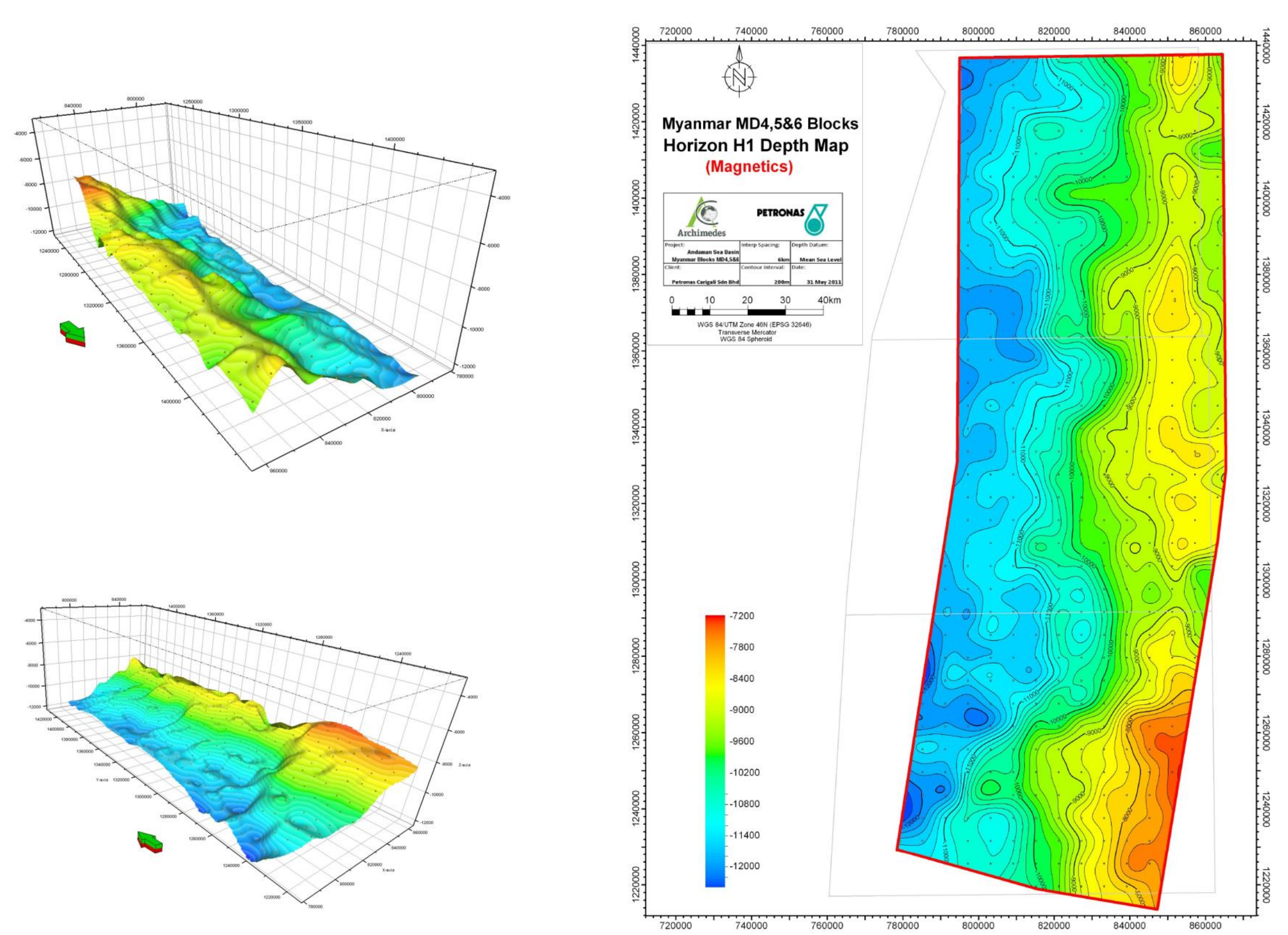

Figure 10. Horizon H1 (Top Crystalline Basement) depth map (right) and in 3D views (left); dots represent interpretation locations; Contour interval: 200m; depth datum: Mean Sea Level.

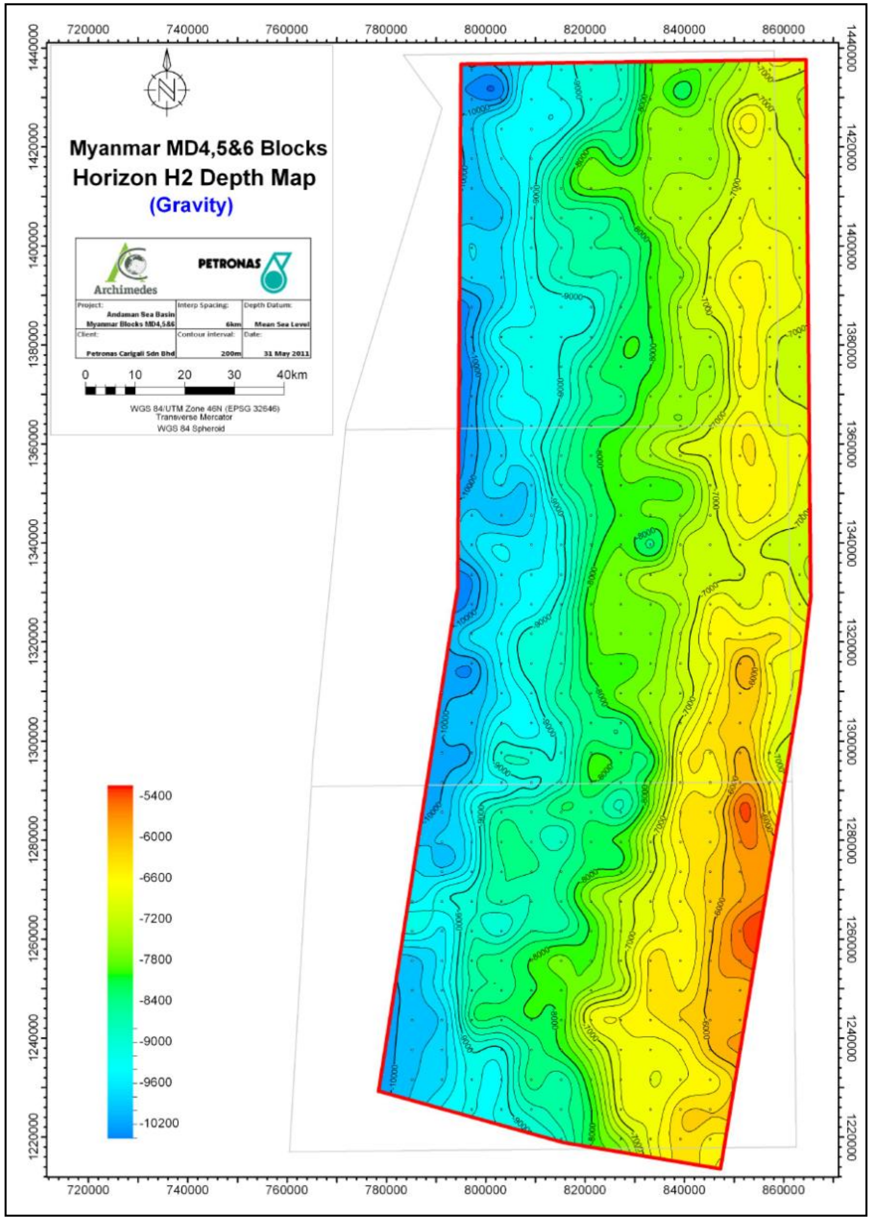

Figure 11. Horizon H2 (Top Economic Basement) depth map; dots represent interpretation locations; Contour interval: 200m; depth datum: Mean Sea Level.

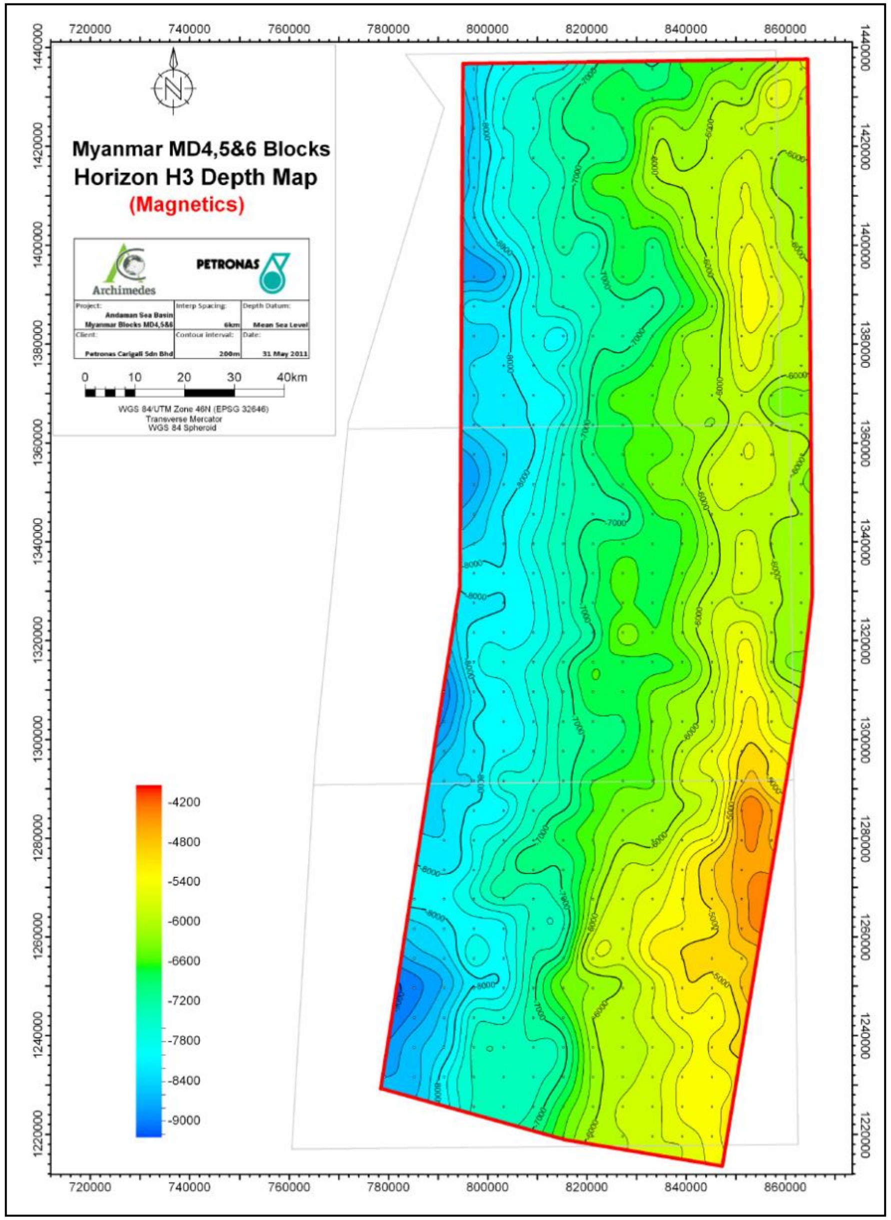

Figure 12. Horizon H3 depth map; dots represent interpretation locations; Contour interval: 200m; depth datum: Mean Sea Level.

Conclusions

Application of the ESA-MWT method on magnetic and gravity data proves to be a useful and robust method in mapping deep crystalline basement as well as sedimentary interfaces. The interpreted magnetic and gravity horizons generally show good broad correlation with corresponding seismic events as well as with the known tectono-structural configuration of the area and the surrounding geology. In a frontier region with limited or no well penetration, such as the studied part of the Andaman Sea basin, integrated use of magnetic, gravity and seismic data provides better outcomes.

Acknowledgments

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