Mapping basement relief of Abu Gharadig Basin, Western Desert of Egypt using 3D inversion of pseudo-gravity data

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SUMMARY

There are a number of magnetic inversion methods that have been developed to map the structure and depth of sedimentary basins, assuming that sediments are non-magnetic and underlain by magnetic basement. Gridding/mapping the basement depth estimates from such methods has two significant problems: 1) the magnetic results are dominated by signals coming from the top edges of basement faults such that the depth information from the down thrown sides of the faults is not captured and 2) within the centres of large basins there is often little variation in the magnetic anomaly to provide depth estimates such that when gridding the depth data, grid interpolation has to rely on a sparse distribution of estimated depths.

In this study we convert the magnetic data into pseudo-gravity which is then inverted to produce a 3D basin model with a constant susceptibility basement. This overcomes the interpolation problem since the 3D model now uses the complete pseudo-gravity field as well as the magnetic depth estimates to constrain the depth model. The method is applied to the Abu Gharadig basin, Western Desert, Egypt and generates results which match well controls on basement depth. The advantages of this method over 3D gravity inversion are that the pseudo-gravity response is not affected by structure within the sediments and is not compensated isostatically as the gravity response of basins often is affected.

Key words: magnetic, inversion, pseudo-gravity, depth, basement

INTRODUCTION

The magnetic exploration method – particularly applied to aeromagnetic data – is routinely used in a variety of geological and exploration settings to identify the location and properties of magnetic rocks. A particular application is the mapping of the basement morphology below sedimentary basins. This "depth to basement" mapping is a cost effective tool in the analysis of frontier sedimentary basin areas. A range of semi-automated methods including Euler Deconvolution (Reid et al., 1990), Source Parameter Imaging (Thurston & Smith, 1997) and Tilt-depth (Salem et al., 2007) are now routinely used to facilitate this process. These tools do not make direct assumptions about magnetic properties and can generally be tuned to particular shapes of geological features (via e.g. "structural index"). They all tend to identify the top edges/corners of magnetised geological structures that have vertical extent (dykes, faults, contacts) due to the fact that they rely on (1st or 2nd order) derivatives of the magnetic field, which enhance the shorter wavelength anomalies and the shallower features. Thus for sedimentary basins, the basement flanks are generally well resolved, but the flat basin bottoms and the base of the bounding faults are not. This implies that the actual depths of the deepest parts of sedimentary basins are often missed or underestimated by such methods.

In contrast, the pseudo-gravity transform (Baranov, 1957) enhances the longer wavelengths of the magnetic field and images the bulk shape of magnetic bodies. The transform essentially consists of a Reduction to Pole operation to centre the magnetic anomaly over its causative body and a vertical integration to simplify the anomaly such that the pseudo-gravity anomaly due to a uniformly, induced magnetised body has the same shape as the gravity anomaly due to the same uniform density body. Pseudo-gravity has been used to map contacts (Pilkington, 2007), as an alternative domain for comparing observed and modelled magnetic fields (Kimbell et al., 2010) or for direct comparison of gravity and magnetic anomalies (Reeh and Aïfa, 2008). The pseudo-gravity can be analysed and modelled in the same manner as gravity data, but it remains a magnetic anomaly and can only be interpreted in terms of magnetisation (or susceptibility as induced magnetisation is effectively assumed).

In this study we invert pseudo-gravity using 3D gravity inversion software (GM-SYS 3D by Geosoft) and applying constraints from basement wells and tilt-depth solutions to map the basement of the Abu Gharadig basin, western Desert of Egypt (Figure 1).

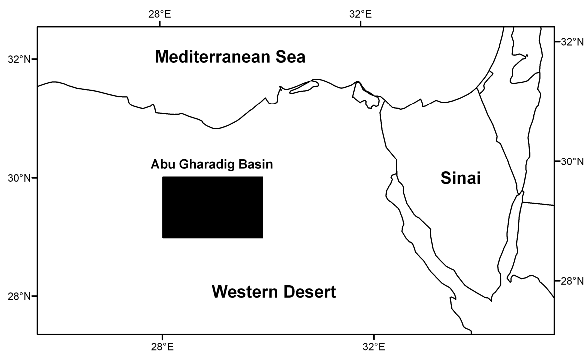

Figure 1. Location map of the Abu Gharadig basin, Egypt

GEOLOGICAL OUTLINE

The surface geology of the Abu Gharadig basin forms a gentle sloping plain with few topographical or geological features. Most of the surface is covered with gently-dipping, generally conformable Cenozoic strata; there is no basement outcrop nearby (Schlumberger, 1984). The Abu Gharadig basin is flanked by two relatively high structural units the Qattara Ridge to the north and the Sirte Platform to the south. The basin is also bounded to the east by the Kattanya High and to the west by the Gib Afia High. The structure of the Abu Gharadig basin is characterised by steep normal faults (Figure 2), having a long growth history, as deduced from seismic and borehole data (Awad, 1985). Some of these faults suffered strike-slip movement during their history. These movements were probably related to the lateral movements of the African plate during the Jurassic and Cretaceous. Most folds in this area result from compressional movements which affected the area during the late Cretaceous-early Tertiary tectonic events (Saleh, 2005). Based on interpretation of seismic data, the sedimentary thickness of Abu Gharadig may reach 12 km (Awad, 1985). Drill hole information from the Abu Gharadig basin indicated that there is a complex geological structure made up of a large numbers of swells and basins. The three basement wells (Figure 2) were used as direct constraints in this study; the remaining wells provide less direct constraints in terms of minimum depth to basement.

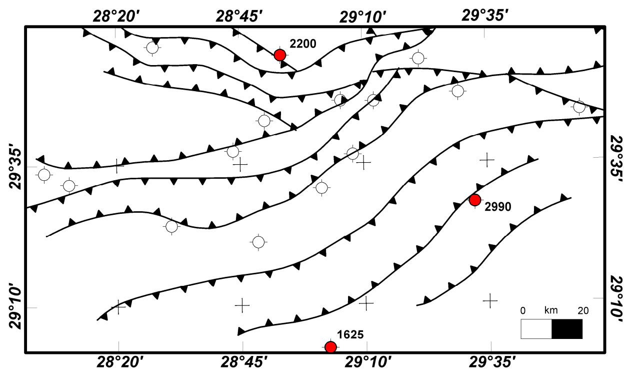

Figure 2. Location of wells in the Abu Gharadig basin with basement depths annotated. Faults are based on the seismic interpretation of Awad (1985).

MAGNETIC DATA

The Abu Gharadig basin was covered by an aeromagnetic survey in 1964. The survey was flown N-S with a line spacing of 3 km, at a constant barometric altitude of about 450 m. Figure 3 shows the reduced to pole magnetic data over the Abu Gharadig basin. Awad (1985) interpreted the magnetic anomaly data of the basin into three regions. The first region (A) represents the north-western part of the area which is characterised by high amplitude anomalies with moderate wavelength; anomalies A1 and A2 are attributed ultrabasic intrusions. The second region (B) is the basin itself, which exhibits anomalies with low amplitudes and long wavelength anomalies. The third is the south-eastern region (C), representing a platform with numerous short wavelength anomalies associated with shallow basement. On this platform, the Diyur well has penetrated granodiorite basement at about 1625 m.

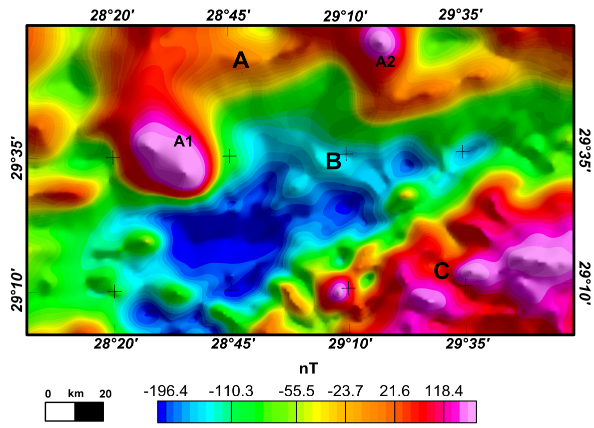

Figure 3. Reduced to pole magnetic anomaly map of the Abu Gharadig basin. A, B, and C are regions of different magnetic patterns. Note potential anomalous basement at points A1 and A2.

PSEUDO-GRAVITY TRANSFORMATION

Transformation of the magnetic data into pseudo-gravity is generally undertaken in the Fourier domain (Blakely (1995). The magnetic data were transformed to pseudo-gravity by integration of the RTP field with scaling such that the resulting field can be interpreted in terms of susceptibility variation. Figure 4 shows the pseudo-gravity map of the Abu Gharadig basin; it can be seen that the transformation has enhanced magnetic anomalies from deeper magnetic sources (longer wavelengths) and reduced the dominance of shallow magnetic sources (shorter wavelengths). The high amplitude anomaly at point A1 is still prominent. Figure 5 shows the total horizontal gradient of the pseudo-gravity data. Maximum values of the gradient indicate the locations of the structures within and around the main basin. These locations were detected using the technique of Blakely and Simpson (1986). The major bounding faults of the basin are clearly seen striking in the ENE direction; these are dissected by transform faults in the NW direction, which are, in fact, more clearly seen in the RTP map. High amplitude features around point A1 are probably indicative of changes in basement geology rather than structure.

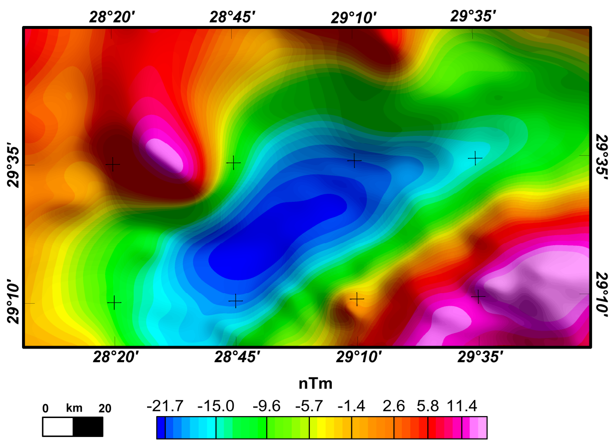

Figure 4. Pseudo-gravity map of the Abu Gharadig basin.

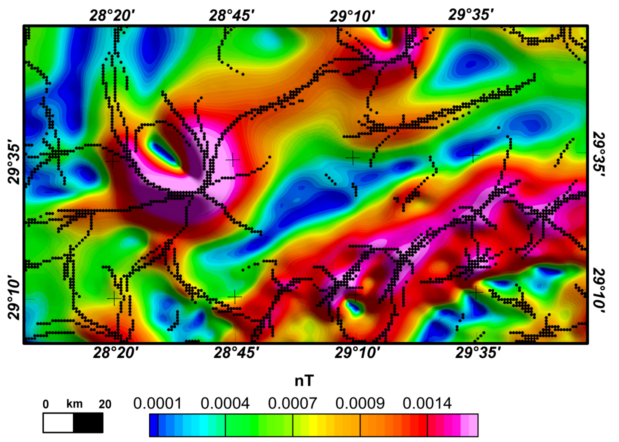

Figure 5. Total horizontal gradient of the Pseudo-gravity of the Abu Gharadig basin. The structural trends identified by the linear maxima are highlighted by the 'ridge grid' based on the method of Blakely and Simpson (1986).

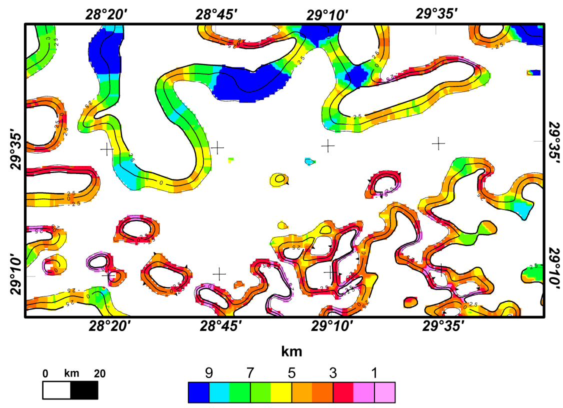

Figure 6. Tilt depth solutions of the Abu Gharadig basin.

3D INVERSION

To invert the pseudo-gravity data, we used GM-SYS software (Geosoft). This software implements the Fourier domain calculation of Parker (1973) to invert for a single constant density contrast surface. Here we assume that the sediments are non-magnetic and invert for a constant susceptibility basement; based on scaling in the pseudo-gravity transform, this susceptibility can be represented by the appropriate density in the gravity inversion software. As with gravity inversion for a basin, we need to ensure that the pseudo-gravity grid to be inverted is wholly ≤ zero and that any control points are honoured. This is achieved by adjusting the pseudo-gravity using a smooth surface so that it matches the control points. If no measured basement susceptibility data are available, the value must be based on knowledge of the regional geology. This value (in this case 0.001 SI) can, to some extent, be tested in the inversion process.

In the study area, there is no outcropping basement and only three basement wells to provide direct control. To generate more control points, we applied the Tilt-depth method (Salem et al., 2007) to estimate the depth to basement relief from the RTP magnetic data. The Tilt depth estimates and structural trends (Figure 6) clearly show a strong two dimensionality (striking ENE-WSW) in its regional character. These tectonic elements are seen in Figures 5 and 6 and are known from the published seismic interpretation (Figure 3) by Awad (1985). In contrast, the central to NE region has few depth solutions (Figure 6) and we would expect the greatest sedimentary thickness to occur in this area.

In addition to the wells which penetrate the basement, additional control points were used based on the Tilt-depth results of shallow structures around the edge of the basin. These depths mark the tops of basin bounding faults and are considered to be the most robust of the Tilt-depth solutions. We then used a simple slab formula (analogous to the Bouguer slab formula) to compute the expected pseudo-gravity at the control points. A smooth surface based on the computed values was used to adjust the pseudo-gravity data (Figure 7).

Note that the high amplitude anomaly at A1 is truncated at a value of zero in this adjusted pseudo-gravity map, despite the fact that the anomaly is expected to have a source at several km depth. The anomaly representing substantial lateral change in the magnetic properties of the basement will not fit the constant susceptibility model used in this study and the result must be considered to be erroneous. A more complex inversion would use a higher susceptibility in this area.

These adjusted data were inverted to produce the basement relief shown in Figure 8. The results of the 3D inversion suggest that the basin is elongated in the ENE direction with a maximum depth of 8 km The estimated maximum depth agrees well with the results of seismic interpretation and in general fits with the depths of non-basement wells. As noted, the significant basement high at point A1 is believed to be an artefact due to intra-basement variability and this part of the basin is, in fact, much deeper. For comparison, the gravity map of the area (Figure 9) shows considerable complexity due to structure and density variation within the basin. Although these anomalies can be used for detailed modelling of the basin, this gravity map is clearly not suitable for depth to basement inversion, without detailed data that could be used to strip out the intra-sedimentary features. Other potential problems with gravity inversion are that the density contrast at the basement can be quite small and that the anomaly of the whole basin can be compensated through isostatic processes.

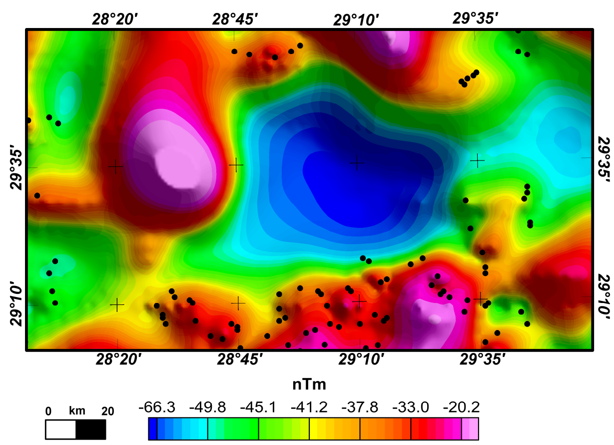

Figure 7. Adjusted pseudo-gravity map of the Abu Gharadig basin. Circles show the control points for the inversion based on wells and Tilt-depth solutions.

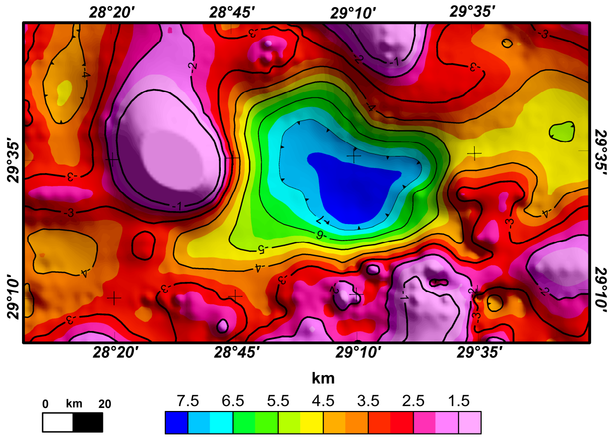

Figure 8. Depth to basement of Abu Gharadig using 3D inversion of the pseudo-gravity data.

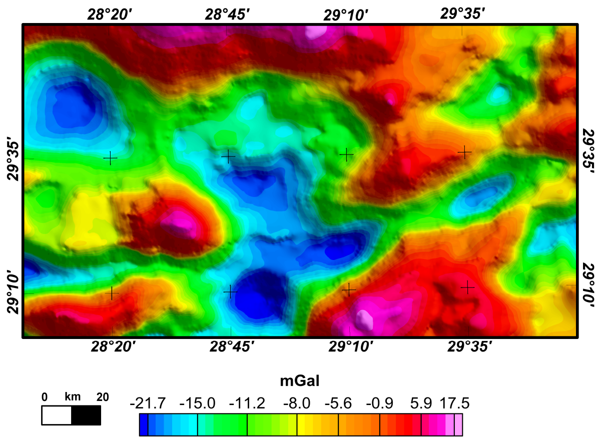

Figure 9. Bouguer gravity map of Abu Gharadig basin (Awad, 1985).

CONCLUSIONS

This simple approach to mapping depth to basement from 3D inversion of pseudo-gravity has proven successful. The fit of the results to the published and described geological information indicates that not only the approach, but also the details of the process and the susceptibility value used are reasonable and can provide insights to the basement morphology of the Abu Gharadig basin. The combination of tilt-depth and pseudo-gravity inversion has been shown to be appropriate in this study. It is clear that, as with gravity inversion, careful selection and application of available control data is essential to the success of the process. The variability of the magnetic properties of basement rocks might be expected to make this process problematic, but in this case, at least, there is only one area that is considered suspect. Inversion of gravity data over Abu Gharadig basin would be much more problematic due to the effects of structures within the basin. Thus 3D pseudo-gravity inversion together with depth estimates could be used more generally, together with control data and possibly 3D gravity inversion to increase the confidence of basement mapping from magnetic data.

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