Mapping horizons and fracture patterns in coal measures using magnetics for coalbed methane exploration in Queensland

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Introduction

Integrating seismic data with potential field data is valuable in coal seam gas (CSG) exploration.

In the Red Hill area, part of the northern Bowen Basin where there is active exploration for CSG, a study was undertaken to map the top and base of coal measures and delineate fault and fracture patterns using high resolution aeromagnetic data. The mapped horizons were the top of the Fair Hill Formation and base of the Goonyella Middle Seam in the Permian Moranbah coal measures. The possibility of mapping these horizons was tested by applying the energy spectral analysis (ESA) method to gridded magnetic data. This horizon mapping technique has been used successfully in many other petroleum provinces to detect and map sedimentary horizons and the underlying basement, so the technique could be of significant value in CSG exploration and development.

A second technique, automatic curve matching (ACM), was applied to map faults and fracture patterns in 3D in the coal measures. This technique is designed to interpret single magnetic anomalies derived from causative sources in the sediments. From this, magnetic lineaments corresponding to faults in the coal measures were interpreted and numerous short extent magnetic features, showing fracture patterns, were mapped in the coal measures.

Geological setting

The Red Hill area is in the northern Moranbah region of the Bowen Basin. The coal units are part of the Fort Cooper and Moranbah coal measures from the Blackwater Group and are of Late Permian age. The two mapped formations were the top Fair Hill Formation in the Fort Cooper coal measures and the case Goonyella Middle Seam. These Permian coals were deposited under dominantly fluvial flood plain environments. Both targeted coal measures have tuff bands from volcanism that occurred at the time of deposition, which increases the likelihood of detection using magnetic data.

Data description

The magnetic data used for this study was acquired in 2002 (Goonyella) and 2004 (Red Hill) airborne surveys. The traverse spacing for both surveys was 40 m with a flight altitude of 50 m; the flight direction for the Goonyella survey was east-west while the Red Hill survey was north-south. The data from these two surveys, covering 7.5 km x 12.5 km, was merged and a uniform total magnetic intensity (TMI) grid was produced.

At the centre of the Red Hill area, the magnetic inclination is -51.52º and the declination is 8.51º. The merged TMI data was then put into a grid with an 8 m x 8 m mesh and was reduced to pole. Topographic data from the area was used to allow correction of the results to mean sea level.

Nine wells that intersected coal measures were drilled in this area and a short section of the seismic line (MGC92-3) was used to validate the results.

Methodology

Two main techniques were applied in this study:

- horizon mapping (energy spectral analysis—ESA) was applied to gridded magnetic data; and,
- fault and fracture detection (automatic curve matching—ACM) was applied to located profile data.

Horizon mapping

The horizon mapping technique was applied in two stages, which were Stage-1: horizon detection, and Stage-2: detailed mapping.

Stage-1: horizon detection

The energy spectral analysis multi-window test (ESA-MWT) procedure (Kivior et al, 2007) was applied to detect the approximate depth of magnetic heterogeneities at stations located on a regular mesh of 400 x 400 m. At each MWT-station, multiple spectra were computed and interpreted across increasing window sizes and a graph of the depth versus the window size was plotted (Kivior et al, 2012). When the window covers the anomaly properly, the depth stabilises and forms a depth-plateau (Fig. 1). By further increasing the window size, deeper depth-plateaus can be detected.

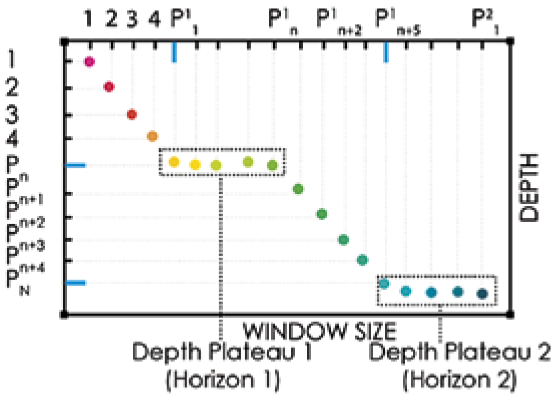

Figure 1. An example of a window size versus depth graph, showing depth plateaus.

The average depth from each depth-plateau is laterally merged with the depth-plateaus from surrounding MWT-stations and integrated with faults detected using the ACM technique, forming a skeleton map of the magnetic interface. This method was used to detect interfaces corresponding to the top and base of the coal. Each depth-plateau provides the optimal window size for higher resolution depth mapping described in the next stage.

Each skeleton horizon was validated by forward modelling, 3D inversion and by comparing them with seismic and well data.

Stage-2: detailed mapping

Using the optimal window size, spectra are computed and interpreted on a higher resolution mesh (100 x 100 m) and a final horizon map is generated. Using this technique, the top and base of coal measure configuration was mapped by laterally merging depth plateaus at different depths.

Fault and fracture detection

To detect faults and fracture patterns at different depths in the coal series and underlying and overlying sediments, the ACM technique was applied to located magnetic profile data extracted from the TMI grid, as well as observed line data. Each single anomaly arising from the targeted depth range is interpreted in an automatic manner and depth to the causative body, its geometry and its magnetic susceptibility is computed. The magnetic sources detected in the coal measures were visualised in a 3D cube. From this, magnetic lineaments corresponding to faults and short extent magnetic features portraying fracture patterns were interpreted at different depths.

Identification of faults is aided by several factors, including changes in magnetic susceptibility along a fault plane and contrasts in magnetic susceptibility between adjacent rocks. These make identification of both non-mineralised and mineralised faults possible and, presumably, open and closed fractures. ACM lineaments detected at different depths can be correlated and so fault faces can be delineated in 3D. A rose diagram of the magnetic lineaments corresponds to the stress field orientation at different depths.

Results

Top and base of coal

The Fair Hill Formation and the Goonyella Middle Seam were targeted because they contain highly magnetic volcanic tuff bands.

The two mapped magnetic horizons showed, based on well data, a good correlation with the top of the Fair Hill Formation and the base of the Goonyella Middle Seam, respectively. The top of the coal shows depth variations of 50–650 m and the base of the coal, 150–900 m below MSL. Both horizons show a similar east-dipping trend with the shallowest point in the west of the study area (Fig. 2).

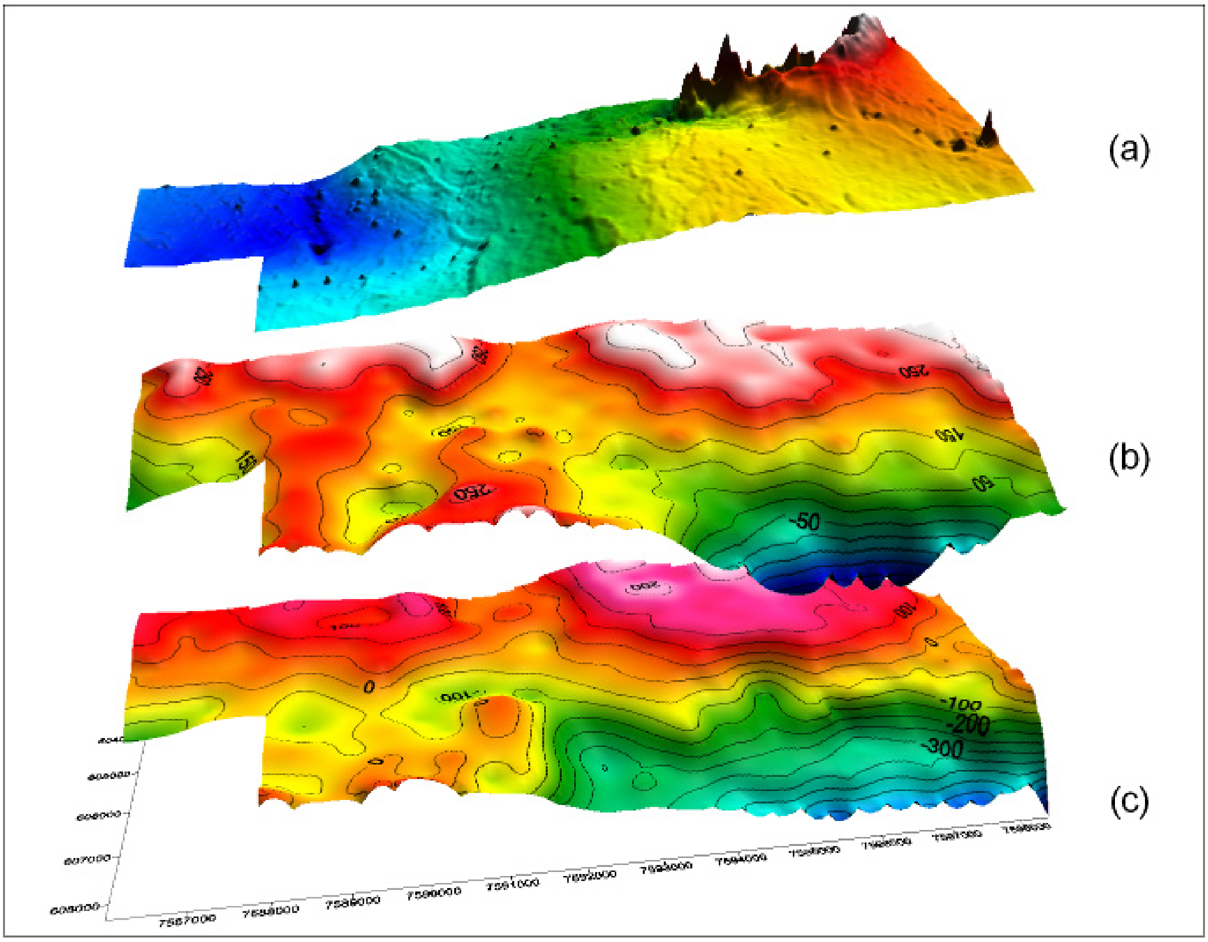

Figure 2. (a) Image of the magnetic data, (b) the top of the Fair Hill Formation and (c) the base of the Goonyella Middle Seam horizons.

Fracture and fault detection

Many faults and fractures are saturated with groundwater, which transports dissolved iron or sulphur to locations where the geochemical conditions change into a reduced environment, leading to the precipitation of insoluble iron sulphides and sometimes magnetite. The stress field applied to coal beds and adjacent formations determine which faults and fractures are open to the migration of groundwater and this can determine where the geochemical conditions are favourable for the formation of magnetic minerals. Fault and fracture orientation was interpreted by analysing the magnetic data using ACM to detect the depth to magnetic sources and their susceptibility. Lineaments were interpreted by assessing the alignment of magnetic sources, such as mineralised faults, while other lineaments were defined from the offset of magnetic markers. Swarms of short extent magnetic features corresponding to fracture patterns in the coal measures were also interpreted. The trends were then grouped into dominant orientations as shown in their rose diagrams (Fig. 3). The trends determined correspond to the known stress field orientation (Gillam et al, 2004).

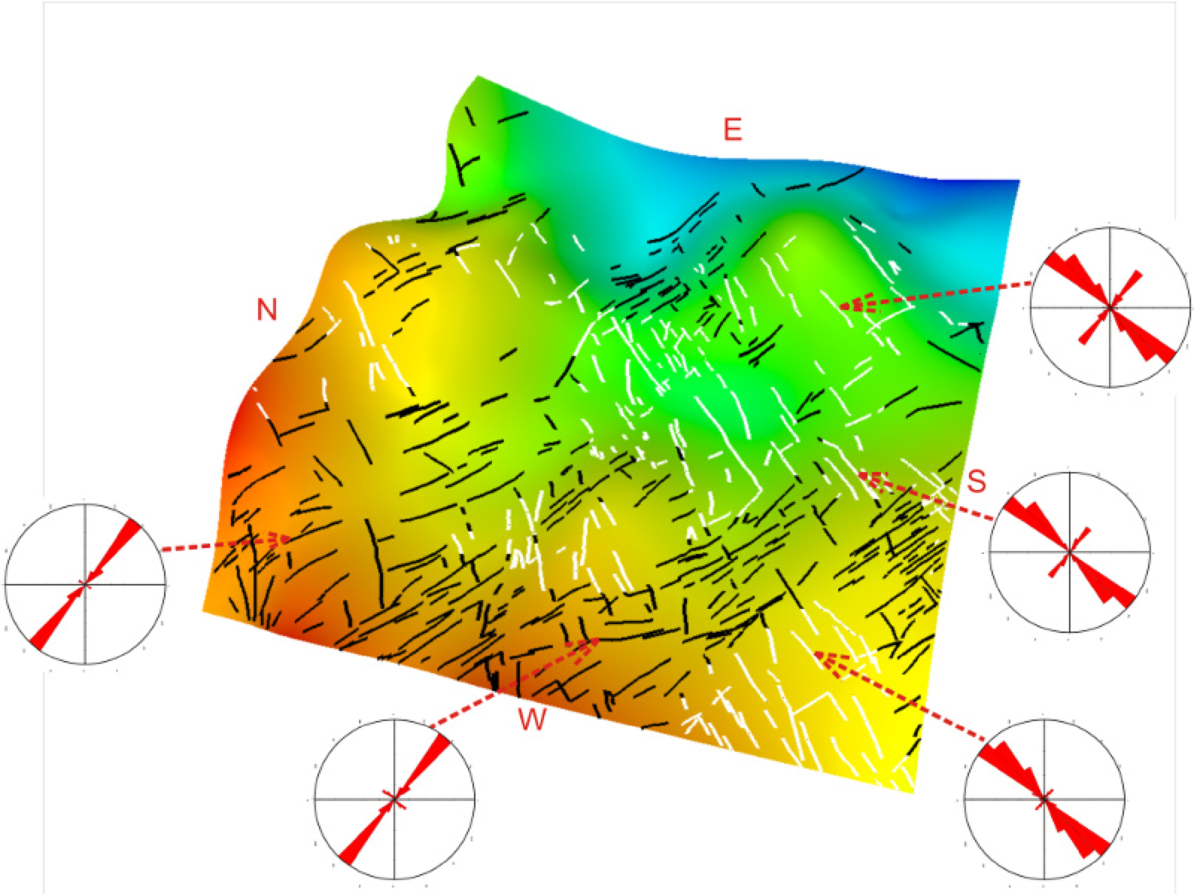

Figure 3. Fault and fracture patterns interpreted from magnetic data, shown on part of the top of the Fair Hill Formation horizon. The rose diagrams show the dominant orientations of lineaments and short extent features.

Conclusions

The case study in the Red Hill area shows that properly interpreted magnetic data can add value to coal bed methane exploration. By using the horizon mapping technique applied to high resolution magnetic data, the top and base of the coal measures were able to be mapped. The mapped formations were the top of the Fair Hill Formation and base of the Goonyella Middle Seam in the Permian Moranbah coal measures.

The ACM technique, applied to profile magnetic data, detected magnetic lineaments at different depths and this allowed the delineation of faults in 3D. Numerous short extent magnetic features, showing fracture patterns, were also mapped in the coal measures. The azimuth of the interpreted magnetic features was grouped by dominant trends for further analysis.

Understanding the fracture pattern in the target area is critically important for exploration and production. The use of these techniques for the interpretation of high resolution magnetic data makes hydrocarbon exploration more economical—particularly in areas where seismic acquisition is not possible.

References

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