Mapping sub-volcanic geology using magnetic data

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SUMMARY

Volcanic layers within sedimentary basins cause significant problems for petroleum exploration because the attenuation of the seismic signal masks the underlying geology.
A test study was conducted for the South Australia Government to map the thickness of volcanics and sub-volcanic geology over a large area in the Gawler Range Volcanics (GRV) province. The area is covered by good quality magnetic data. The thickness of volcanics and basement configuration was unknown as there has only been a limited amount of drilling.
The Automatic Curve Matching (ACM) method was applied to located magnetic data and detected magnetic sources within different rock units, providing their depth, location, geometry and magnetic susceptibility. The magnetic susceptibilities detected by ACM allowed the differentiation of the volcanics and the underlying basement. The base of volcanics and the depth to the top of basement was mapped along 75km North-South profiles, that were spaced 1km apart over a distance of 220km. The volcanic and basement magnetic susceptibilities and the magnetic source distribution pattern, were used as key determinants to interpret the depth to the two interfaces. After the results for each interface were gridded, the surfaces were used to produce a 3D voxel model of the volcanics. A magnetic field was generated from the model and subtracted from the RTP data to produce the field generated by the sub-volcanic geology.

Key words: Sub-volcanic geology, Automatic Curve Matching, 3D voxel model.

INTRODUCTION

This method was developed as a part of the test project in the Gawler Range Volcanics (GRV) province conducted for the South Australian government. This province which is a part of the Western Gawler Craton in South Australia (Figure 1A), is an under-explored area covered by good quality, open file magnetic data. Using these data, a test study was conducted to map the thickness of volcanics and the configuration of the sub-volcanic metamorphic, Proterozoic basement over an area of 16,500km^2 (Figure 1B).The northern part of the test area is covered by the generally outcropping GRV of unknown thickness, while south of the volcanics, there is outcropping basement partially covered by a thin veneer of alluvium. Beneath the thick volcanics, the depth to basement is unknown as there are a limited number of drill holes penetrating the volcanics.

The aim of the test project was to map the base of volcanics and the depth to sub-volcanic basement. To map base of volcanics

and top of the underlying basement, the ACM method was applied to located magnetic data to detect magnetic sources within different rock units of the crust: volcanics, sediments or underlying basement.

METHOD AND RESULTS

Automatic Curve Matching (ACM) was used to analyse and interpret millions of individual magnetic anomalies along profiles extracted from the Total Magnetic Intensity (TMI) grid in NS, EW, NW-SE and NE-SW directions. For each individual anomaly, ACM detected the depth, location, geometry and magnetic susceptibility of magnetic sources generating the anomalies. To produce a 3D image of the GRV, the high-frequency and medium-frequency components of the magnetic field were analysed and interpreted by ACM. The TMI field and its 1st vertical derivative were analysed using special geophysical algorithms to simulate volcanic lava flows, and to model the basement geology's complexity.

The magnetic susceptibilities of the magnetic sources detected by ACM show a different range of values for the volcanics than the underlying metamorphic basement. Different distribution patterns and the abundance of the magnetic sources within the volcanics and the underlying metamorphic basement rocks define a distinct boundary between the base of volcanics and the top of basement (Figure 2). This boundary was continuously mapped along 75km long, NS profiles spaced around 5km apart over the 220km wide project area (Figure 3). The results were gridded to generate a map of the base of volcanics (Figure 4). Within the volcanics, the magnetic susceptibility values detected by ACM indicate the different geochemical composition of various lava flows, possibly distinguishing the Upper and Lower GRV (Figure 7).

The same criteria were used to map the top of the sub-volcanic magnetic basement along the same profiles. Often, the top of basement is coincident with the base of volcanics; however, there are areas where basement is deeper, possibly due to the presence of sub-volcanic sediments, or a thick weathering zone. As with the Base of Volcanics, the results were gridded to generate a map of the top of basement (Figure 6).

The results show that the volcanics are, on average, 700m-900m thick with a very thick section exceeding 3.4 km in the east, and around 1.5km in the west of the study area. The thickness of the volcanics was validated by comparison with drill-hole data with all of the results showing a good match. A passive seismic survey conducted after this study at the eastern end of the project area, indicated depth to the base of volcanics of about 4 km, which further confirms our results.

The Base of Volcanics and the topography was used to construct a 3D-voxel synthetic model simulating the GRV. The voxels were populated with magnetic susceptibilities computed by ACM, and the magnetic field due to volcanics was generated (Figure 7) using in-house software. This magnetic field was subtracted from the TMI data and the resultant magnetic field of the sub-volcanic crust was computed (Figure 8). Such a resultant magnetic field, if computed over a sedimentary basin, can be further analysed and interpreted using the Horizon Mapping technique discussed in Kivior et al, 2015 and 2018. This would allow mapping of multiple sub-volcanic sedimentary horizons and structures.

CONCLUSIONS

This study has shown that it is possible to map the thickness of volcanic units and determine magnetic susceptibilities of different lava layers within them. It has also shown that a 3D voxel model can be constructed from the top and base of volcanics, and magnetic susceptibilities derived from ACM can be used to compute the magnetic field of the volcanic layers. This can be subtracted from the regional field to produce the sub-volcanic magnetic field.

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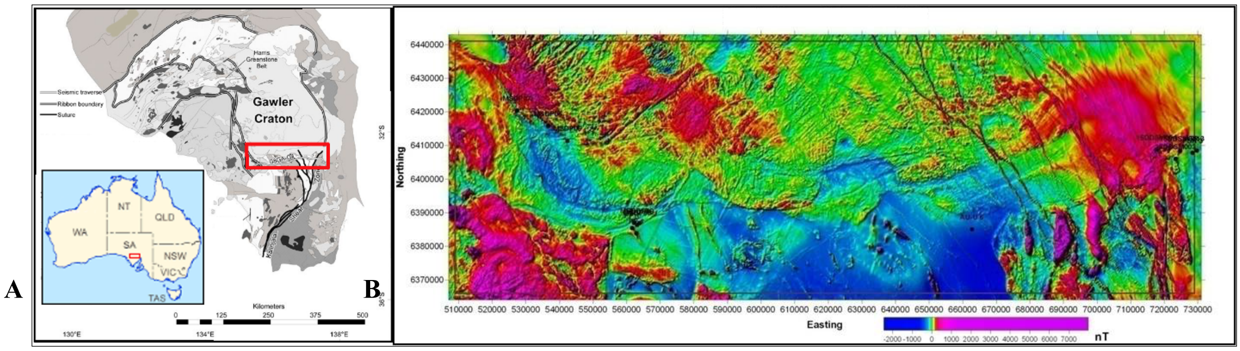

Figure 1A. Location of the study area; B Total Magnetic Intensity, Reduced To Pole Image

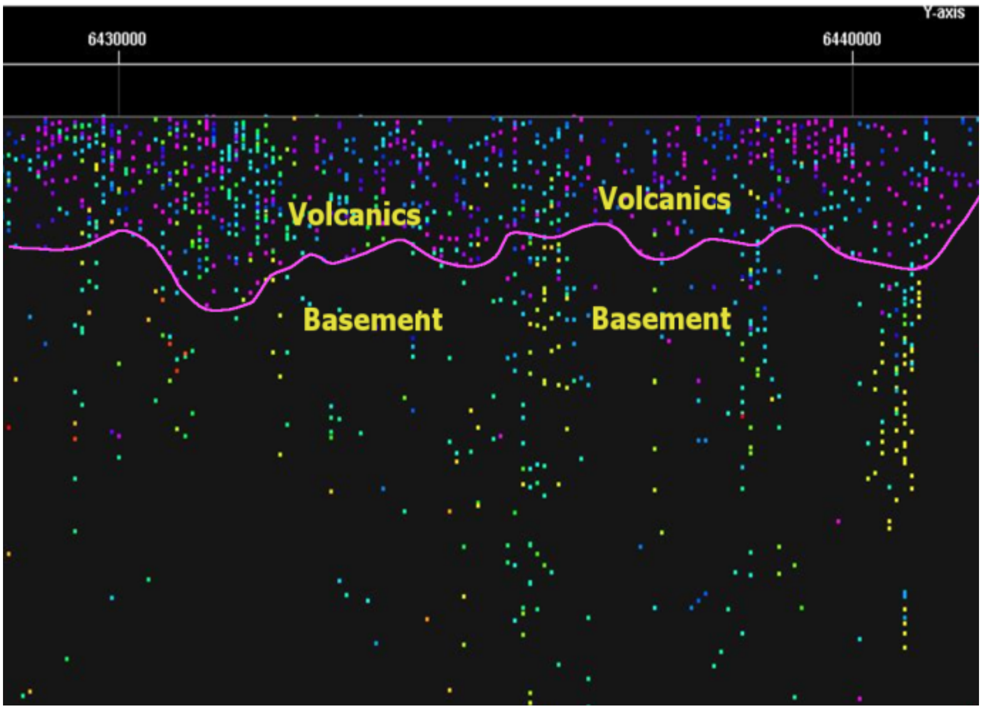

Figure 2. Vertical cross-section through ACM results showing interpretation of Base Volcanics and Top Basement. Colour indicates magnetic susceptibility

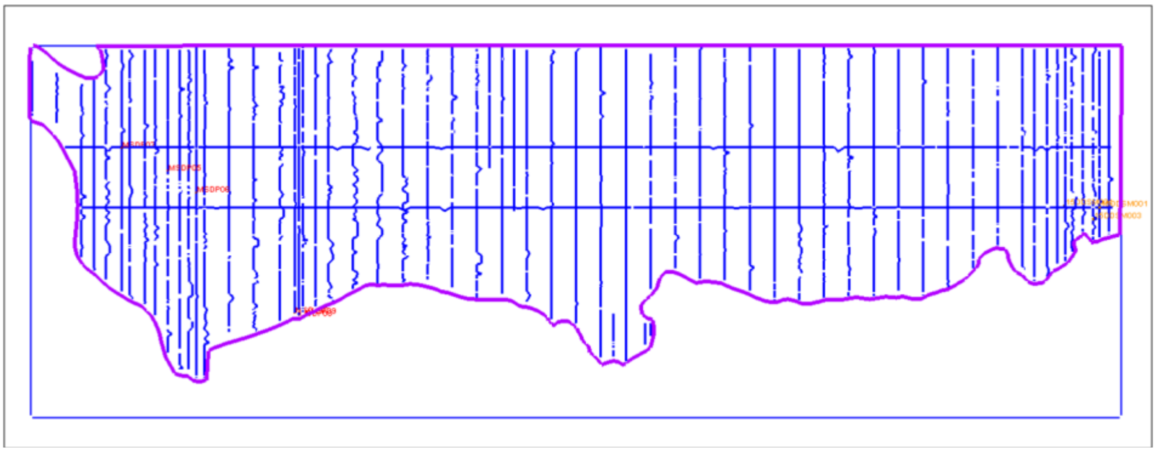

Figure 3. Location of NS vertical cross-sections through project area used for interpretation of Base Volcanics and Top Basement.

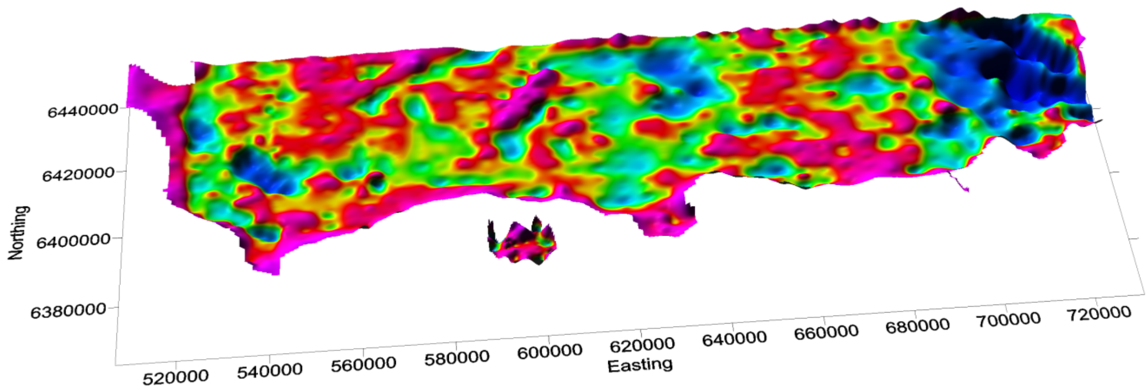

Figure 4. Base Volcanics interface interpreted from ACM results

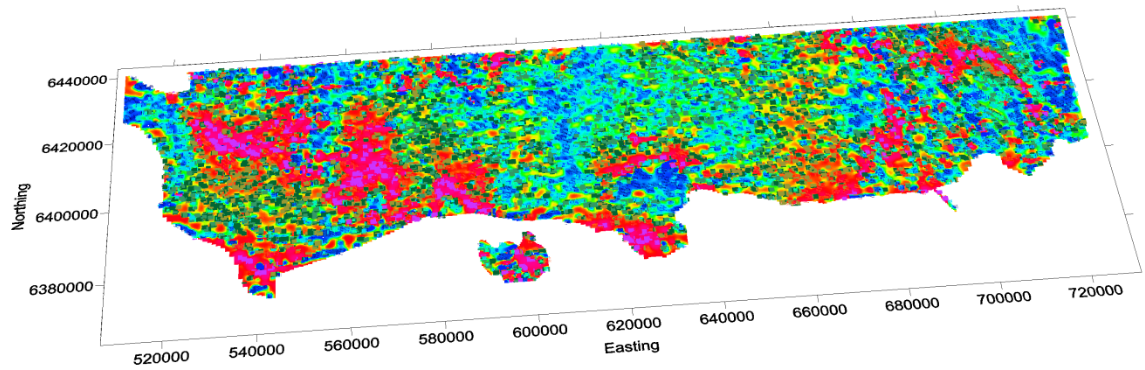

Figure 5. Magnetic Susceptibilities calculated from ACM results.

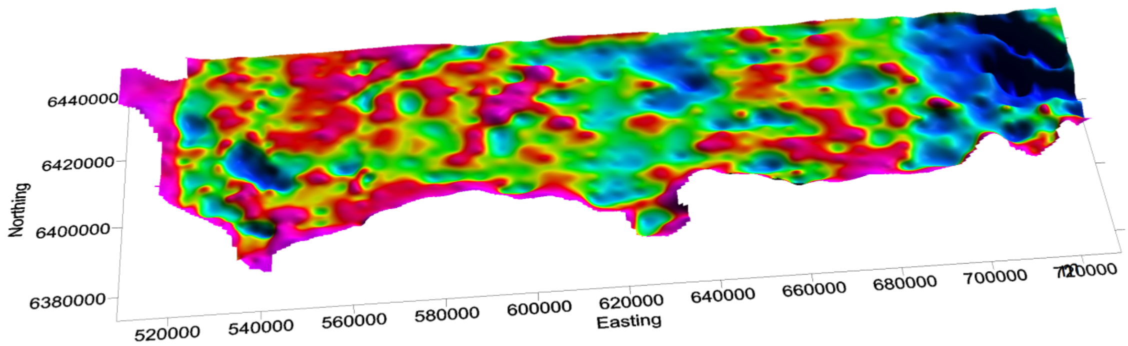

Figure 6. Sub-Volcanic Basement interpreted from ACM results

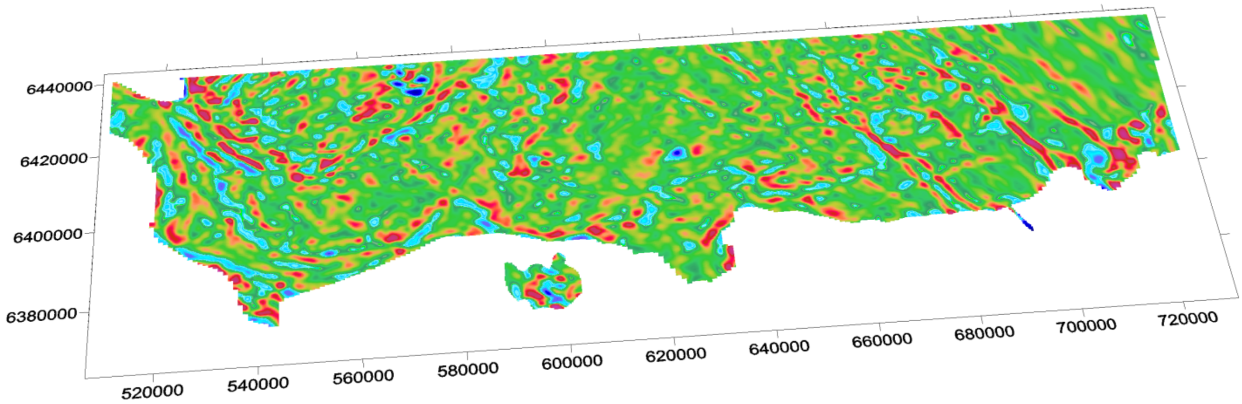

Figure 7. Magnetic field computed from 3D voxel model of volcanics

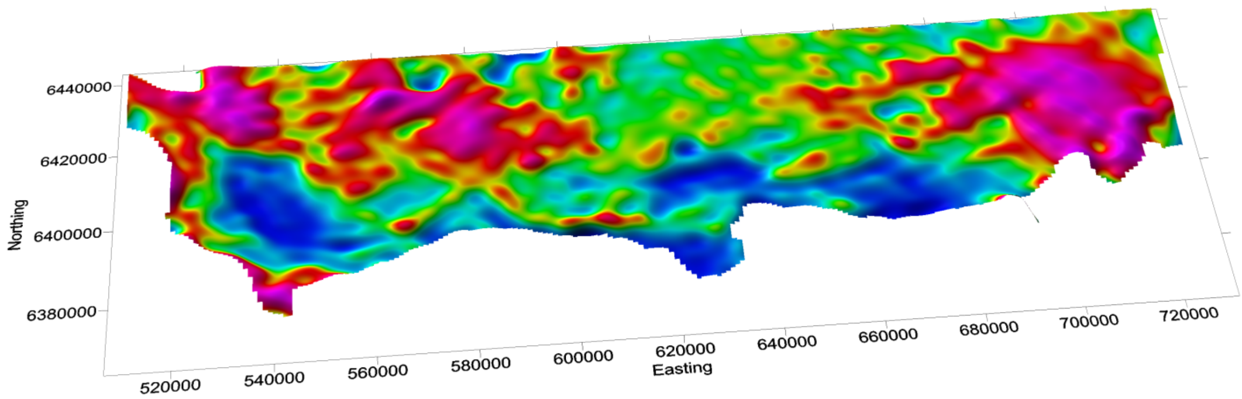

Figure 8. Magnetic field remaining after magnetic field generated by 3D voxel model of volcanics was subtracted from Total Magnetic Intensity field.