Using Potential Field Data for Petroleum Exploration Targeting, Amadeus Basin, Australia

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Abstract

The Amadeus Basin, a large Proterozoic basin located in central Australia, is the least explored onshore petroleum-bearing basin with proven reserves in Australia. The size and remoteness of the Amadeus Basin makes ground exploration expensive, but airborne gravity and magnetic surveys have been shown to be capable of resolving intra-basin structures in sufficient detail to allow prospective areas to be identified.

In the western part of the basin the Gillen Petroleum System is considered most significant: This system has the important characteristic that the source is stratigraphically higher than the reservoir. Thin skinned deformation is expected at the source level and above, with detachments at evaporitic horizons, but deformation of the reservoir is expected to be thick-skinned. This model can form the basis for predicting potential field responses. The most prospective areas are where (i) gravity suggests basement (and reservoir) is shallow, (ii) magnetics maps fold-thrust complexes (structural trap), (iii) these features occur adjacent to gravity lows, indicative of significant thicknesses of basin fill (source at depth and below reservoir). Faults at the margins of the depocentre (mapped using magnetic data) provide a possible migration path for the hydrocarbons.

Introduction

The conventional use of gravity and magnetic methods in petroleum exploration is to determine depth to basement and to map major geological structures within the basement. Such data are not usually expected to provide information about the sediments comprising the basin fill. This paper describes the use of gravity and magnetic methods in petroleum exploration in the Amadeus Basin in Western Australia, and shows that such data can be used to map intra-basin structure and hence directly identify prospects. This is a considerable assistance to exploration since the area is little explored, vast and remote, making ground based operations expensive and ground selection speculative.

Petroleum Geology of the Amadeus Basin

The Amadeus Basin, one of the major basins of central Australia, is the least explored onshore petroleum-bearing basin with proven reserves in Australia. It is located in the southern part of the Northern Territory and extends westward into Western Australia (Fig.1). The basin comprises rocks recording nearly 500 million years of Earth history ranging from the latest part of the Precambrian into the Mid-Paleozoic (~800 to 300 Ma; Lindsay et al., 2005). The sedimentary fill in the basin is at least 10 km thick.

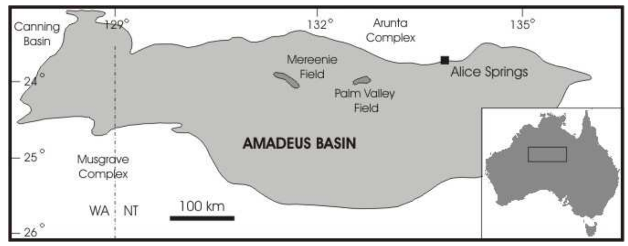

Figure 1. Location map for the Amadeus Basin. NT – Northern Territory, WA – Western Australia.

The Amadeus Basin hosts two producing petroleum fields (Fig.1). Mereenie contains oil and gas and Palm Valley has gas. Both fields are in structural traps that were discovered in the mid 1960s and developed in the mid 1980s. Despite the low number of wells drilled to date, these fields attest to the prospectivity of the Amadeus Basin in comparison with other well-known petroleum-bearing basins in Australia. Moreover, the wells drilled have recorded a higher than average discovery rate of 4 MMboe per exploration well and at relatively shallow depths compared to similar basins in Australia. A significant result of exploration in the Amadeus Basin is the discovery of reservoirs which not only contain natural gas (methane) but also helium.

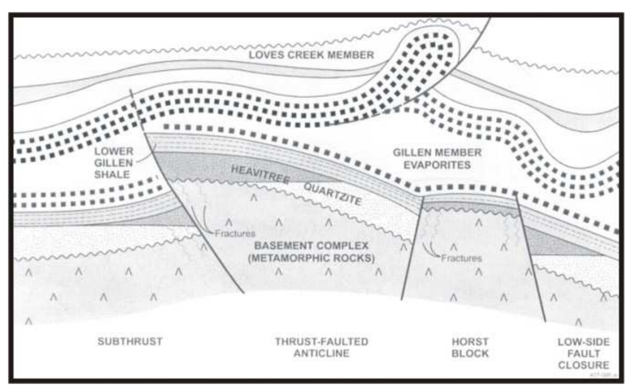

Figure 2. Schematic cross-section illustrating potential trap structures for the Gillen Petroleum System (Young and Ambrose, 2005).

There are several possible petroleum systems in the Amadeus Basin. The most important in the Western Australian part of the basin is the Gillen Petroleum

System (Fig.2). This system has a reservoir comprising the Dean/Heavitree Quartzite and source in the overlying Bitter Springs Formation. Both units occur near the base of the sedimentary succession. Importantly, in this system the reservoir is stratigraphically below the source rock. Figure 2 adopts Marshall and Wiltshire's (2005) model of thin skinned/detachment tectonics above the evaporate-containing Gillen Member of the Bitter Springs Formation and thick-skinned basement-involved below, i.e. that part of the section including the Heavitree Quartzite.

Data Acquisition and Processing

High quality modern basin-wide aeromagnetic data have been flown across the Amadeus Basin in Western Australia by the Geological Survey of Western Australia. Line spacing was 400 m, flight height was 80 m. In 2008 Central Petroleum Ltd, pursuing an aggressive exploration strategy in the Amadeus Basin, flew a major airborne gravity survey across the entire Rawlinson and Macdonald 1:250,000 map sheets in the Western Australian section of the basin; an area of more than 34,000 km^2. Line spacing was 2500 m. This is, probably, the largest high resolution airborne gravity survey undertaken in the southern hemisphere.

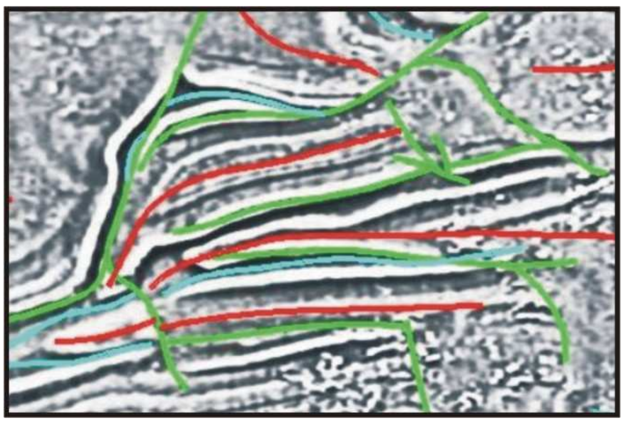

Figure 3. Fold-thrust zone mapped from magnetic responses. Image is 45 km east-west. Red – synforms, cyan – antiforms, green – faults. Differentiation of antiforms and synforms is speculative.

A variety of data products were created from the potential field datasets. Of these, the 'separation filtered' aeromagnetic data and 'residual gravity' data were found to be most useful and are used to illustrate aspects of the geology of the study area. A separation filter is an upward continuation-based wavenumber filter which produces a minimum of artefacts in the output. Filtering the data to emphasis features originating within the basin fill has proved very effective, although the data still contain some contamination from magnetic sources within the near-surface drainage. The residual gravity image, derived by subtraction of a polynomial surface from the Bouguer anomaly data, effectively highlights shorter wavelength variations which originate from the basin fill and/or the surface of the underlying basement.

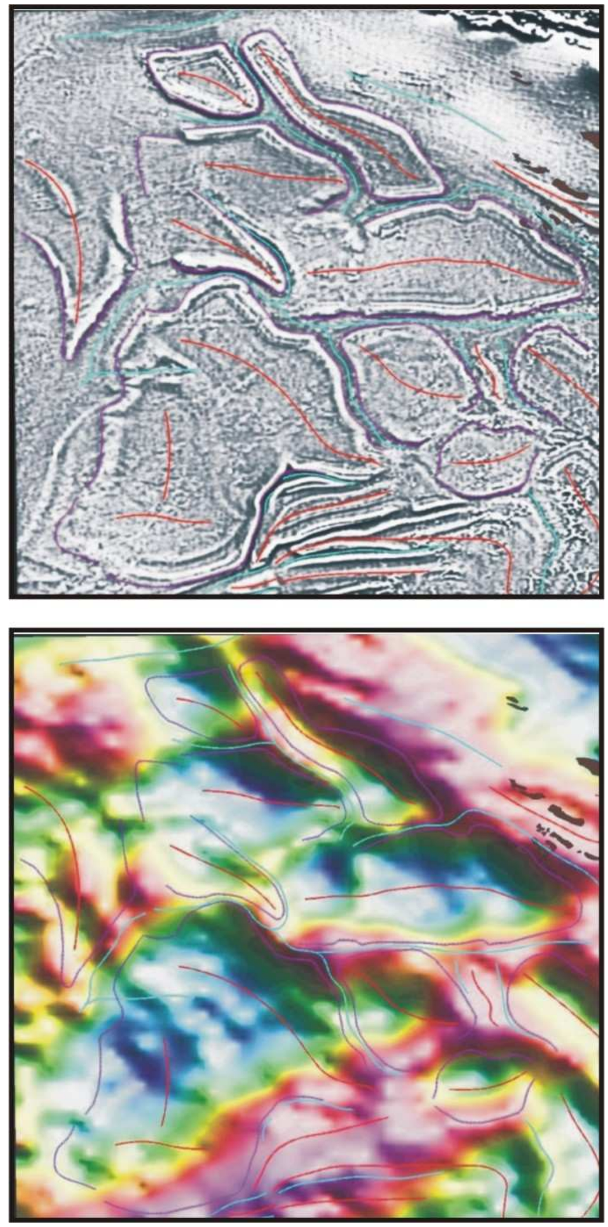

Figure 4. Separation filtered magnetic and residual gravity data from areas of salt withdrawal basins. Red – synforms, cyan – antiforms, purple – salt withdrawal basins. Images are about 100 km east-west.

Petrophysics

Crucial information constraining the interpretation of geophysical data is the variation in magnetism and density within the local rocks. Unfortunately there is no such information from the study area itself. Publications describing magnetic data from the Amadeus Basin refer to volcanic rocks in the Bitter Springs Formation as a source of magnetic anomalies (c.f. Burgess et al., 2002) and comparison of the geological map and the magnetic data shows that the Bitter Springs Formation has a characteristic magnetic texture. Linear magnetic anomalies in the younger basin fill may be sourced by magnetic 'recessive shale units' (Foss and Marshall, 2005).

A summary of density differences in different stratigraphic units provided by Schroder and Gorter (1984) shows the Bitter Springs Formation as having a density about 0.2 g/cm^3 greater than the rest of the sequence. The density data implies outcrop of the Bitter Springs Formation will be associated with generally higher than average gravity (as is observed to be the case). It also means distinguishing between basement highs and variations in thickness of Bitter Springs Formation (either primary or due to halotectonic movements) will not be possible.

Magnetic and Gravity Responses of Basin Fill

Linear magnetic responses, from comparison with outcrop geology, are clearly of stratigraphic origin. The magnetic signatures do not vary sufficiently to allow ‘mapping’ of specific marker horizons. In fact, responses from what are shown as the same stratigraphic level on the geological maps can have quite different magnetic responses. It is possible the maps are incorrect or that different lithotypes and/or different metamorphic/alteration/weathering histories have changed magnetic properties. At present there is insufficient data to better understand the magnetic responses.

The magnetic anomaly pattern in the central part of the study area (Fig.3) is strongly suggestive of a fold-thrust terrain; as occurs in the better known parts of the Amadeus Basin to the east and as strongly suggested by the outcrop geology. In the absence of geological control, establishing whether closures in the anomaly patterns are due to antiforms or synforms is equivocal. Dips cannot be reliably derived from the gridded magnetic data (although modeling of individual flight lines may allow this). Dips from outcrop are often sparse and many are derived from aerial photography, not ground measurement. This means only the general magnitude of dips is derived and importantly the possibility that strata are inverted cannot be explored.

Best developed in the northwest of the study area, but also present elsewhere, are structures interpreted as salt withdrawal basins. These form by lateral migration of salt due to overburden pressure and form characteristic polygonal outlines and box-fold geometries separated by much shorter wavelength antiforms (Fig.4). The geological interpretation of these structures is based on their similarity to structures observed in the Gulf of Mexico, plus the known presence of evaporates in the deeper part of the Amadeus Basin and numerous studies emphasizing the importance of halotectonic processes in the eastern part of this basin.

The residual gravity data shows variations which closely correspond with outcrop geology and the structural trends inferred from the magnetic data. Shallow Bitter Springs Formation or Heavitree/Dean Quartzite mostly coincides with the higher gravity values. Salt-withdrawal basins in the north of the study area closely coincide with sub-circular regions of lower gravity with narrow gravity ridges between them (Fig.4).

Implications for Petroleum Potential

Based on the model in Figure 2, positive basement relief is a key indicator of the likelihood of trap structures. Structures formed by thin skinned deformation (which dominate the near-surface/outcrop geology) may not involve the Heavitree/Dean Quartzite and hence the reservoir will not deformed in to a potential trap structure. As shown in Figure 2, hydrocarbon fields created by the Gillen Petroleum System require a means of shifting the stratigraphically older reservoir to a higher elevation whilst remaining juxtaposed to the source.

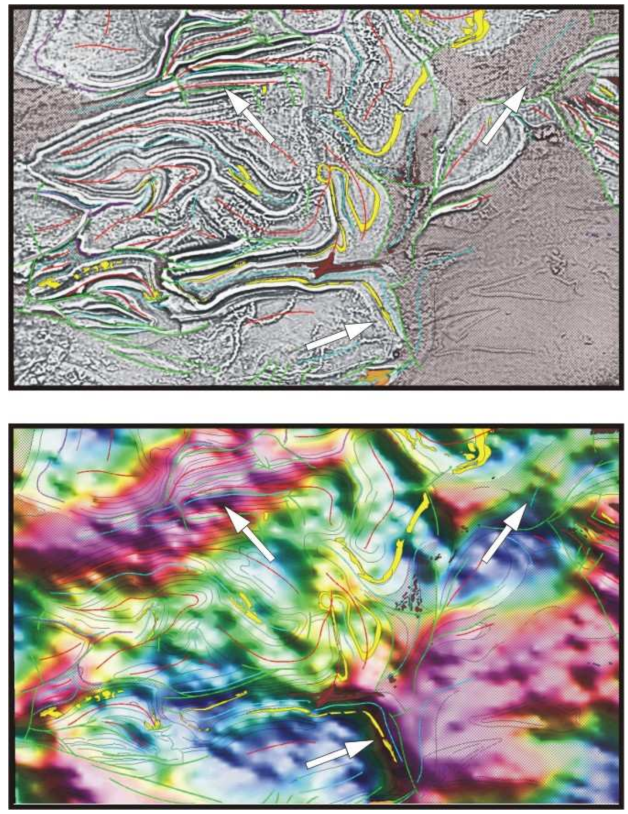

Figure 5. Residual gravity and separation filtered aeromagnetic image, with interpretation overlain, showing potentially prospective area for the Gillen Petroleum System. Red – synforms, cyan – antiforms, green – faults, yellow outcrop of Heavitree Quartzite, brown – outcrop/subcrop of Bitter Springs Fm. Arrows represent potential hydrocarbon migration.

The available geophysical data cannot definitely resolve basement-involved faulting under a thick cover of Proterozoic sediments. However, outcrop/subcrop of Bitter Springs Formation, with Heavitree/Dean Quartzite assumed to be underneath, adjacent to depocentres, represents a favorable scenario. If it is assumed that halotectonics are less likely to have occurred where the cover thickness to the Bitter Springs Formation is thinner, then in such areas anticlinal structures mapped in the Bitter Springs Formation (using the distinctive magnetic response) near the surface may continue into the underlying quartzite units. Referring to Figure 5, areas where gravity suggests basement is shallow and magnetics suggests favorable structures, and which occur adjacent to gravity lows indicative of significant thicknesses of Proterozoic sediments (source at depth), are considered significant. Faulted margins of the depocentre, mapped using magnetics, provide a possible migration path.

Conclusions

Carefully processed gravity and magnetic data have been shown to be useful tools for identifying prospective areas in the Proterozoic succession in the Amadeus Basin in Western Australia. Density and magnetic variations within the basin fill, considered in the context of the likely petroleum system, allow the 'signatures' of prospective areas to be identified. In the case of the Gillen Petroleum System, magnetic data allow potential structural traps to be mapped, gravity data allow regions of potential source rocks, structurally below the reservoir, to be identified.

Acknowledgments

Central Petroleum Ltd is thanked for permission to describe this work.

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