Onshore northern Perth Basin gravity project

by R. P. Iasky

Abstract

A series of gravity surveys have been conducted along seismic lines in the onshore northern Perth Basin. The data collected were combined with data from the Australian National Gravity Database, which is maintained by the Australian Geological Survey Organisation, and were processed to produce images. The images were manipulated to highlight structural features and provide new insights into the structural evolution of the area.

The gravity images of the onshore northern Perth Basin were analysed for lineaments and four major trends were identified: north-northwesterly, easterly, northeasterly to east-northeasterly, and northwesterly. These trends on the gravity maps correlate directly with faults and lineaments that have been mapped using seismic and magnetic data. The most intense structural fabric occurs along the north-northwest trend within the Darling–Urella Fault System. The easterly trend is in the northern part of the Perth Basin, near the southern extension of the Northampton Complex, suggesting that faulting related to this trend is a result of the interaction of pre-existing basement terranes. The northeast trend is interpreted as antithetic strike-slip faulting, and the northwest trend corresponds to transfer faults that are also observed on aeromagnetic maps. Both northeast- and northwest-trending sets of faults were developed during the separation of Greater India from Australia, in the Early Cretaceous.

KEYWORDS: Perth Basin, gravity, Bouguer anomaly maps, lineaments, structural evolution.

Potential-field data have been used in the petroleum industry to analyse subsurface geological structures since the 1920s, but the seismic-reflection method has predominated throughout the history of exploration because the resultant reflections can be correlated directly to geologic strata (Nettleton, 1971). In the 1990s, there has been a revival in the use of aeromagnetic methods in petroleum exploration because technological advances in computing, satellite navigation, and instrumentation have improved the resolution of smaller anomalies. The new data have enabled the identification of small anomalies that relate to structures within the sedimentary strata, whereas, in the past, potential-field data were mainly used for identification of broad, basement-related features. Mapping the gravity field, especially onshore, has not been as popular as the use of aeromagnetic methods because airborne gravity surveying is inaccurate and ground surveying is logistically more difficult to conduct. This has resulted in sparse coverage of the area and poor resolution of small anomalies.

In the last decade, potential-field data have been displayed as images similar to those produced with satellite spectral data, and this has improved interpretation because it is easier to visualize trends and lineaments on these images. Gravity anomalies are produced when horizontal and vertical density differences occur in sedimentary and basement lithologies. Unlike magnetic anomalies, gravity anomalies are not affected by surface cultural effects and surficial magnetic rocks and sediments. Processed gravity images show lineaments caused by faulting; intra-basement structural and lithological changes; and, possibly, intra-sedimentary variations in density. Gravity surveys represent a relatively low-cost method of addressing local and regional structural problems. Depending on the amount of coverage, gravity surveys can provide a powerful complementary dataset to seismic and magnetic data, which can be used to analyse subsurface geological structures.

A regional study of the onshore northern Perth Basin between latitudes 29°S and 31°S (Fig. 1), which has just been completed (Mory and Iasky, in prep.), uses integrated well, outcrop, seismic, aeromagnetic, and gravity data to review the structure and stratigraphy of this part of the Perth Basin. An opportunity to improve the gravity coverage in the study area, with minimal logistical problems, arose in late 1993 and early 1994, when a number of seismic surveys were to be recorded in the northern Perth Basin. West Australian Petroleum (WAPET) planned to record a two-dimensional and three-dimensional seismic survey over the Strawberry

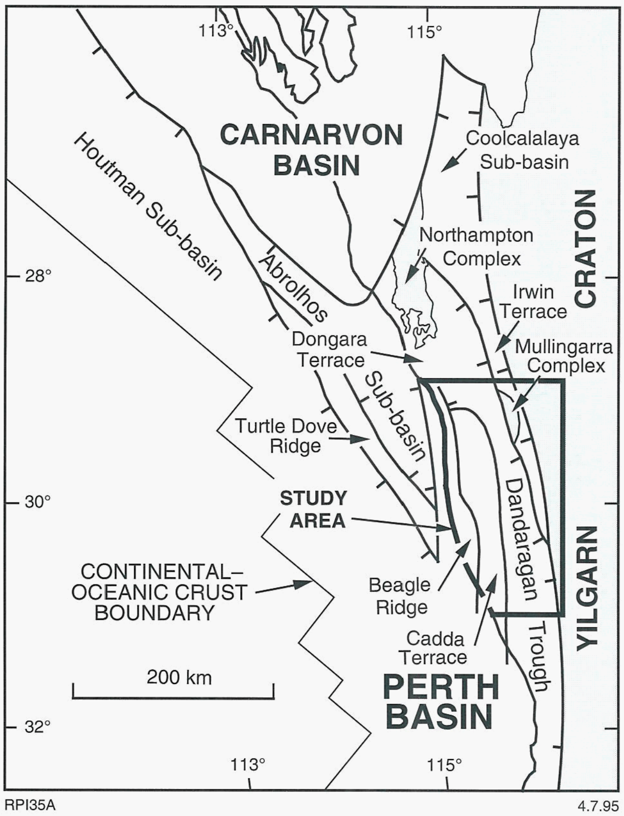


Figure 1. Location of study area in the onshore northern Perth Basin, including tectonic elements

Hill structure and the Dongara field respectively. The three-dimensional survey was an ideal place to record gravity data along a regular grid and achieve a station spacing that is close to that obtained in aeromagnetic surveys. These surveys were followed by two-dimensional surveys by Discovery Petroleum over the Mount Horner field; by Victoria Petroleum to delineate a small structure northwest of Mount Horner; and by Consolidated Gas over the Woodada field. The Geological Survey of Western Australia (GSWA), in cooperation with these companies, proceeded to collect gravity measurements along seismic lines (Fig. 2) where topographic control was being established as part of seismic surveying.

Data coverage

Data was collected in the onshore northern Perth Basin between latitudes 29°00′S and 31°00′S and longitudes 114°55′E and 116°00′E. Data from a total of 3299 new stations, recorded over the 1993–94 seismic-survey lines, and 4269 existing gravity stations from the Australian Geological Survey Organisation (AGSO) database were processed to produce images of gravity anomalies over the basin. The northern quarter of the area between latitudes 29°00′S and 29°30′S is the most densely covered (good to average) and contains 4643 stations (61% of all stations). The remaining stations are spread over the southern three-quarters of the study area; the southern half only has regional coverage at a station spacing of 10–12 km.

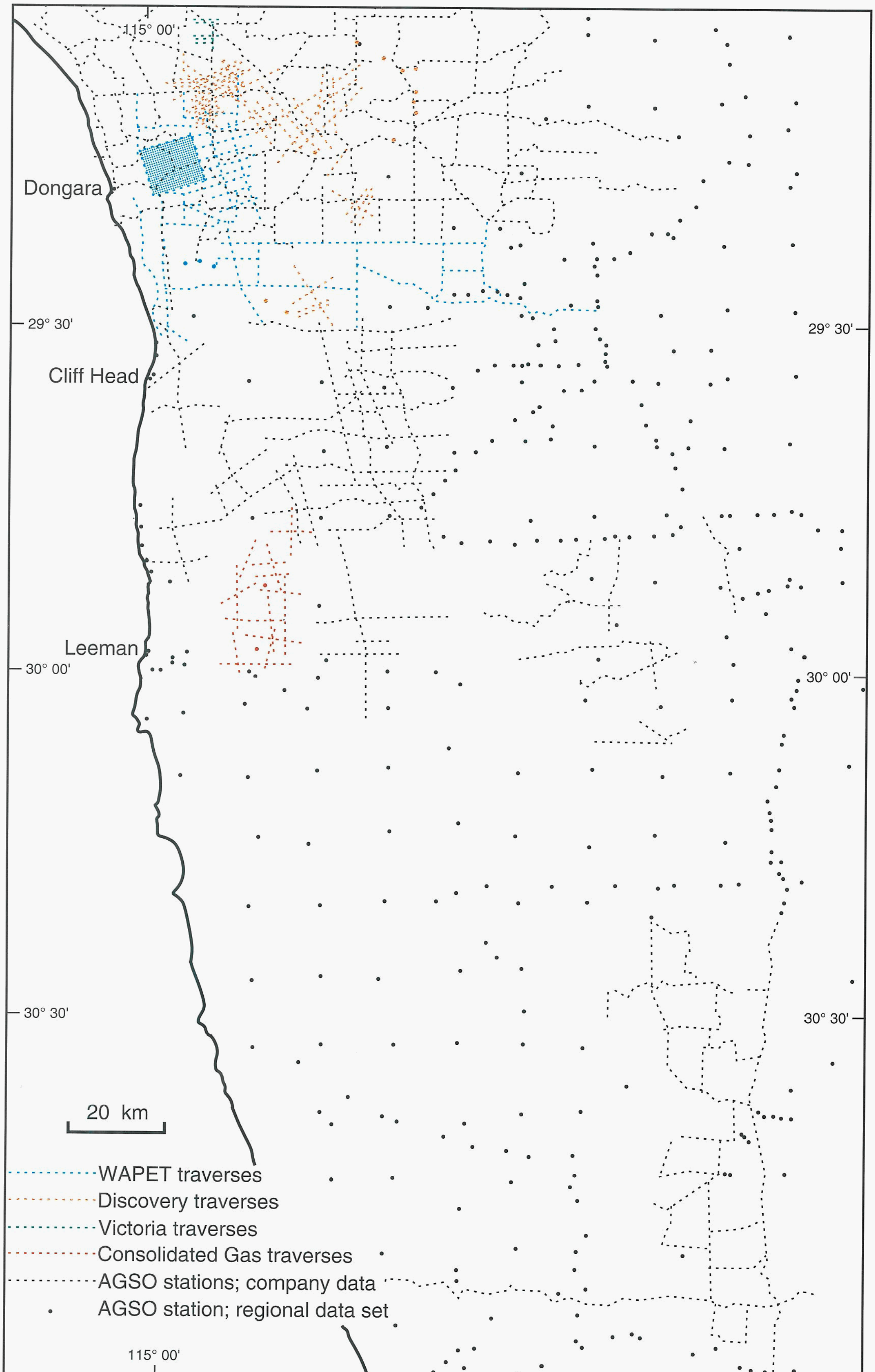
Five seismic surveys were conducted in the northern Perth Basin from November 1993 to April 1994. At the same time, the GSWA recorded gravity at regular intervals along the seismic lines. In addition, north of latitude 29°30′S, gravity was recorded on regional traverses along farm tracks, bush tracks, and pipelines to infill sparsely covered areas in the basin and to add control across major faults (Fig. 2). The amount and timing of the respective gravity surveys is listed in Table 1.

The recently collected data consist of measurements along seismic lines at a station spacing of 300 to 500 m, and additional regional traverses along main roads and tracks at 500 m spacing. By comparison, the AGSO data consist of: a compilation of data collected by WAPET in the 1960s at 800 m (half a mile) spacing; Bureau of Mineral Resources (BMR) regional data collected at 10–12 km spacing; and a number of other smaller mineral exploration surveys at the eastern boundary of the basin, spaced at 500 to 1000 m. The area of investigation has good coverage over the Dongara and Mount Horner fields, medium coverage over the Woodada field and the Darling Fault, and poor coverage in the rest of the area.

The data were reduced to the 1967 International Gravity Formula, and corrected for latitude, free-air, and Bouguer anomalies to sea-level datum (Wellman at al., 1985). The densities used in the Bouguer correction were 2.00 g/cm^3 in the Perth Basin, and 2.67 g/cm^3 over crystalline rocks on the Yilgarn Craton and Mullingarra Complex. The Bouguer gravity data were grided and filtered using the Intrepid geophysical processing package, and a series of images were produced using the ER-Mapper image-processing software.

Identification of structural features

The following discussion is based on the identification of structural trends and lineaments observed on the gravity images of the study area. Many images of Bouguer gravity, and first and second derivatives of the gravity field, illuminated from different directions, were produced to identify structural features. While it is beyond the scope of this paper to show all the results, the image on Figure 3 shows the location of major structural features and summarizes the observed lineaments in the onshore northern Perth Basin. The northern part of the study area has a more detailed interpretation because of the higher resolution resulting from better coverage. The position of the lineaments when compared to faults mapped on seismic horizons (Fig. 4) suggests that the majority can be attributed to basement structures.


115° 00'
Dongara
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WAPET traverses
Discovery traverses
Victoria traverses
Consolidated Gas traverses
AGSO stations; company data
AGSO station; regional data set
115° 00'

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Table 1. Gravity surveys recorded between November 1993 and April 1994

Survey name	Company	Start date	End date	Line kilometres	Station spacing (m)	Number of stations
Regional infill — Dongara–Arrowsmith area	WAPET	22/11/93	14/12/93	382.0	500	703
Strawberry Hill 2D SS	WAPET	15/12/93	04/01/94	114.8	500	223
North Dongara 3D SS	WAPET	05/01/94	05/02/94	469.8	300	815
Mingenew SS	Discovery Petroleum NL	17/02/94	26/03/94	371.8	300, 450	1 161
Tabletop SS	Victoria Petroleum NL	22/02/94	23/02/94	24.5	300	55
Logue SS	Consolidated Gas Pty Ltd	13/04/94	19/04/94	136.0	450	342

SS: Seismic survey

Northerly to northwesterly striking lineaments

The Darling Fault is apparent as a major north- to north-northwesterly trending feature on the southeastern part of the image, but the anomaly has a considerably reduced amplitude in the north. Between 29°40'S and 30°05'S the throw on the Darling Fault decreases significantly as the throw on the Urella Fault increases. This type of fault geometry and kinematics has been described as a relay ramp (Peacock and Sanderson, 1994). Northeast-trending lineaments displace the Darling Fault in a sinistral sense in several places along its length. The most dominant of these is at approximately at 29°40'S where the throw of the Darling Fault is relayed to the Urella Fault. Both faults appear to continue to the north and south respectively, but their gravity anomaly is considerably smaller. Where the Yilgarn Craton is juxtaposed with the Mullingarra Complex, the Darling Fault cannot be clearly identified because of the minimal density contrast. At this point the anomaly representing the Urella Fault increases in width because of the effect of the near-surface rocks of the Mullingarra Complex.

Figure 2. (opposite) Distribution of gravity stations in the study area, indicating the position of new gravity traverses

The Urella Fault is the major north-northwesterly trending feature in the northeastern part of the image, with the Darling Fault parallel to it on the eastern side. A major splay of the Urella Fault which strikes west at approximately 29°10'S, is interpreted as the intersection with the Allanooka Fault. North of the Allanooka Fault the gravity data show that the throw of the Urella Fault diminishes and that two other smaller splays striking west are present. A high-amplitude lineament parallel to, and to the west of, the Urella Fault is interpreted as the Wicherina Fault to the north of the Allanooka Fault.

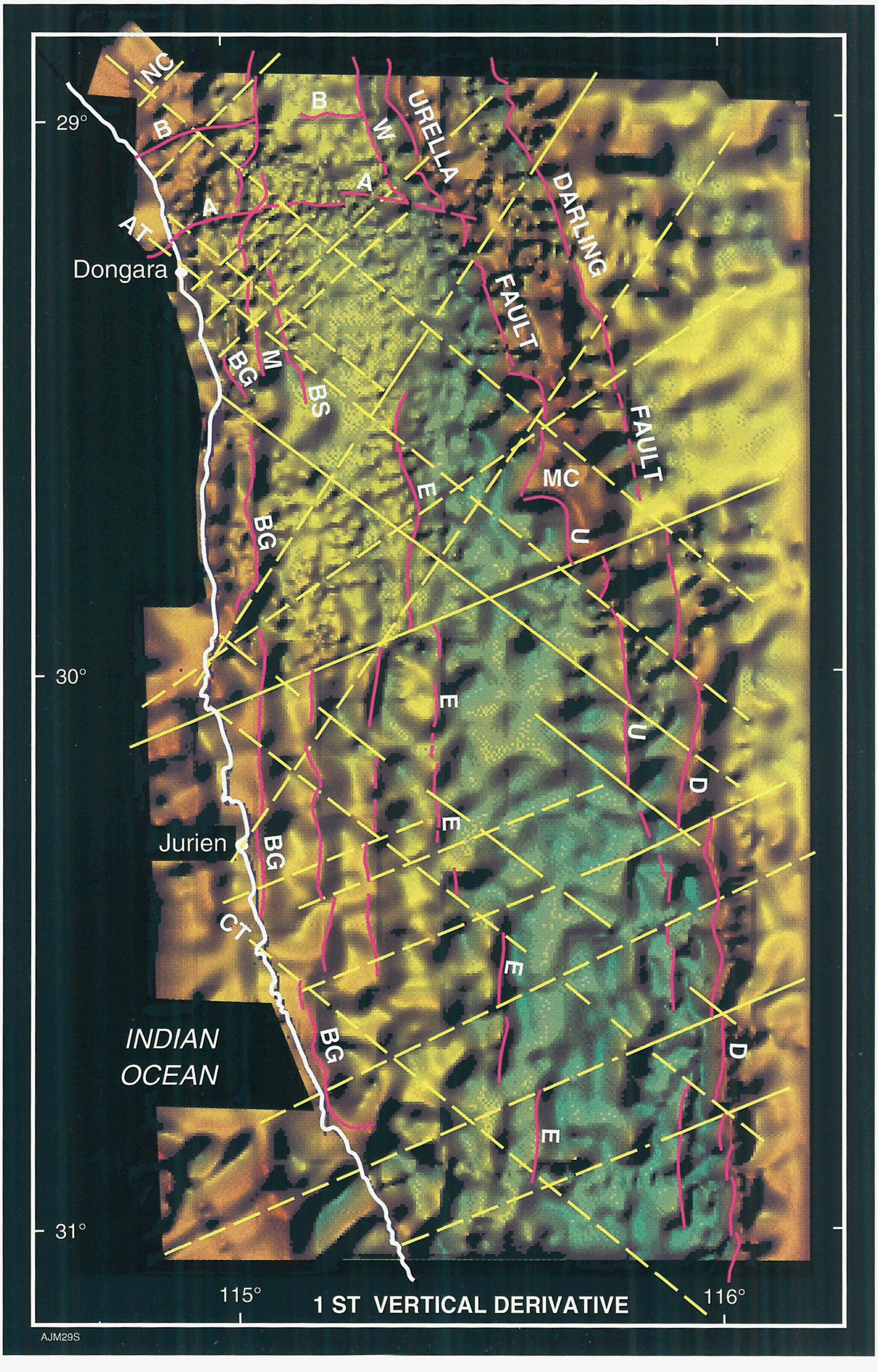
The Beagle Fault System is identified by the higher-amplitude anomalies on the western part of the images, bordering the coast. There are several broken lineaments striking north to northwest that probably represent several en echelon faults as mapped with seismic data (Fig. 4). Unfortunately, the data coverage near the coast is poor and the resolution of these lineaments is low.

The Mountain Bridge Fault is represented by a set of lineaments striking north, which have been identified north of approximately 29°30'S, immediately east of the Beagle Fault System (Fig. 3). Another set of near-parallel lineaments, immediately to the east and at the same northing, represents the Beharra Springs Fault as mapped with seismic data. The lineaments representing these two faults are discontinuous, indicating that the faults may not penetrate basement in places, even though they may be present within the sediments. North of the Allanooka Fault, other larger-amplitude, north-northeasterly striking lineaments appear to be unrelated to these two faults. Both the Mountain Bridge and Beharra Springs Faults appear to be dissected by northeast-striking lineaments.

The Eneabba Fault System can be identified in the central part of the image as a series of north-striking lineaments that divide the deeper Dandaragan Trough in the east from the shallower Cadda Terrace to the west. These lineaments extend throughout the length of the image, south of the Allanooka Fault.

Easterly striking lineaments

At approximately 29°10'S, the Allanooka Fault is well defined on both its western and eastern margins. In the west it is a linear feature that strikes east-northeast, and it diminishes in amplitude towards the east. The high-amplitude, broad anomaly to the northwest of the Allanooka Fault represents the southern extension of the Northampton Complex, and the Allanooka Fault is the southern edge of this high basement block. The fault appears to comprise a


NC
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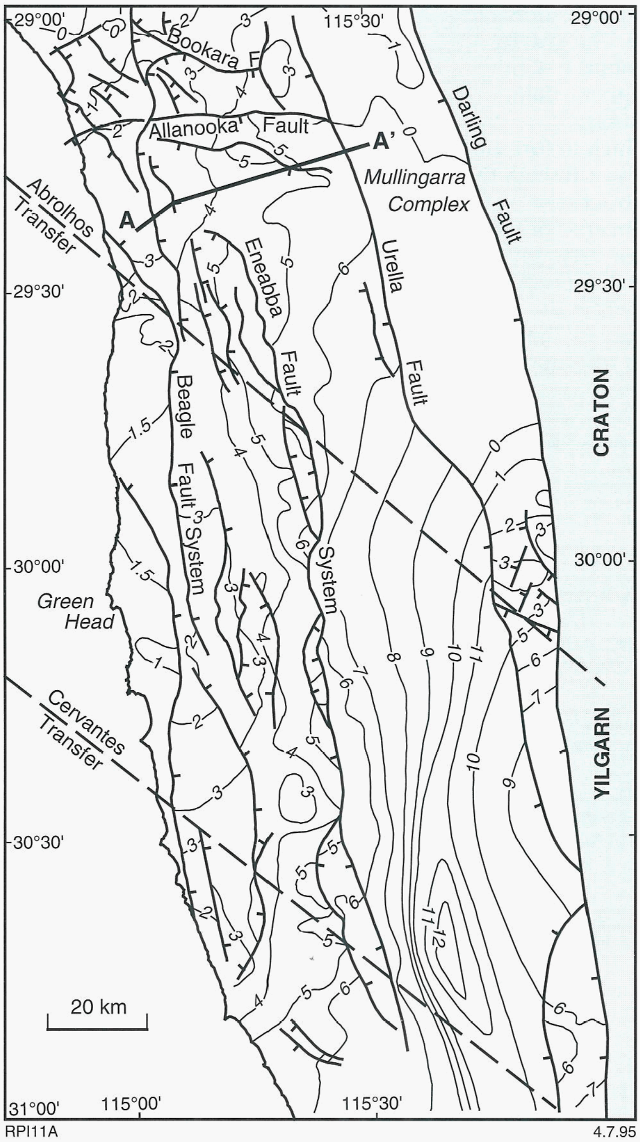

Figure 4. Depth to basement structure of the onshore northern Perth Basin, interpreted from seismic data. Contours in kilometres below Australian Height Datum (AHD)

series of east-northeasterly striking lineaments that are not necessarily continuous at basement level.

The Bookara Fault is identified as an east-striking lineament on the northwest part of the image at approximately 29°00'S. It is a high-amplitude lineament in the west where basement is shallower, and its amplitude diminishes to the east as sediment thickens, continuing through to the Wicherina Fault. Two other lineaments, also striking east, are displayed north of the mapped position of the fault, indicating further, similar, easterly trending faulting to the north.

It is important to note that easterly trending lineaments occur only in the northern part of the study area, adjacent to the southern extension of the Northampton Complex. Mory and Iasky (1994) suggested that the east-striking faults are a direct result of a northerly extension phase in the Permian; however, Harris et al. (in prep.) could not reproduce these faults in analogue modelling experiments, which indicates that the lineaments are a consequence of pre-existing structures within the two basement terranes of the Yilgarn Craton and the Northampton Complex.

Northeasterly to east-northeasterly striking lineaments

There are numerous northeasterly trending lineaments striking between 45° and 65°N throughout the image (Fig. 3). These appear to displace northerly trending lineaments in a left-lateral sense, and examples of this displacement occur on the Allanooka, Darling, and Urella Fault systems. One of the east-northeasterly trending lineaments at the southern edge of the image was identified from seismic mapping and named the Vlaming Transfer by Hall and Kneale (1992). The northeasterly trending lineaments were also identified in the aeromagnetic images, and correspond to strike-slip faults that are antithetic to the northwestern extension phase of tectonism that occurred at continental breakup (Harris, 1994). They were also recognized by Harris et al. (in prep.) in an analogue-modelling experiment. The direction of these lineaments correlates with the direction of dolerite dykes in the Northampton Complex, and it is possible that they represent reactivated basement fractures.

Northwesterly striking lineaments

Northwesterly striking lineaments (along approximately 300°) correspond to fractures associated with the transfer faulting initiated at breakup, such as the Abrolhos Transfer (Hall and Kneale, 1992; Mory and Iasky, 1994), and appear to displace northerly trending lineaments in a sinistral sense on the images and seismic sections (Fig. 4). These lineaments are more prominent when the gravity image is illuminated from the southwestern direction and, therefore, are not delineated clearly in Figure 3. Although only a few of these lineaments have

Figure 3. (opposite) Image of first derivative of Bouguer gravity (northwest sun illumination), with a summary of interpreted lineaments. The abbreviations used in the diagram are: A — Allanooka Fault; AT — Abrolhos Transfer; B — Bookara Fault; BG — Beagle Fault System; BS — Beharra Springs Fault; CT — Cervantes Transfer; D — Darling Fault; E — Eneabba Fault System; M — Mountain Bridge Fault; MC — Mullingarra Complex; NC — Northampton Complex; U — Urella Fault; W — Wicherina Fault

been identified in gravity images, they are numerous in aero-magnetic images and are spaced between three and six kilometres apart. The analogue modelling performed by Harris et al. (in prep.) showed that pre-existing north-northwest faults acted as transfer faults during the northwest–southeast extension at breakup. This modelling indicates the influence of earlier deformation on the pattern of faulting during subsequent tectonism.

Conclusions

Gravity images of the onshore northern Perth Basin show that there are four families of lineaments, trending north-northwest, east, northeast, and northwest. The north-northwesterly and easterly trending lineaments correlate directly with faults mapped using seismic data, whereas northeasterly trending lineaments are observed on aeromagnetic maps, and northwesterly trending lineaments are observed on aeromagnetic maps and also implied on seismic maps. The good correlation with other datasets suggests that gravity mapping may be a very attractive, low-cost method of obtaining structural information in sedimentary basins.

Gravity data can be collected along seismic lines at a small additional cost to the seismic program. The resolution of the data, and therefore the degree of interpretation that can be made, is directly proportional to the station coverage. The gravity mapping, when combined with seismic and aeromagnetic data, provides complementary information with which to formulate structural models. Even though the effect of basement structures dominates images because of the large density contrast between sediments and crystalline rock, smaller anomalies within the sedimentary strata can be identified, given adequate data resolution.

Acknowledgements

Cooperation and financial sponsorship were provided by West Australian Petroleum Pty Ltd, Discovery Petroleum NL, Victoria Petroleum NL, and Consolidated Gas Pty Ltd during the gravity surveying. Special thanks are extended to Serguei Chevtchenko for joining the project at very short notice and providing invaluable assistance with the acquisition program.

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