The role of deep seismic reflection data in understanding the architecture and petroleum potential of Australia's onshore sedimentary basins

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KEYWORDS

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Introduction

Many of Australia's onshore basins are under-explored with respect to hydrocarbons. To date, only the Cooper-Eromanga basin system maintains its status as a major commercial oil and natural gas producer, but recently this has been complemented by commercialisation of coal seam gas resources in the Bowen and Surat basins in Queensland. With domestic oil production in steady decline, and increasing offshore exploration costs, the Onshore Energy Security Program was funded by the Australian Government with ~$59 million over five years (2006–2011). The program is conducted by Geoscience Australia and aims to provide pre-competitive geoscience data and assessments of the potential for onshore energy resources, including hydrocarbons, uranium, thorium and geothermal energy.

As part of the Onshore Energy Security Program, deep seismic reflection data have been acquired across several frontier sedimentary basins to stimulate petroleum exploration in onshore Australia. Interpretation of deep seismic reflection profiles from four onshore basins—focussing on the overall architecture of the basins and their internal geometry—will be discussed here, with the eventual aim of assessing the petroleum potential of these basins. The basins studied here are: the Georgina Basin (northwest Queensland); Millungera Basin (northwest Queensland); eastern Darling Basin (western NSW); and, Arrowie Basin in SA (Fig 1).

Georgina Basin, Northwest Queensland

Figure 1
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At the southern end of the exposed part of the Mt Isa Province, northwest Queensland, a deep seismic line (06GA-M6) crossed the Burke River Structural Zone of the Neoproterozoic to Early Paleozoic Georgina Basin (Fig. 1). In the Northern Territory, there are numerous oil and gas shows in the basin, and solid bitumen has been recovered from drillcore (Volk et al, 2007). The basin is considered to be prospective for hydrocarbons, with parts of the basin in southeastern NT considered to be in the oil window. Although exploration drilling has been very limited, there are several known Middle to Late Cambrian prospective petroleum systems in the NT part of the Georgina Basin (Boreham et al, 2007). Although the Burke River Structural Zone is known for its phosphate resources (e.g. the Duchess phosphate mine), virtually no exploration has been undertaken for hydrocarbons in this area.

Seismic line 06GA-M6 (Fig. 2a) provides the first seismic image across the Burke River Structural Zone. Here, the basin is ~65 km wide, with a half graben geometry, being bounded in the west by a rift border fault. It has a maximum thickness of ~2,800 m (calculated from stacking velocities). Interpretation of the stratigraphy is constrained by scattered outcrops in the vicinity of the seismic line. The lower-most sequence is interpreted to be the Early Cambrian Mount Birnie beds. Based on well control from the nearby BMR Duchess 18 drillhole, the overlying Thorntonia Limestone is identified as a pair of strong seismic reflections. Stratigraphic units adjacent to the basin-bounding fault do not occur farther to the east, suggesting that they were either not deposited or have been eroded, with a major unconformity occurring above the Thorntonia Limestone. There has been intense inversion on the basin-bounding fault, with the strata rotated to steep dips (up to 75º). The zone of inversion is bounded to the west by the Pilgrim Fault, which is a re-activated basement fault. To the east of the Pilgrim Fault, the basin is essentially undeformed and preserves it original geometry.

Millungera Basin, northwest Queensland

The Millungera Basin in northwest Queensland is completely covered by the thin Jurassic-Cretaceous Eromanga-Carpentaria Basin, and was not discovered until 2006 when relatively short segments across the western part of the basin were first observed on two seismic lines (06GA-M4 and 06GA-M5). Following this, seismic line 07GA-IG1 (Fig. 1) imaged a 65 km wide section of the basin (Korsch et al, 2009) (Fig. 2b). Interpretation of aeromagnetic data suggests that the basin could have horizontal dimensions of up to 280 km by 95 km. Apart from geophysical data, virtually no geological information exists on the basin.

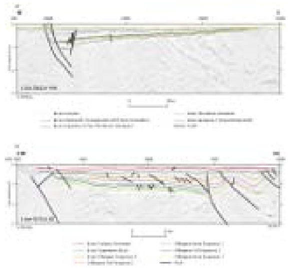

Figure 2
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Scarce water bores in the overlying Eromanga-Carpentaria Basin intersect the organic-rich Toolebuc Formation at a depth of about 185 m, with the basin being about 200–300 m thick in this region. Below this, the Millungera Basin consists of three distinct sedimentary packages, mapped in the seismic section that thicken slightly to the east (Fig. 2b). In the seismic section, the base of the basin is at a maximum depth of ~3,200 m (calculated from stacking velocities). Interpretation of gravity profiles suggests that the basin deepens to the south, possibly reaching a maximum thickness of 4,000 m. There is a noticeable angular unconformity between the two basins, indicating that part of the Millungera Basin was eroded prior to deposition of the Eromanga-Carpentaria Basin. Both the western and eastern margins of the Millungera Basin are truncated by thrust faults, with well-developed hangingwall anticlines occurring above the thrusts at the eastern margin (Fig. 2b). Several granites are interpreted to occur below the Millungera Basin, raising the possibility of geothermal plays. Given the unknown age of the basin, several possibilities exist. It might be related to the Galilee Basin to the southeast, the Georgina Basin to the southwest, the Adavale Basin to the south, or even to Mesoproterozoic rocks of the Isa Superbasin to the northwest. The geometry of internal stratigraphic sequences and post-depositional thrust margins indicate that the original succession was much thicker than preserved today, and the basin may have potential for a petroleum system. Further work is warranted.

Yathong Trough, Darling Basin, Western NSW

The Darling Basin, in western NSW, is known to contain more than 8,000 m of Late Silurian to Early Carboniferous sedimentary rocks, but is dominated by Middle to Late Devonian red beds, with potential source rocks at depth. Although the basin is under-explored, previous studies indicate the existence of at least one active Paleozoic petroleum system (Alder et al, 1998). The Darling Basin was last deformed during the Carboniferous Kanimblan Orogeny, with thrust faults and related hangingwall anticlines having the potential to act as traps for hydrocarbons.

The Yathong Trough occurs in the southeast part of the Darling Basin, and prior to this work has not been explored through seismic acquisition or drilling. The trough was imaged in seismic line 08GA-RS2 (Fig. 3b), which shows that the basin fill consists of a thick succession characterised by alternating high and low amplitude seismic reflections, interpreted to represent the expected Devonian succession of non-marine mudstones and sandstones. Using sequence stratigraphic principles, four major packages have been identified, and interpreted to be (from the bottom up): Ordovician turbidites of the Lachlan Orogen forming the basement; the Late Silurian-Early Devonian rift-fill package; the Early Devonian Winduck Group deposited on a shallow marine shelf; and, a very thick succession of Middle-Late Devonian red beds forming the Mulga Downs Group. The Winduck and Mulga Downs groups form a very thick succession up to ~2.95 s TWT (~7,200 m) thick. The sequence boundary at the base of the Mulga Downs Group is a marked erosion surface, denoting the change from shelf to continental sedimentation (Fig 3b). The trough is fault bounded in the west by a positive flower structure associated with a north-south trending strike-slip fault. Near the eastern margin of the trough, an east-directed thrust fault has a hanging wall anticline on its western side. The eastern margin of the trough is terminated by a major, west-directed thrust fault. Possible traps include anticlinal and fault closures near the eastern margin of the trough.

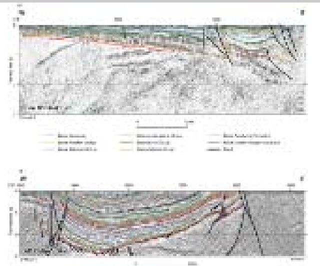

Figure 3
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Arrowie Basin, South Australia

The western part of the Arrowie Basin, west of the central Flinders Ranges, forms part of the Stuart Shelf and the Torrens Hinge Zone. This part of the basin has received almost no attention for hydrocarbon exploration since the shallow Wilkatana wells were drilled in the 1950s to a maximum depth of ~670 m. Some of these wells encountered non-commercial bituminous hydrocarbons in the Cambrian succession. The Cambrian source rocks are considered to have previously generated oil and, in some places, are still within the oil generation and preservation window (McKirdy, 1994).

Seismic line 08GA-A1 (Fig. 1) crossed the Cambrian Arrowie Basin, which is underlain by a Neoproterozoic succession of the Adelaide Rift System. Stratigraphic sequences have been mapped and are tied to recent drilling for mineral and geothermal exploration. The seismic line shows that the Arrowie Basin (Fig. 3a) is asymmetrical, varying in thickness from about 700 m in the west, up to about 3,800 m in the east. There is very limited stratigraphic control in this region, with the Wilkatana wells—about 15 km to the south of the seismic section—ending in the Cambrian succession. Recent industry drilling (TDKH1A, 1,002 m total depth) to the south of the seismic line, intersected part of the Neoproterozoic succession. Several sequence boundaries, mapped using sequence stratigraphic principles, are correlated tentatively with the sequence boundaries between the major Neoproterozoic stratigraphic groups in the Adelaide Rift System, which have been mapped in outcrop in the Flinders Ranges to the east.

The east-dipping Yadlamalka Fault is a post-depositional thrust fault defining the eastern limit of the Stuart Shelf, to the east of which is the Torrens Hinge Zone. To the south of the seismic line, recent mineral exploration drilling intersected the Beda Volcanics (part of the basal Neoproterozoic Callanna Group) in the hanging wall of the thrust, indicating that there has been at least 1,200 m of pre-Cenozoic throw on the fault. A narrow, linear magnetic high on the aeromagnetic images is interpreted to represent the upthrust Beda Volcanics on the eastern side of the Yadlamalka Fault. In this seismic section, there is only a thin remnant of the Cambrian succession preserved, occurring to the east of the Yadlamalka Fault. A series of east-dipping thrust faults disrupt the stratigraphic section in the easternmost part of the seismic section. These faults might be related, in part, to the currently active, east-dipping, Wilkatana Fault, which occurs immediately east of the seismic line and is associated with the recent uplift of the Flinders Ranges.

Conclusions

Deep seismic reflection profiles from sedimentary basins from onshore Australia, collected as part of the Onshore Energy Security Program, are providing new information on the basin architecture and internal geometries of these frontier basins. This will provide the basis for ongoing work that will aim to assess the petroleum potential of these basins.

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BIOGRAPHIES

Lidena is a geologist for the onshore petroleum project in the onshore energy and minerals division at Geoscience Australia. She graduated from the Australian National University (ANU) majoring in geology and human ecology with a BA/BSc (Hons) in 2004, and began working as a technical officer at the Research School of Earth Sciences (ANU).

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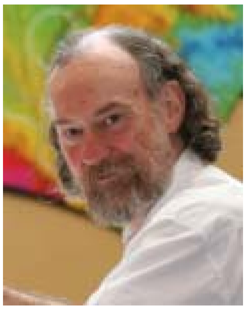

Russell Korsch is Group Leader—Onshore Energy and Minerals Division at Geoscience Australia and is responsible for the onshore petroleum and energy geodynamics components of the Australian Government's Onshore Energy Security Program.

Russell has a BSc (Hons), PhD and DipEd from the University of New England and is on the Executive of the Editorial Board of Australian Journal of Earth Sciences.

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Leonie Jones has a BSc (Hons) in physics from the University of Queensland and a PhD in geophysics from the Australian National University. She has worked as a geophysicist in the petroleum industry, in academia and in government.

Her initial laboratory research interests in elastic properties of minerals and rocks at ultrasonic frequencies have evolved into regional seismic reflection investigations of the Australian continent. She now works at Geoscience Australia in the Seismic Acquisition and Processing Project in the Onshore Energy and Minerals Division.

Josef Holzschuh has been a seismic processor with Geoscience Australia since 2007 and he has processed numerous onshore deep crustal seismic data from different parts of Australia, including seismic line 08GA-A1.

He graduated with a BSc (Hons) in geology and geophysics from the University of Sydney in 1995 and with a PhD in geophysics from the University of Western Australia in 2000.