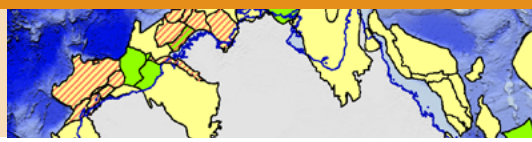
Australian Government
Geoscience Australia

AUSGEO news
ISSUE 85 MARCH 2007

Assessing *prospectivity in offshore frontier basins*

Frontier basin studies identify new exploration opportunities



Barry Bradshaw

Recent increases in global demand for hydrocarbons, declining production from mature provinces, and high oil prices are driving a new phase of international exploration for petroleum resources in frontier basins. These are often data-poor areas where the basin geology is poorly understood, making prospectivity and exploration risks difficult to evaluate.

"Vast frontier areas in offshore Australia remain unexplored and offer the potential for discovery of significant new provinces to maintain our energy security"

Most exploration companies manage these risks by developing an international portfolio of opportunities, and highgrading areas with evidence of a world-class petroleum system together with pool sizes greater than 250 million barrels (mmbbl) oil equivalent.

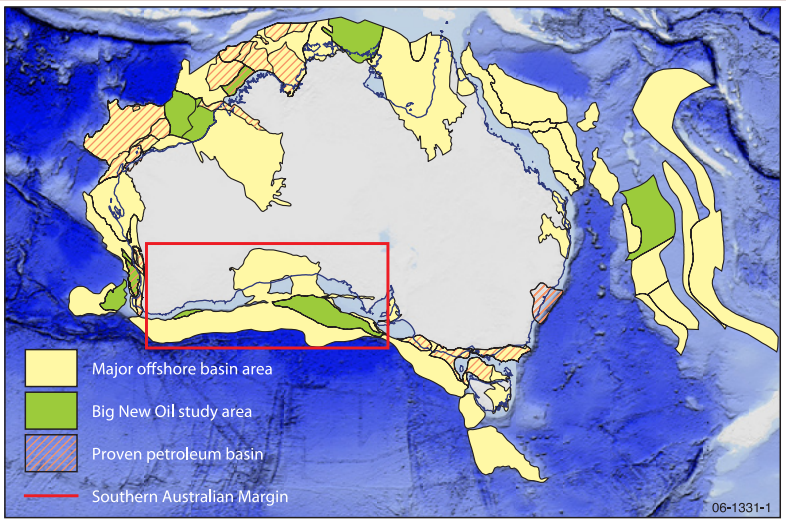


Figure 1. Australia's major offshore basin areas, highlighting proven petroleum basins, and frontier basins studied under Geoscience Australia's Big New Oil Program. The southern Australian margin study area is outlined by the red rectangle.

Australia's offshore frontier basins

Australia remains underexplored for hydrocarbon resources, with only about 8000 wells drilled. Most offshore exploration has been in basins with proven potential: the Gippsland, Bass and Otway basins in southeast Australia; the Perth Basin on the southwest margin; and the Northern Carnarvon, Browse and Bonaparte basins on the northwest shelf (figure 1). Seven major oil fields were discovered in the offshore Gippsland and Northern Carnarvon basins from 1960 to 1990 (Foster 2006). Until recently, numerous smaller discoveries in the Northern Carnarvon and Bonaparte basins have maintained our oil reserves. Vast frontier areas in offshore Australia remain unexplored and offer the potential for discovery of significant new provinces to maintain our energy security.

Since 2003, the Australian Government has funded a geoscientific program of data acquisition that aims to identify and promote new exploration opportunities in key offshore frontier basins (figure 1). Geoscience Australia's role in

the Big New Oil Program has been to acquire new datasets and apply integrated basin analysis to model petroleum systems and plays at a regional scale. The datasets underpinning these studies vary according to such factors as regional geology, exploration history, sea-floor geomorphology, and budget constraints.

Two case studies from the southern Australian deepwater margin demonstrate how integrated basin studies are used to assess the petroleum prospectivity of frontier basins at a regional scale.

Figure 2. Location of the Bight Basin along the southern Australian margin, with component sub-basins.

Southern Australian frontiers

Geoscience Australia's study of southern Australian frontiers has focused on the Bight Basin. This major extensional system comprises a series of Middle Jurassic–Cretaceous depocentres that developed during the break-up of Australia and Antarctica (figure 2). Most of the basin is formed by the very large Recherche and Ceduna sub-basins, with a series of smaller half-grabens around the main rift basin margin, including the Bremer and Denmark sub-basins in the west, and the Eyre and Duntroon sub-basins in the east. The main depocentres extend over water depths between 100 and 5000 metres, and are relatively unexplored. Only 10 wells have been drilled, all in the eastern part of the Bight Basin.

"case studies from the southern Australian deepwater margin demonstrate how integrated basin studies are used to assess the petroleum prospectivity"

Bremer Sub-basin

The Bremer Sub-basin is a half-graben system located in the western part of the Bight Basin (figure 2). Until recently, exploration was limited to a regional seismic grid acquired in 1974. This showed the presence of potentially prospective structures for trapping hydrocarbons; however, the absence of subsurface geological data from wells and the deepwater setting (100–4000 metres) discouraged further exploration.

Geoscience Australia began a study of the Bremer Sub-basin in 2004 to determine whether it contained suitable geological conditions to generate and trap hydrocarbons and to identify further exploration opportunities. A major challenge was building a geological framework, without any well data, that would allow petroleum systems and plays to be modelled to support a new phase of exploration.

An integrated basin study was undertaken using 1300 kilometres of new seismic data and several hundred rock samples obtained by dredging submarine canyons that cross the continental slope and incise up to two kilometres into the basin fill (figure 3). Results from the Bremer Sub-basin Study are documented in Blevin (2005) and Bradshaw (2005).

The stratigraphy of the Bremer Sub-basin was determined by linking dredge

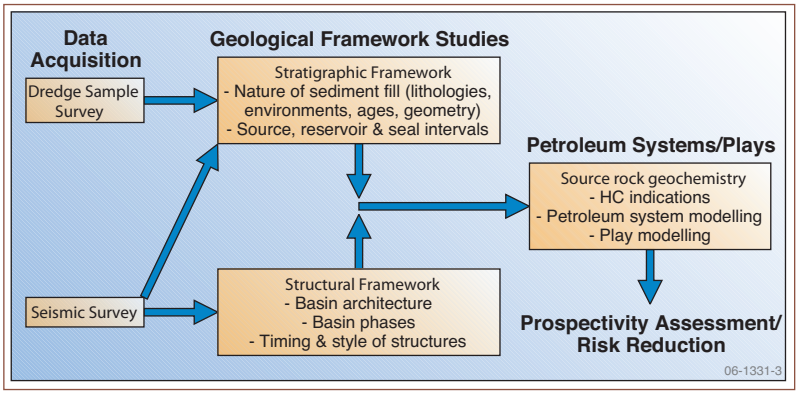


Figure 3. Summary of the integrated basin analysis workflow used in the Bremer Sub-basin study.

samples—analysed for age, palaeoenvironment and lithofacies—with interpreted seismic sequences and facies. This stratigraphic framework was further refined using genetically related depocentres from the eastern Bight and southern Perth basins as geological analogues. Potential source, reservoir and seal rocks were identified within a series of three fluvial–lacustrine cycles beginning in the Late Jurassic and continuing through until the Valanginian (see *AusGeo News 81*). Further analysis of dredge samples from these fluvial–lacustrine strata provided quantitative data confirming the presence of rocks with source, reservoir and seal potential.

"Trap preservation is the main exploration risk for this play type, with many faults showing evidence of a later phase of reactivation."

A structural framework study was undertaken using seismic reflection and refraction data to determine whether these potential source intervals are buried deeply enough to have generated hydrocarbons and, if so, the timing of generation and expulsion and the presence of suitable traps.

Structural mapping highlighted a large potential source kitchen in the central part of the sub-basin, containing 4 to 9.5 kilometres of strata (see *AusGeo News 81*). Potential traps were generated during a period of upper crustal extension that began in the Valanginian and continued until the Aptian. These include fault block traps associated with a major intrabasinal fault system in the central sub-basin area, and large anticlines that formed in the hanging wall of the rift-border faults from smaller eastern and western depocentres.

Results of the structural and stratigraphic framework studies were integrated to model petroleum systems and plays. Petroleum systems were modelled by generating a series of pseudo-wells in each depocentre, constrained by depth conversion of seismic interpretations and source rock analysis from dredge samples. One-dimensional burial history modelling of pseudo-wells indicates favourable timing of hydrocarbon expulsion from Late Jurassic to Early Cretaceous source intervals relative to trap generation in the central sub-basin area, where fault blocks have the potential to trap 250 mmbbl of oil (P_{50} estimate; see *AusGeo News 81*). Trap preservation is the main exploration risk for this play type, with many faults showing evidence of a later phase of reactivation.

Smaller depocentres in the eastern and western parts of the sub-basin contain large anticlines with the potential to trap 500 mmbbl of oil (P_{50} estimate), and may have favourable timing to be charged from Middle Jurassic source rocks (see *AusGeo News 81*). However, hydrocarbon charge is the main exploration risk for this play type because only small potential source kitchen areas are present.

Geoscience Australia used results from the Bremer Sub-basin study to support the release of two designated frontier permits in 2005. The permits (WA-379-P and WA-380-P) were subsequently awarded to Plectrum Petroleum plc, which bid an $80 million indicative exploration program. This included the acquisition of 3500 kilometres of new seismic data and an option to drill two wells in a secondary exploration program.

Eastern Bight Basin

The eastern part of the Bight Basin is one of the most prospective deepwater frontier basins in offshore Australia. Of particular interest to petroleum explorers is the Ceduna Sub-basin, which contains at least 15 kilometres of sedimentary section. Though still a frontier region, the eastern Bight Basin has had several phases of exploration, including drilling campaigns by Shell (1960s to mid 1970s), Esso Australia (1979–1983), BP (1980s), BHP (early 1990s) and Woodside Petroleum (current).

"The eastern part of the Bight Basin is one of the most prospective deepwater frontier basins in offshore Australia."

Geoscience Australia undertook an integrated basin study of the eastern Bight Basin between 1998 and 2004, using regional seismic and well data. Petroleum system and play models from these studies predict favourable geological conditions to generate and trap hydrocarbons in thick mid to Late Cretaceous deltaic and marine sediments within the Ceduna Sub-basin (Blevin et al 2000, Totterdell et al 2000, Struckmeyer et al 2001).

Only 10 wells have been drilled in the eastern Bight Basin. No commercial hydrocarbons have been discovered, with the most significant result to date being an oil show at Greenly-1. Most wells have been drilled around the landward margins of the rift system in water depths between 70 and 260 metres where the source rock quality of mid to Late Cretaceous strata is reduced by large amounts of terrigenous organic matter associated with proximal depositional environments.

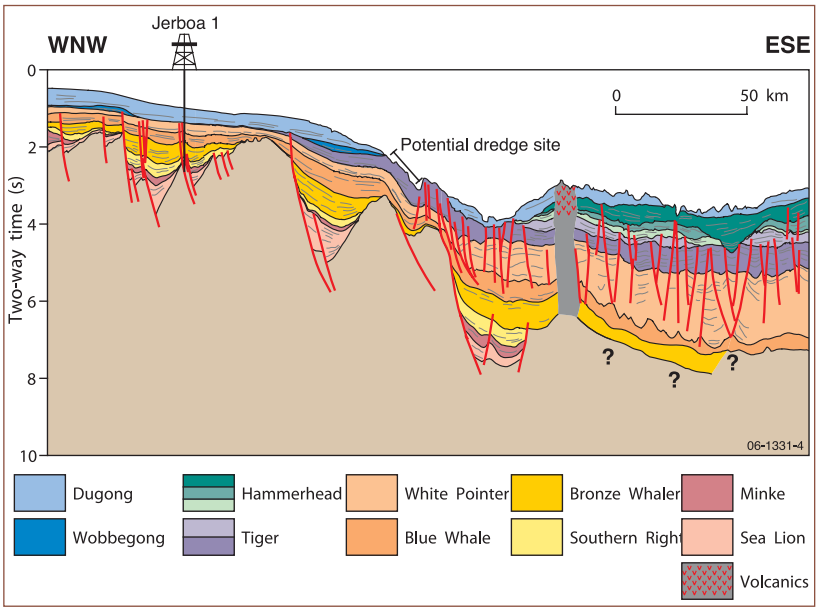


Figure 4. Location of planned dredge sampling site at the boundary between the Ceduna and Eyre sub-basins, where an interpreted source rock interval from the Turonian to Santonian age Tiger Supersequence is exposed at the seafloor.

In April 2003, Woodside Petroleum and joint venture partners drilled Gnarlyknots-1A in 1316 metres of water to test the petroleum systems within more distal Late Cretaceous depositional systems. However, because of adverse weather conditions, the well was abandoned at the top of the Tiger Supersequence, some 1500 metres above the planned completion depth, and encountered oil indications within proximal sand-prone deposits (Tapley et al 2005). Although a valid trap is yet to be tested in the Ceduna Sub-basin, one of the key uncertainties for explorers is whether a viable petroleum system is present.

Some indications of an active petroleum system have previously come from:

- hydrocarbon seep studies using synthetic aperture radar (SAR) and airborne laser fluorosensor (ALF) data (Struckmeyer et al 2002)
- geochemical studies of asphaltite strandings along the southern margin (Boreham et al 2001)
- fluid inclusion studies of wells (Ruble et al 2001).

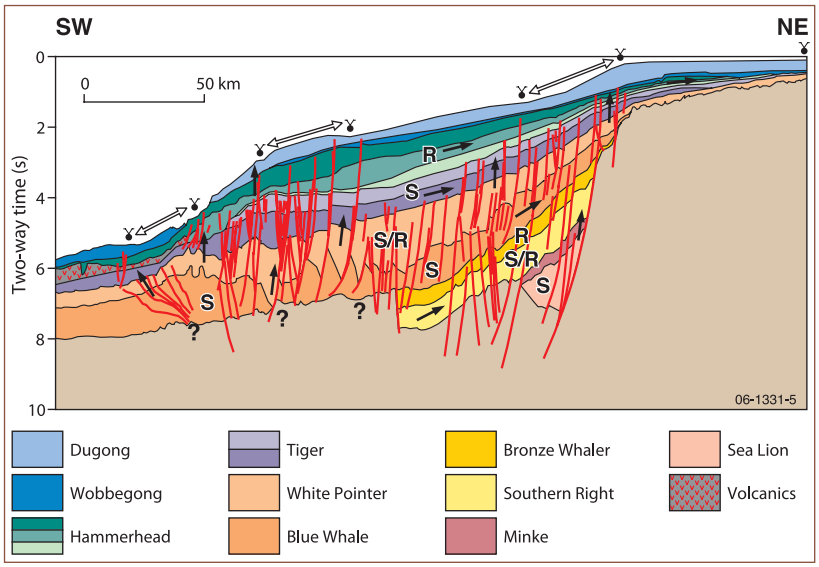


Figure 5. Natural hydrocarbon seep model for the Ceduna Sub-basin published by Struckmeyer et al (2002). Arrows show the three regions of interpreted hydrocarbon seepage that will be surveyed and sampled.

Marine survey

To reduce the hydrocarbon charge risk for explorers, direct physical evidence for high-quality source rocks and/or an active petroleum system in the Ceduna Sub-basin are needed. To obtain this, Geoscience Australia is currently undertaking a marine survey using the National Research Facility, the RV *Southern Surveyor*.

"This will be the first time that these technologies have been used in water depths greater than 1000 metres"

The survey has two objectives:

- Dredge sample areas where seismic data indicate that source rock intervals are exposed on the seafloor in the distal parts of the Ceduna Sub-basin (figure 4). Rock samples obtained from the survey will be geochemically analysed for their source rock quality.
- Test for an active petroleum system by investigating and sampling potential natural hydrocarbon seepage sites. Existing seismic, SAR and ALF data indicate that seepage is most likely to occur in three broad areas of the Ceduna Sub-basin (figure 5): along faults that extend to the seafloor near the landward margins (100 to 1100 metres water depth); where growth faults extend to the seafloor around the southern and southwestern edges of the Ceduna Terrace (1600 to 2700 metres); and above shallow shale ridges at the basinward margin of the sub-basin (3000 to 4500 metres).

The tools that will be used to detect and sample seeps have been developed and applied on the northern Australian margin by Geoscience Australia's Seeps and Signature Project (see *AusGeo News 81*). This will be the first time that these technologies have been used in water depths greater than 1000 metres.

This survey of potential seep sites, together with targeted dredge sampling of source intervals, aims to demonstrate that a viable petroleum system exists in the Ceduna Sub-basin.

Conclusions

Case studies from the southern Australian margin show that assessing the petroleum potential of frontier basins requires development of our geological knowledge so that petroleum systems and plays can be modelled at a regional scale. Geoscience Australia employs integrated basin analysis using all available datasets to model regional petroleum systems and plays in frontier areas. However, each frontier region has unique challenges in terms of the complexity of basin geology, the availability of existing datasets, and budget constraints on the acquisition of new datasets. Innovative approaches are therefore often necessary to acquire key datasets. Good quality regional seismic lines comprise the essential data for our integrated basin studies, given that well data is often sparse or absent in frontier basins.

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Related websites/articles

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