Development of new play concepts using sequence stratigraphy: Devonian–Carboniferous, Canning Basin, Western Australia

Using the new concepts of sequence stratigraphy, we are interpreting and integrating subsurface data in the northern part of the Canning Basin (Fig. 1) to provide a better understanding of basin evolution and petroleum prospectivity. These data comprise shallow seismic, BMR deep seismic, drillhole information, and biostratigraphic reassessment of available palaeontological information. The main outcomes are:

- more confident correlation between seismic and well data
- recognition of extensive Late Devonian lowstand deposits along the northern edge of the Fitzroy Trough
- identification of several new petroleum play concepts
- better understanding of the evolution of subsurface and exposed reef complexes, and
- development of a detailed relative sea-level curve for Late Devonian–Early Carboniferous time

As the first stage of the Canning Basin Project a detailed sequence-stratigraphic interpretation of about 1200 line-km of seismic and 40 wells was undertaken for the central part of the Lennard Shelf and adjacent Fitzroy Trough. At least 24 ‘Vail-type’ sequences have been identified in this area; 16 Devonian–Carboniferous sequences are shown in Figure 2.

Even in such a small area, this new style of genetic approach is solving problems of correlation that have arisen from using traditional lithostratigraphic techniques. For example, we are now able to link genetically five diachronous lithostratigraphic units near the contact between the Nullara Cycle and the overlying Fairfield Group. Our Famennian 2 sequence comprises three systems tracts: lowstand clastics (Clanmeyer Formation), transgressive calcareous shales (May River Shale), and highstand carbonates (variably referred to as the Windjana Limestone, Nullara Limestone, and Gumhole Formation). Ultimately this sequence analysis will generate a genetic stratigraphic framework to systematically relate the plethora of existing lithostratigraphic units.

Detailed sequence analysis of the Devonian–Carboniferous succession has enabled us to identify and map systems tracts and to distinguish two phases of sedimentation: (1) a Givetian–Famennian reef-rimmed platform complex, and (2) a Famennian–Tournaisian ramp complex (Fig. 3).

The reef complex consists of two cycles of progressively onlapping sequences: the lower Pillara cycle displays successively backstepping platform margins (Givetian–Frasnian sequences 0 to 4), whereas the upper Nullara cycle displays successively advancing platform margins (Givetian–Frasnian sequence 5 and Famennian sequences 1 and 2). Each sequence is characterised by reciprocal lowstand-highstand sedimentation: lowstand clastic-rich sediments restricted to the basin, and highstand carbonate sediments across the platform and platform margin. The lowstand deposits consist of three systems: basin floor fan, slope fan, and prograding complex.

The basin floor fans form sheets tens of kilometres across and 40–100 m thick that onlap the basal sequence boundary basinward of the platform margin. Their upper surfaces are commonly defined by reflectors with high impedance contrasts. These fans were probably deposited during periods of relative lowstand when the platform was exposed, and are likely to comprise terrigenous sands fed by incised river systems whose proximal deposits are preserved locally on the platform (e.g. conglomerates in Meda 1 and Yarrada 1, and conglomerate outcrops in Fig. 1).

The slope fans form thick wedges above the basin floor fans and pinch out against the platform slope. They generally have a mounded seismic character, and locally contain distinct ‘gull-wing’ reflectors that indicate channel-levee complexes within the mounds. The flanks of the mounds display subparallel reflectors interpreted as distal turbidite aprons. The slope fans consist of siltstone, shale and minor sandstone, and their upper faces are prominent downlap surfaces.

The prograding complex forms a thick progradational and aggradational lens which
onlaps the basal sequence boundary at or near the platform margin, and downlaps basinward, onto the slope fan. In places this downlap surface climbs basinward, suggesting the presence of shingled turbidites at the toe of the prograding complex. The prograding complex is commonly the most volumetrically important depositional system within the reef sequences, and is characterised by well-defined sigmoidal clinoforms. It has been penetrated in several wells; in the Famennian 2 sequence the distal part consists of calcareous siltstone and minor sandstone (Lukins 1), and the proximal parts comprise micritic pelletal carbonates (Mariana 1, Yarrada 1).

Highstand reef carbonates are volumetrically minor compared to the lowstand deposits, but have been intersected in many wells. Transgressive deposits are generally below seismic resolution. The highstand deposits have oblique progradational geometries at the platform margin and parallel reflectors across the platform; they downlap onto the prograding complex. They comprise back-reef, reef, and fore-reef carbonates.

The Famennian–Tournaisian ramp complex comprises successively offlapping lenticular sequences (Famennian 3 to Tournaisian 4) overlain by two progressively onlapping tabular sequences (Tournaisian 5 and 6). Each offlapping sequence consists of a lowstand clastic wedge with sigmoidal internal reflectors, and a more laterally extensive, mixed carbonate and clastic highstand deposit with oblique internal reflectors. Lowstand slope fans are restricted to Famennian sequences 3 and 4 which mark the transition from a reef-rimmed platform to a ramp. These fans are overlain by lowstand prograding complexes which are the sole lowstand component of the overlying ramp sequences. The highstand systems tracts prograde several kilometres across their lowstand counterparts. In contrast, the onlapping tabular ramp sequences comprise relatively thin lowstand prograding complexes, and thicker mixed carbonate and clastic highstand deposits.

**Petroleum plays**

This analysis has identified three petroleum plays (Fig. 3): (1) offlapping highstand carbonate-clastic ramps of Famennian and Tournaisian age; (2) lowstand basin floor and slope fans of Frasnian and Famennian age: and (3) backstepping transgressive and highstand pinnacle and barrier reefs of late Famennian age (Pillara cycle). Previous exploration has been focused mainly on structural closures in the advancing platform of the Famennian Nullara Cycle. Out of 22 wildcats with reef targets, 17 had primary Famennian targets, 5 had primary Frasnian targets, and 3 had secondary Frasnian targets; however, none are considered to have been valid Frasnian reef tests.

The **highstand-ramp play** occurs in an elongate belt near the northern margin of the Fitzroy Trough. It consists of ooid and/or bioclastic shoals which grade basinward into outer-shelf and slope bioclastic micritic carbonate and calcareous siltstone, and pass landward into inner-shelf and coastal micritic carbonate, siltstone, and possible evaporite. Outer-ramp facies and underlying and overlying transgressive shales are potential source rocks. Potential seals are the overlying progradational inner-shelf and coastal facies, or transgressive shales. Reservoir quality is controlled by primary porosity and porosity generated by meteoric diagenesis and dolomitisation during subsequent lowstands. Although this is chiefly a stratigraphic trap, combined stratigraphic-structural traps are likely as a result of Carboniferous faulting. Analogs of this highstand ramp play are the Permian Grayburg and San Andres Fields of the Delaware-Midland Basin, USA, and the Jurassic–Cretaceous fields of the Neuquen Basin, Argentina. This play is similar to the older Yellow Drum Sandstone plays on the Lennard Shelf (a secondary production interval at Blina), but differs in that it is primarily controlled by depositional facies and porosity trends may be easier to predict.

The **lowstand-fan play** is also along the northern edge of the Fitzroy Trough. Potential reservoirs are turbidite sand sheets within the basin-floor fans, and sand channels flanked by levee complexes in the slope fans. Potential source rocks and seals are provided by interbedded shales and distal deposits of the overlying and underlying prograding complexes. Up-dip pinchouts of the fans are obvious stratigraphic traps. Since many of the Frasnian fans lie deep
Exploration opportunities exist in several vacant areas of the Ashmore-Cartier region in the offshore Bonaparte Basin off northwestern Australia (Figs. 4, 5). The areas, which cover parts of the Ashmore Platform, Vulcan Sub-basin, and Jabiru Terrace, are likely to be available for application under the Petroleum (Submerged Lands) Act in the next release of platform-drowning and backstepping, and could be sourced and sealed by onlapping basin- and seal sediments in the sub-basin appear to be thin or of some residual or biodegraded accumulations. Most of the major oil accumulations, e.g. Jabiru, Challis, Cassini, Skua, and Talbot, are trapped in Triassic and/or Jurassic reservoirs sealed by Cretaceous marine shale. Estimated recoverable petroleum reserves in the Bonaparte Basin as at 31 December 1990 comprised 3.902 x 10^7 m^3 of oil, 18.70 x 10^6 m^3 of natural gas liquids, and 111.189 x 10^6 m^3 of sales gas.

**Ashmore-Cartier geological setting**

The Vulcan Sub-basin, Ashmore Platform, Jabiru Terrace, and Northern Browse Basin are in the Commonwealth Territory of Ashmore-Cartier Islands. They were the major structural elements formed here during the Mesozoic breakup of Gondwana. They were created by crustal extension mainly during the Middle and Late Jurassic, and together constitute a structurally complex zone.

Petroleum plays

The known oil accumulations are all located on a structural high up-dip of or next to a major fault system along which oil has migrated out of mature Jurassic source rocks. The tilted horsts comprise Plover Formation (Jurassic), Flamingo Group (Jurassic), and Sahul Group (Triassic) reservoirs, overlain by the base-Cretaceous regional seal of the Bathurst Island Group. Closure is fault-dependent, the faults being Late Jurassic, although post-Miocene reactivation has caused some trap destruction. Additional potential exists to test further valid plays that may involve some elements from previously successful play types. Submarine fan complexes in the Flamingo Group are a significant new play with very large potential trap sizes. Mainly located on the downthrow side of generally Oxfordian fault scarps they would rely on migration from downdip Jurassic source rocks. Maastrichtian turbidite sands are a further play that has demonstrated potential (oil in Puffin 1 and 2 wells).

**Petroleum resources**

As at 1 January 1991 the Bonaparte Basin was known to contain five major and nine minor petroleum accumulations, and over 20 wells with significant indications of hydrocarbons, including some residual or biodegraded accumulations. Although the major oil accumulations, e.g. Jabiru, Challis, Cassini, Skua, and Talbot, are trapped in Triassic and/or Jurassic reservoirs sealed by Cretaceous marine shale. Estimated recoverable petroleum reserves in the Bonaparte Basin as at 31 December 1990 comprised 3.902 x 10^7 m^3 of oil, 18.70 x 10^6 m^3 of natural gas liquids, and 111.189 x 10^6 m^3 of sales gas.

**Fig. 4. Structural elements and petroleum resources**

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