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Diagenesis of the Nullawarre Greensand, a Late Cretaceous Oolitic Ironstone facies in southeastern Australia

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The Late Cretaceous Nullawarre Greensand of the Sherbrook Group, Otway Basin, is dominated by a marine oolitic ironstone facies.

The colour of Nullawarre Greensand is usually attributed to the presence of glauconite. Investigation has revealed, however, that within the Port Campbell Embayment the green clay mineral berthierine is a more dominant pigment than glauconite. The berthierine is present as a thin coating over quartz grains. Further petrological studies, scanning electron microscope analysis, and microprobe results have revealed an unusual mineralogy and texture in the Nullawarre Greensand that includes the presence of berthierine ooids, glauconite pellets, siderite and phosphate cements, pyrite, and the rare-earth-element (REE) phosphate mineral rhabdophane. Together, these grains, cements, and minerals provide strong evidence that the Nullawarre Greensand was deposited in a relatively high energy shallow to near coastal marine environment during a period of reduced clastic sediment influx.

The unusual mineralogy of the Nullawarre Greensand has given insight into the unit's environment of deposition and in turn has given new perspective on the depositional history of the Sherbrook Group.

A revised structural framework for frontier petroleum basins on the southern and southwestern Australian continental margin

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The southern and southwestern Australian continental margin is a vast, under-explored area with sufficiently thick sedimentary strata (>3 km) to generate substantial quantities of hydrocarbons. One impediment to petroleum exploration has been a limited understanding of the geological framework of the basins in this region. Three frontier petroleum basins, the Bight, Mentelle and Perth basins, are now recognised along the southern and southwestern margin. Each basin is defined by component structural elements that relate to different stages in their evolution. The Bight Basin extends for about 2,000 km along the southern margin. It formed during rifting between Australia and Antarctica in the Middle Jurassic–Late Cretaceous. Sub-divisions of the Bight Basin include the previously recognised Eyre, Ceduna and Recherche sub-basins, along with a series of newly defined Middle Jurassic–Early Cretaceous half-graben systems, the Duntroon, Bremer and Denmark sub-basins, and a Cretaceous platform cover, the Madura Shelf. The Perth Basin extends about 1,300 km along the southwestern continental margin, and formed during rifting between Australia and India in the Permian–Early Cretaceous. A new sub-division of the Perth Basin, the Zeewyck Sub-basin, is a deep water pull-apart basin that formed during Early Cretaceous break-up. The Mentelle Basin, located between the Naturaliste Plateau and Leeuwin Block, is a newly defined frontier basin that formed at a triple junction between Australia, Antarctica and India during the Middle Jurassic–Early Cretaceous. This revised structural framework of basins along the southern and southwestern margin will benefit petroleum explorers by more clearly delineating the main petroleum provinces in this frontier region.

Integrated seismic stratigraphy, sequence biostratigraphy and forward tectonic modelling: Insights into late Paleogene–Early Neogene prograding clinoforms in the northern Carnarvon Basin

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Two- and three-dimensional (2D and 3D) seismic stratigraphic interpretation, palaeobathymetric analysis from benthic foraminifera, and 2D forward tectonic modelling are combined to show the genetic significance of prominent seismic discontinuity surfaces. Such surfaces are typically mapped as sequence boundaries and flooding surfaces, and their intervening sequences. Integration of these data has allowed interpretation of the Tertiary, heterozoan (i.e., non-photozoan) carbonate-dominated succession, detailing the evolution of five prograding clinoformal sequences (2–5 m.y. duration), and 19 subsequences (<0.5–1 m.y. duration), along the Rankin Trend. The major observations and implications of this study are:

- Onlap onto the clinoform front of primary mappable surfaces is submarine with minimum estimated palaeowater depths >100 m at the shelf edge. Exposure surfaces identified in the middle Miocene are seismically less prominent, with potential karstification identified 6–8 km landward of shelf edges.
- Systems tracts could not be consistently identified in the progradation-dominated succession. Lowstand basin-floor fans/aprons and transgressive systems tracts are largely absent at seismic scale, resulting in downlap directly onto sequence boundaries.
- Linear, (30–80 km along strike), two-dimensional mapped sequences, consist of local sedimentary lobes up to 10 km in diameter.
- Canyon development may be controlled by inclination on gully failure walls rather than variations in sea level. Gully initiation is coincident with the mid-Miocene climatic Optimum. Once established, however, erosion paths are maintained and enlarged by downslope sediment flows, derived from headward failure, regardless of proposed sea-level variations.
- Variations in accommodation space, as modelled across the Dampier Sub-basin using 2D kinematic and flexural modelling, are the combined result of synrift and postrift thermal subsidence, inversion and eustatic variations. The magnitude of inversion-related uplift is small, reaching a maximum of 50–70 m at anticlinal crests focussed along the Rankin, Madeleine and Rosemary trends. Although this is of a similar scale to postulated eustatic variations that increase or decrease accommodation space across the entire margin, unconformities and onlap discontinuity surfaces related to these inversion structures are areally restricted.

Well abandonment using highly compressed sodium bentonite

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In 1999, in response to concerns within the USA over the escalating number of wells requiring abandonment with no known operator, ChevronTexaco's Environmental Management Company initiated research into the use of compressed sodium bentonite as an alternative to cement for well abandonments. The objective was to identify a process to reduce abandonment costs by at least 40%. A subsidiary company, Benterra, was established to manage ChevronTexaco's bentonite R&D and the subsequent commercialisation of its abandonment process. Following successful pilot studies, Benterra received regulatory approval to use bentonite for well abandonments and trademarked the design of the compressed bentonite nodules as Zonite™. To date, over 400 wells across California have been successfully abandoned using Benterra's process and Zonite.

In early 2002, ChevronTexaco identified the potential application of Zonite for abandoning shallow oil wells in

its mature Barrow Island oilfield, offshore Western Australia. A one-well zonite trial has been scheduled for October 2002, pending final Government approvals. This well will be monitored after abandonment for 9–12 months and will be the first well to be abandoned using Benterra's process outside the USA. The total cost for the trial is estimated to be about 75% of the cost of a conventional cement job, including the one-off costs associated with post-abandonment well monitoring. Once the process and technology has been proven, a more extensive campaign is envisaged for 2004 when it is expected that per well abandonment costs could reduce to 50–60% of the cost of cement jobs.

This poster presents the development of Benterra's abandonment process, in particular the early and close involvement of all key stakeholders and the physical properties and limitations of Zonite. The poster also presents the results of the 2002 Barrow Island trial and the potential future economic and environmental benefits to ChevronTexaco Australia.

Late Tertiary clinoform progrades of the North West Shelf—Significance for basin subsidence and hydrocarbon expulsion models

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New geohistory models for clinoform progradation during the late Tertiary on the North West Shelf have been integrated with recently re-interpreted foraminiferal data from petroleum exploration wells to help define the palaeo-bathymetry of these features on the Browse margin. These carbonate progrades are a prominent feature of North West Shelf regional seismic sections and the interpretation of their palaeo-water depths has significant implications for developing basin subsidence models. These clinoforms record the progradation of the palaeogeographic shelf edge, in water depths in the range 100–300 m, into considerably deeper water environments. This palaeo-water depth interpretation is supported by previous detailed benthonic foraminiferal assemblage interpretations, particularly of the outer high wells.

Most one-dimensional subsidence models have assumed a simple crustal stretching tectonic subsidence curve, which has either:

- relatively shallow water depths in the mid-Tertiary section; or
- deeper mid-Tertiary water depths while incorrectly modelling the shallowing during Late Tertiary progradation.

The latter would necessarily imply a greater Late Jurassic stretching (beta) factor, while the former implies greater Late Tertiary collisional subsidence.

These models have ignored the flexural rigidity of the plate margin, which must increase with time, since stretching (Middle–Late Jurassic) increases and the plate cools. On such a cool plate, airy isostasy no longer applies, so that simple cool-down tectonic subsidence curves are not valid.

This study examines the expected shape of the tectonic subsidence curves, and how we can extract crustal stretching information from the curves. This problem is examined from two aspects:

1. Re-examining the approach used to estimate bottomset water depths, which has implications for 1D modelling on a rigid flexural plate margin.
2. Using recently acquired and re-interpreted foraminiferal data to determine pre-clinoform water depths. This data suggests that the bottomsets are deposited in water depths greater than 700 m.

We conclude that honouring palaeo-water depth and sequence geometry leads to a more accurate assessment of tectonic subsidence. This has critical implications for palaeo-heat flow and palaeo-sea bottom temperature modelling, timing of oil and gas expulsion, and quantification of the effects of the collision of the Australian and Indonesian Plate. In particular it indicates that, contrary to accepted models, expelled hydrocarbons may be forced towards the outer high by a sediment compaction wave that migrates seawards beneath the Late Tertiary progrades.

Late Tertiary deformation in the Colac area, eastern Otway Basin, Victoria

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The base Tertiary unconformity is the most prominent feature on seismic lines in the Colac area of the Otway Basin, west of Geelong. In general the surface is very planar, with only minor palaeotopography truncating predominantly south dipping, early Cretaceous sediments. It is overlain by uniformly layered, Tertiary marine sands and deeper marine marls.

North of a line extending east-northeast–west-southwest between Colac and Winchelsea, the unconformity dips very gently south but is dislocated by a few small reverse faults that clearly link with early Cretaceous normal faults. South of the Colac-Winchelsea line, the Tertiary sediments become more strongly folded and a major south dipping reverse fault, also linking to a reactivated early Cretaceous normal fault, elevates the base Tertiary unconformity up to 500 m in its hanging wall.

Further south, a series of broad, fault related folds, striking generally east-northeast, deform the Tertiary sediments, with synclines lying between reverse faults dipping in opposite directions. Small anticlines occur in the hanging wall of reverse faults which link to early Cretaceous normal faults. These are also bounded by a number of younger reverse faults and thrusts.

The total change in elevation of the base Tertiary unconformity, from north to south, is over 800 m. Tertiary sediments have been uplifted and completely removed from areas just south of Colac and in the Otway Ranges.

Broome—Petroleum and productivity in paradise

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Historic Broome, Australia's pearling capital and Western Australia's tropical tourist paradise, is also the port hub for the offshore oil and gas industry in the Browse Basin.

The port was first used for offshore exploration of the entire North West Continental Shelf from the North West Cape to the Timor Sea by Woodside Energy (then Woodside Burmah Oil) from 1968 to 1984.

Woodside's major Browse Basin gas fields, Scott Reef and Brecknock, were discovered during that time.

Since more intensive exploration in the Browse Basin resumed in 2000, Broome has again become an important port for petroleum exploration. During 2003, up to eight exploration or appraisal wells are planned for the Browse Basin.

The port of Broome is well resourced to service the needs of offshore explorers around the clock with its own team of skilled, flexible and customer focussed stevedores and its own cranes and material handling equipment.

Broome's turn around times for rig tenders are the best in the business and re-supply rates for water and fuel (100 tonnes per hour plus) are unmatched by competing ports.

A supply base, operated by Mermaid Marine, is located next to the jetty. Health, safety and environmental standards of the port meet the petroleum industry's high expectations.

Being located close to the Browse Basin greatly improves sailing times for rig tenders for most of the region compared with the competing ports and the pricing structure is very competitive.

Broome is a sophisticated and fast growing town with excellent accommodation, frequent air services for rig crew changes and lifestyle attractions for permanent residents.

The potential use of synthetic natural gas hydrates for gas storage and transport

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Synthetic natural-gas hydrates (SNGH) are man-made hydrates using natural gas, water and often hydrate promoting chemicals. Gas hydrates are treated as a nuisance in the oil and gas industry, and various techniques are used to prevent the formation of hydrates in wells, pipelines and process equipment. SNGH, however, has potential applications for gas storage and transport. Gas hydrates are clathrate compounds, in which gas molecules are hosted in hydrogen-bonded water cages. They form when gas and water are subjected to hydrate-forming pressure-temperature conditions and they have an ice-like crystalline appearance. The gas content storable in SNGH is indicated by a gas to hydrate volume ratio of 165:1 (at STP conditions), which is stable at atmospheric pressures and temperatures around –5 to –15° C. This property of gas hydrates could be exploited for natural gas storage and natural gas transport applications. Natural gas pipeline transport networks commonly face the dilemma of storing and supplying natural gas from main gas suppliers to domestic markets according to varying daily demand patterns.

Compressors are used to pressurise and store the gas at various gate stations in a high-pressure natural gas transmission network. The compression energy costs involved in these peak-shaving operations could be reduced by storing natural gas in the form of hydrates. Gas hydrates could also be used as a means of natural gas transport; often referred to as Gas-to-Solids (GtS) technology. The volume of gas that could be stored per volume of product is low compared to other gas transport/utilisation technologies such as CNG (300:1) and LNG (600:1), but the GtS process does not involve high temperatures (as in GtL) or low temperatures (as in LNG), or high pressures (as in CNG). It provides a safe and cost-effective alternative to utilise stranded and marginal gas fields. Woodside Research Foundation at Curtin University of Technology has been involved in gas hydrate related research for the past three years, focussing on the applications of SNGH for gas storage and transportation. Current research involves the study of hydrate promoting chemicals and SNGH formation process modelling and optimisation. The SNGH production pilot plant facility developed at Curtin University uses a semi-batch spray reactor, where water with the hydrate promotion additive is sprayed into a pressurised natural gas vessel. This vessel is operated at moderate pressures of 10–50 bar and temperatures of –5 to –15 °C. SNGH quality are measured by re-gasifying the hydrates and determining the gas to liquid volume ratios.

The impact of 3D AVO analysis on exploration and development within WA-271-P

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WA-271-P is a highly prospective permit located in the southern Exmouth Basin of offshore Western Australia. Coincidence between elevated seismic amplitudes and the presence of hydrocarbon bearing rocks has provided the basis for a highly successful exploration campaign yielding three major hydrocarbon discoveries; the Vincent, Enfield and Laverda Fields.

The Enfield oil and gas field was discovered in 1999 after encountering a 21.5 m oil column in Early Cretaceous Lower Barrow Group sandstones. The results of the Enfield discovery were successfully incorporated into further prospect appraisal with the discovery of the Laverda oil and gas field in October 2000 after encountering a 9 m gas column overlying a 63 m oil column.

A primary goal of the WA-271-P exploration strategy has been to identify additional reserves to possibly impact the design of a production facility for the discovered fields. Hence, the Montesa prospect, in an adjacent fault block to the Laverda Field, was drilled in early 2001 but failed to encounter any hydrocarbons.

The pre-drill expectation of Montesa was tempered somewhat by a subtler AVO response. The well highlighted the need for strong conformity of amplitude to structure. In addition the need to be able to identify not only the presence of hydrocarbons, but also accurately predict phase, has become increasingly important not only over prospects but also within sections of fields. Minimising reserves uncertainty can be problematic. The AVO response can be clouded by the complex interplay between fluid phase, reservoir quality (in particular net:gross)and thickness and variations in the impedance contrast at the reservoir interfaces. The recent appraisal wells Enfield-4 and-5 attest to the need to reduce reserves uncertainty. This poster highlights the key issues surrounding AVO analysis within WA-271-P.

Minimising structural risk on prospects and play fairways

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Most hydrocarbon prospects are critically dependent upon structural interpretation yet a rigorous structural method and routine validation of the interpretation is rare. A rigorous structural analysis workflow, particularly applied by seismic interpreters, would greatly assist in the quantification of risk. In hydrocarbon exploration areas dominated by low temperature brittle sediments, it is vital to define the geometrical relationships between faults, folds, sedimentary packages and regional elevation. It is also important to use them predictively to validate an interpretation and hence a prospect. These techniques can be easily applied to seismic data in two way time if the section is displayed at approximately 1:1 in the zone of interest. To further constrain an interpretation, it is necessary to define the structural family present in an area; this depends strongly on the basement architecture and tectonic history. Finally, multiple valid interpretations should be considered. To improve the structural interpretation of seismic and outcrop data, the so-called F.I.R.S.T.O. workflow for structural analysis is recommended:

- **F Factual interpretation of bedding, faults and fractures where well defined.**
- **I Internally Consistent geometry so that faults match faults and fractures.**
- **R Regional elevation and extension vs compression from regional data.**
- **S Structural Style—geometry, rheology, basement control and tectonic history.**
- **T Test by restoration, visually, by hand or computer restoration.**
- **O Other Options, Open Mind. Quantify the risk.**

Application of the workflow is illustrated with seismic and field examples from the Timor Sea, Bass Strait, Watchet, the Otway Basin, Cape Liptrap, and the Canadian Rockies.

Evolution of the Bight Basin—Palaeobathymetry and structure

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Geoscience Australia's interpretations of four deep-seismic profiles across the Bight Basin, from stable craton to oceanic crust, have been backstripped, decompacted and structurally restored. Modern water depths range from 0–5 km but were significantly less in the past, so palaeo-bathymetry has been regionally modelled to generate smooth subsidence patterns through time. The restorations constrain the depositional, tectonic, and subsidence history of the basin.

Totterdell and Krassay (2003) modelled a progradational delta in the Cenomanian with extensive growth faulting and reactive diapirism, accommodated down-dip by minor active shale diapirism and contractional deformation including toe-thrusts. Their model was based on gravity spreading and gravity sliding processes and involved minimal net extension. The depositional setting was a shallow intra-continental seaway 200 km wide between the Australian and Antarctic cratons, with ample sediment supply from the east matching accommodation volume. Deposition was aggradational except in the west where a marginal delta developed.

The restorations presented here suggest that southwesterly growth faulting was instead linked to a 10–30% crustal extension rather than gravity sliding. Subsidence created a saucer-like sag geometry that persisted to the present.

Late Santonian break-up generated an open ocean to the south. A new Hammerhead (Campanian to Maastrichtian) deltaic megasequence prograded strongly southward and then aggraded, loading underlying source rocks.

Significant but areally restricted deltaic growth faulting was linked to toe-thrusts. Tertiary sediment starvation and continued subsidence caused foundering into deepwater and cessation of hydrocarbon generation.

Significant play fairways with large hydrocarbon prospects are likely. The saucer-shape of the basin implies higher prospectivity around the rim, that is, deepwater traps beneath the Hammerhead delta front or nearshore traps, close to basin-bounding faults. Hydrocarbons must be preserved from the Cretaceous, or remigrated, as traps tilt seaward.

Understanding deepwater prospects—New approaches to palaeobathymetry and base level from seismic data

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In modern exploration, the focus is increasingly on deepwater basins where it is often difficult to make a link to the shallow-water equivalents. Since turbidite sand reservoirs in deepwater basins represent a major component of future petroleum reserves, understanding deepwater deposition and sequence architecture issues are crucial for the future of the petroleum industry. The well-known techniques of seismic sequence stratigraphy need to be modified for use in deepwater basins.

In this presentation seismic data is used from Australia's northwestern and southern margins to illustrate a new approach to deepwater sequence stratigraphy, incorporating palaeobathymetry and section restoration to better understand prospectivity in terms of source and reservoir effectiveness, hydrocarbon generation and migration, and seal integrity. The validity of individual prospects and entire play fairways depends on understanding the different responses of deepwater sedimentary systems to changes of input parameters.

Instead of base level, we introduce the concept of equilibrium slope— equivalent to the ideal graded profile of an alluvial system. A turbidite slope in equilibrium will aggrade steadily as sediment is fed into the system. If the local slope is less than the equilibrium slope, then rapid aggradation and turbidite progradation will occur. If the slope is greater than equilibrium then bypass, channelling, or scouring will take place. Changes of slope are triggered by tectonic events and by changes in sediment type and rate. In turn, slope can of itself, trigger tectonic events (slumps) and affect downstream sediment supply.

At individual prospect scale, Palaeobathymetry changes are a vital component of hydrocarbon migration studies. Understanding deposition in deep water allows tectonism and prospect risk to be evaluated more rigorously.

Minerva gas field development, offshore Otway Basin

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The drilling and installation of two subsea well completions on the Minerva gas field marks the beginning of the first offshore gas development in the Otway Basin. The field was discovered in 1993 with the drilling of Minerva–1 and was appraised with Minerva–2A in late 1993 and a 3D seismic survey acquired in 1994. Since 1994 BHP Billiton has investigated a range of development opportunities culminating in the signing of a gas sales agreement for supply of gas to the Pelican Point Power Station in South Australia in March 2002.

Field size and environmental issues were primary concerns when a fit for purpose well design and development plan was selected. Subsea completions were selected to minimise environmental impact. Vertical development wells with expandable sand screens were installed in the crestal regions of the northern and southern fault blocks. A drill-in fluid was selected to minimise formation damage and a combination of LWD and wireline logs acquired to establish reservoir quality. Only the upper 60 m of the Minerva Formation was completed in each well to minimise water production whilst maximising production both above and below potential reservoir baffles. Sand-screens were installed to mitigate sand production problems during field life as no well re-entries are planned. Both wells were produced prior to suspension to clean up the formation and confirm flow above and below potential production baffles prior to suspension. Each well has been designed to be capable of meeting the required project production capacity of 150 MMscf/day.

The two subsea completions will be tied back to an onshore gas plant by means of a single 10 inch gas production pipeline and a subterranean shore crossing in late 2003/early 2004. First gas is planned for early 2004.

The structural and thermal history of the Wild Dog Valley, Wongarra Region, Otway Ranges, Victoria

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The Wild Dog Valley–Wongarra region lies on the southeastern coastal margin of the Otway Ranges, immediately east of Apollo Bay and about 160 km southwest of Melbourne. The region hosts spectacular outcrops of the Aptian-Albian Eumeralla Formation. These are dominated by fluvial sandstone packages and the uncharacteristically thick overbank-lacustrine mudstone sequence of the Skenes Creek Coal Measures.

Detailed mapping has revealed three major fault and fold trends. In the west, a number of northeast trending thrusts/reverse faults break through the steep southern limb of a regional scale anticline and are associated with the Skenes Creek Monocline and local asymmetric folds. Along strike to the east this fault trend gives way to northeast oriented folds and a smaller east–west fault trend. These northeast and east–west trending faults are interpreted as Early Cretaceous extensional structures that have been subsequently reversed during mid-Cretaceous and/or post-Miocene uplift and structural inversion. Other trends in the region include a pervasive north-northwest fault trend, tentatively related to Late Cretaceous extension, and a north-northeast trend associated with a dextral shear zone in the northwest, which may be a reactivated basement fault.

Vitrinite reflectance (VR) contours exhibit sharp increases across major northeast trending thrusts/reverse faults. These range from about 0.40–0.65 on coastal platforms to about 1.8 in the north and west. Cross-sections reconstructed with VR data constraints show over 1 km of cumulative vertical displacement across the faults.

Cenozoic submarine canyons of the Otway Basin, Victoria

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The canyons incising the shelf and slope along the Otway margin are diverse in both their morphologies and origin. Seismic data show there are two morphologically distinct submarine canyon systems present in the Cenozoic carbonates:

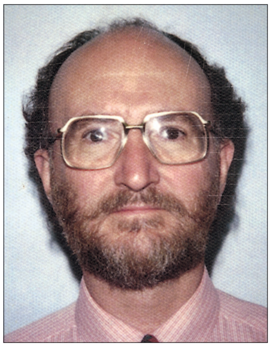
1. **Oligocene-Miocene canyon systems found within the Heytesbury Group; and**
2. **Pliocene–Recent canyon systems within the Whalers Bluff Formation.**

The Oligocene-Miocene canyon systems are made up of stacked, westward-migrating canyons. Found on the eastern side of the Otway Basin, each progressively younger canyon is located slightly westward of the older, underlying canyon. The fill within each canyon also progrades towards the west. The sediments within the canyon fill are mainly coarse-grained packstones, with high carbonate contents and sonic velocities in the basal sediments of the laterally migrating canyon.

The oldest canyons were initiated after deposition of the Clifton Formation during the Latest Oligocene-Earliest Miocene deposits of the Gellibrand Marl. This period is characterised by a widespread transgression and this may be a factor controlling canyon formation during this time. The position of the migrating canyons is controlled by the Oligo-Miocene depocentre in the eastern Otway Basin.

The fill within the Pliocene–Recent canyons is symmetrical or eastward orientated and can be seen on magnetic images. This would suggest that these canyons are filled with magnetic (probably clastic) material. Canyons found on the modern slope occupy positions directly seawards of the older Pliocene canyons. This relative stability in their positions results from shelf progradation. Throughout the Pliocene and Recent, the slope and the canyons, have prograded seawards. The change in canyon position and morphology from Miocene–Pliocene is likely to be a result of uplift at the Mio-Pliocene boundary and major oceanographic changes in the region.

New insights into the Triassic plate tectonics and palaeogeography of the northern edge of the Australian plate—Implications for sediment source, drainage evolution and petroleum systems



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Triassic plate models for northern Australia allow better appreciation of palaeogeography. Also, depositional facies mapping in the Carnarvon Basin, together with hinterland cooling history from imaging apatite fission track data, provides new information on drainage evolution. Integrating these studies, we can draw new Triassic palaeogeographic maps, which help explain petroleum reservoir and source distribution.

In the Permian, the Sibumasu micro-continent rotated clockwise away from northern Australia. A continuous passive margin linked the North West Shelf to the Irian Jaya Birds Head. Southwest-dipping subduction along the northeast side of Sibumasu, New Guinea, and Queensland, caused magmatism and tectonism on this margin in the Middle Triassic, representing continuation of the New England Orogen. In the Middle Norian, the Lhasa micro-continent broke up from Greater India, coincident with, and possibly forming the Fitzroy Fold Belt.

Deltas began developing in northwestern Australia during the Permian, the thickest being the Triassic Mungaroo delta in the Carnarvon Basin, which was fed from rivers eroding adjacent Pilbara-Yilgarn, Alice Springs, Kimberley and Argoland uplands. These areas probably became uplifted in the Carboniferous Alice Springs Orogeny and were re-shaped by Early Permian Gondwana glaciation. Depositional facies mapping of the Triassic in the Carnarvon Basin helps constrain derivation of the Mungaroo delta, which was fed from the north during the Anisian to Early Norian. In the *M. crenulatus* biozone (Late Norian), the northern rivers died and were replaced by a southeasterly derivation from the Pilbara and southern Canning. Apatite fission track data confirm that at least the Pilbara-Yilgarn uplands were eroding from Permian to Middle Jurassic times. In Seram, Timor, Sulawesi, the Ashmore Platform and the Wombat Plateau, the deltas passed seawards into turbidites, deepwater marls and shallow marine carbonates.

Deltaic Middle and Upper Triassic rocks are well known as the source of North West Shelf gas. Anoxic deepwater marls in grabens seawards of the deltas, however, are probably responsible for a second Triassic petroleum system in Seram and Timor. There, sulphur-bearing oils have different carbonate-related biomarkers to Jurassic-derived oils from northwest Australia. The challenge is now to determine whether the outer margins of northwest Australia also contain this Triassic oil-prone source.

Early Cretaceous structure and deposition, Colac area, eastern Otway Basin, Victoria

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In the Colac area, west of Geelong, large east– northeast striking normal faults, dipping predominantly northwards in the north of the area and south in the southern part, define the structure of the northern margin of the eastern Otway Basin. The top basement unconformity becomes regionally shallower to the north, and deeper to the south and is locally displaced over 2 km.

These faults bound blocks that controlled early Cretaceous deposition, with wedge-shaped packages forming in individual half-grabens. The sediments also thicken regionally southwards and this, together with the presence of south-dipping faults, indicates that the Otway Ranges may occupy the site of an early Cretaceous depocentre.

The stratigraphy is poorly constrained, due to a lack of deep wells, and is based on outcrops of Aptian-Albian Eumeralla Formation in the Otway Ranges.

A wedge shaped package of probably locally derived, fluvial, quartz-rich arkosic sands (Pretty Hill Formation equivalents) were the first sediments deposited in at least one half-graben. The basin was then flooded with volcaniclastic sediments transported into the area from the east via a major fluvial system. These sediments include both channel sandstones and overbank/floodplain and lacustrine mudstones. They can be divided seismically into four sequences, each separated by the widespread development of coal measures. By backstripping these sequences it is possible to determine a more accurate history for this part of the Otway Basin.

Structural styles, depocentres and plate tectonic setting in the offshore Otway Basin

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The Cretaceous history of the offshore Otway Basin is characterised by the development of southward shifting depocentres in a wide spread extensional regime. In the Late Cretaceous, this is interpreted to have been controlled by continuous lithospheric stretching with the upper crust deformed by simple shear along a regional detachment, prior to Early Tertiary break-up.

Early Cretaceous sedimentation, including the Eumarella Formation, was restricted to deep half-graben depocentres onshore and near-shore under today's shelf. With the development of the Tartwaup-Mussel-Hinge-Zone during the Turonian Sherbrook Group, sediments increase to more than 5 km across this fault zone. Deposition of restricted marine sediments of the Belfast Mudstone and Paaratte Formation was controlled by deep-crustal listric growth faults forming large roll-over anticlines.

The Tertiary of the Voluta Trough is characterised by a thick sequence of up to 4 km of turbidites with their maximum thickness south of the main Sherbrook Group depocentre. The main sediment source for the clastic Early Tertiary sediment input is interpreted to be to the east of the Sorrell Fault Zone. Inversion of the major extensional faults, interpreted as being a result of ridge push, enhances rollover-anticlinal structures in the eastern deepwater Otway Basin.

The Morum Sub-basin is characterised by similar restricted marine sediments and growth-faults as in the Voluta Trough, but lacks the turbiditic Tertiary sequence. Strong inversion and erosion and a possible lack of sediments are interpreted to be the reason for limited distribution of Early Tertiary sediments in the western Otway Basin.

Source rocks in restricted marine sediments of the Sherbrook Group started to mature during the Maastrichtian. With progressive Tertiary sediment cover, maturation continued through to the present day. Any generated hydrocarbons migrated up-dip into structures close to the Mussel Fault Zone and into large inverted rollover anticlines in today's deepwater.

A ponded basin floor fan outcrop analogue: Bunkers sandstone, northern Flinders Ranges, Australia

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The Donkey Bore Syncline in the Northern Flinders Ranges of South Australia contains a generally fine-grained deepwater succession of Early Cambrian age (Bunkers Sandstone) that outcrops on three sides of a syncline and flanks an active salt diapir to the east (Wirrealpa Diapir). Within the succession lies a basal sand-prone interval interpreted as a basin floor fan (BFF) ponded within a mini-basin on a topographically complex slope.

The BFF comprises over 30 m of section with deposits that are dominantly massive clean sandstone beds (0.1–3 m thick) that are stacked or interbedded with siltstones and pinch out along strike.

Eight stratigraphic sections and accompanying spectral gamma ray logs (using a hand held scintillometer) were measured through the BFF. Using spectral gamma ray log analysis combined with stratigraphic logs, four alternative correlation panels were constructed. Quantitative analysis of sand-prone intervals interpreted in each of the panels provided data on the vertical and horizontal connectivity within the BFF as different correlation methods were explored and the geological model improved.

Quantitative analysis of vertical and horizontal connectivity values indicates a high degree of heterogeneity within the BFF, with poor–moderate vertical connectivity, with individual beds rarely correlating >500 m along strike. This heterogeneity is poorly resolved using conventional wireline log suites, but is greatly improved if spectral gamma ray logs are used (especially Thorium).

The data set provides a high-resolution analogue for understanding the internal architecture of deepwater hydrocarbon reservoirs.

Equipment strategy development for down-hole tubulars

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A risk-based inspection and equipment strategy program was developed for mature down-hole tubulars in Bass Strait oil and gas wells. This poster outlines the major features of the program including identifying components, describing degradation mechanisms, assigning a credible failure scenario, defining the probability and consequence of failure, development of strategies to mitigate unacceptable risk and finally assigning a mitigated risk.

The strategy development is applicable for caliper and pro-active work-over candidate selection, work-over rig plans, reservoir depletion strategies, down-hole corrosion management and platform life end plans.

A key feature of strategies is determining the probability and consequence of tubing failure. The consequence of failure determined in these reviews is based on financial criteria, given that Safety, Health and Environment (SHE) risk is low due to completion design. The basis for obtaining these is described in the poster. Corrosion rate and failure prediction are based on Bass Strait field data and are used in determining probability. Consequence based on reserves remaining in the combined with probability is plotted on a risk matrix. A multi-functional team assesses and recommends a range of strategies to mitigate risks such as inhibition, patch tubing, coil tubing, work-over, pro-active work-over, utilising corrosion resistant alloy, caliper and continuing to monitor. The team selects the appropriate strategy by determining the resultant mitigated risk.

The poster describes a process that enhances the tubing life cycle management process. Using this tool, cost effective upgrades can be determined through pro-active preventative programs and utilisation of experience based failure prediction.

Whales, dolphins and the EPBC Act

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Environment Australia administers the Environment Protection and Biodiversity Conservation Act 1999 (the EPBC Act), which came into effect in July 2000. The Act established the Australian Whale Sanctuary which provides protection for whales, dolphins and porpoises (cetaceans) in Commonwealth waters. Under the Act, it is an offence to kill, injure, take, trade, keep, move or interfere with a cetacean in the Australian Whale Sanctuary. The Act also allows, however, for permits to be issued in certain circumstances to allow a permit holder to take an action without breaching the offence provisions of the Act.

The Act also established a system of environmental impact assessment for actions which may have a significant impact on matters of national environmental significance (NES matters). NES matters include listed threatened or migratory species and the Commonwealth marine environment. Several species of whales and dolphins are listed under the EPBC Act.

This poster will review the operation of the Act over its first two and a half years, in terms of the protection it has provided to cetacean species, with particular regard to interactions with the oil and gas industry.

Evaluation of exploration risk in the Bass Basin—Results of a well audit study

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Results from an audit of 32 petroleum exploration wells in the Bass Basin have shown that about half of the wells in the basin were invalid tests, due to off-structure drilling or mis-interpretation. Of the remaining wells, primary reasons for failure were lack of effective seal, timing,

trap validity, lack of access to mature source rocks or reservoir problems. In parts of the basin, the regional seal (Demons Bluff Shale) has undergone a period of structural inversion during the late Tertiary resulting in seal breach. Anticlinal closures of Eocene age were particularly affected, while structures located on fault-bounded basement highs were less affected, and provide the only fields within the basin. In the Yolla and White Ibis fields, access to mature source rocks was provided by large-displacement, non-sealing faults, that linked the upper EVG reservoirs with deeper source rocks. Traps without this conduit have, so far, been unsuccessful. Sandy units within the Eastern View Group in the Pelican Trough are tight reservoirs that have good porosity but poor permeability. This is due to diagenetic effects that prohibited the creation of secondary porosity and permeability. Although identified risks within the basin can be minimised, the key to successful exploration will be finding traps that were in-place prior to the generation of hydrocarbons, but which did not undergo significant Tertiary inversion.

Development of the Thylacine and Geographe Fields, offshore Otway Basin, southeast Australia

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In May 2001, Woodside, together with Joint Venture partners, discovered the Thylacine gas field some 70 km off Port Campbell, Victoria, in exploration permit T/30P. This was immediately followed by a similar discovery in the Geographe field 15 km closer to the coast in exploration permit VIC/P43. The fields contain combined recoverable expectation reserves of some 0.8 TCF raw gas (1.5 MMTonnes LPG, 9 MMbbls condensate).

Market analysis has indicated uncontracted gas demand in South Australia and Victoria from 2004, with an opportunity to supply around 60 PJ/a from 2006. In order to capitalise on this market opportunity, and to build a competitive advantage, an accelerated development project has been commenced, with first gas scheduled for 2006.

Efforts since discovery have focussed on understanding the technical and economic uncertainties around the resource then formulating concepts and strategies to most effectively manage this uncertainty to enable development in a time frame to meet the market opportunity.

A state-of-the-art review of fuzzy logic for reservoir evaluation

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Application of new mathematics using fuzzy logic has been successful in several areas of petroleum engineering. This poster reviews the state-of-the-art fuzzy logic applied for reservoir evaluation, especially in the area of petrophysical properties prediction and lithofacies prediction from well logs. Well log data analysis plays an important role in petroleum exploration. It is used to identify the potential for oil production at a given source and so forms the basis for estimating the financial returns and economic benefits. In this poster, we will also review some fuzzy methods that have been successfully applied to case studies. Besides using fuzzy logic in establishing the model itself, it is also used in some cases as pre-processing or post-processing tools. One of the main problems when extracting fuzzy rules directly from the data is the gap present in the fuzzy rule base. Application of the fuzzy rule interpolation technique has been discussed in the poster. This poster will act as a guide for petroleum engineers to take advantage of these advanced technologies as well as those undertaking research in this field.