The Angel Formation - a Classic Example of a Sheet Turbidite Reservoir from the North West Shelf, Australia

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Deepwater sheet sandstones, deposited from decelerating turbidity currents, are considered to be excellent hydrocarbon reservoir systems due to their geometry, lateral continuity, sorting and internal high net-to-gross (NTG) ratios. The Late Jurassic Angel Formation of the Dampier Sub-Basin on the NW Shelf of Australia contains classic examples of sheet turbidite sandstone bodies, which are reservoirs for the oil and gas fields in this area.

Sandstone sheets in the Angel Formation can be subdivided into two distinct groups based upon their internal architecture: (1) layered sheets and, (2) amalgamated sheets. Sheets exhibit a decrease in thickness and NTG and are transitional from an amalgamated to a layered form in a down dip direction. Examination of wireline logs and cores between the Wanaea Field and Madeleine-1 well, reveals layered sheets within a low NTG (i.e approx 0.25) setting that contains interbedded heterolithic/clay and sandstone beds, which occasionally showing upper classic Bouma turbidite sequence. Amalgamated sheets are recognised in the Angel and Cossack fields, which are characterized by higher NTG values (i.e approx 0.9) and contain stacked event beds commonly form flat-based sandbodies with fewer interbedded heterolithic/clay layers.

This change in sandbody architectures has a significant control on reservoir heterogeneity. Additional heterogeneity is created by stratigraphic pinch-out and sandstone injection features, as well as localised dolomite cementation, which appears to be at least partially structurally controlled. The Angel Formation is also a regional aquifer and field development strategies are thus impacted by the various reservoir heterogeneities encountered in different fan settings. Heterolithic/clays are also very laterally extensive and field scale pressure barriers.

Late Authigenic Pyrite as an Indicator of Oil Entrapment: Case Histories from the North West Shelf, Australia

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Late authigenic pyrite cementation is common within sandstone reservoirs of the North West Shelf of Australia. It is well developed in the Early Cretaceous to Late Jurassic Angel Formation sandstone and in the Late Triassic Mungaroo Formation in wells in the Dampier Sub-basin of the Carnarvon Basin. It is also present in the Middle Jurassic Plover Formation sandstone in some wells in the Vulcan Sub-basin, and in the Middle Jurassic Laminaria Formation sandstone in wells on the western margin of the Flamingo Syncline in the northern Bonaparte Basin.

The pyrite-cemented sandstone in these wells developed by bacterial and/or thermochemical reduction of formation water sulphate and the resultant production of hydrogen sulphide at palaeo-oil/water contacts. Development of pyrite cementation in the sandstone is dependent on the presence of sulphate-rich formation water. In the Dampier Sub-basin, the present formation water is generally sulphate-rich and the presence of late authigenic pyrite cementation indicates sulphate-rich formation water during oil entrapment in the past. However, in the Bonaparte Basin the formation water sulphate content is quite variable ranging from moderate to very low. Accordingly, the distribution of pyrite-cemented sandstones is more scattered and in many cases indicates a change in formation water sulphate chemistry subsequent to oil entrapment.

The occurrence of late authigenic pyrite-cemented sandstone is therefore an invaluable indicator of palaeo-oil accumulations and of chemical evolution of formation water through time.

Stratigraphic Framework of the Cenozoic Carbonates of the Northern Carnarvon Basin, North West Shelf, Western Australia

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The North West Shelf extends 2400kms along the Western Australian margin and is divided into the Carnarvon, Canning, Browse, and Bonaparte sedimentary basins. Significant quantities of carbonate were deposited on this shelf during the Cenozoic. These carbonates are the dominant cover sequence to the hydrocarbon-producing Mesozoic successions and cause considerable problems in the seismic interpretation of structural traps due to strong lateral variations in sonic velocity. Despite their large distribution, stratigraphic thickness and interference with seismic interpretation, these carbonates have remained poorly documented. Using seismic properties, geochemical analyses (carbonate and elemental), well log data, petrological data and foraminiferal analyses, this study establishes the stratigraphic framework of Cenozoic carbonates in the Exmouth-Barrow sub-basins, Northern Carnarvon Basin. These carbonates were divided into six lithological facies, from oldest to youngest; basinal facies, slope facies, shelf facies, planktonic ooze/canyon fill facies, sand barrier facies, and ramp facies. The sequence represents a shallowing upwards sequence from Eocene to Early Pliocene age. The base of the sequence is dominated by deep basinal facies, overlain by prograding Oligocene-Miocene shelf and slope sediments. These are inturn overlain by quartz-rich sediments interpreted to represent a sand barrier. A transgression during the Pliocene altered the depositional environment and formed a prograding ramp. This study is one of the first to concentrate on both the stratigraphy and the geological controls on sonic velocity in Cenozoic carbonates of the North West Shelf.

Plio-Pleistocene Shelf Evolution and the Origin of the Reefs in the Northwest Shelf

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The strata of the Delambre Formation of the Northwest Shelf preserve a detailed Mio-Pleistocene record of oceanographic change and reef growth related to the development of the Leeuwin Current. At present the Leeuwin Current transports warm low salinity nutrient deficient water from the equatorial West Pacific Warm Pool southwards along the west coast of Australia. This current extends modern reefal development to 29S and the tropical to subtropical transition as far south as Rottnest Island (33S). Our study focuses on the Carnavon Basin (18 to 21S) and incorporates foraminiferal, facies and seismic analyses from the Maitland, Tryal Rocks, Goodwyn and Bounty areas. Subtropical oligotrophic platform carbonates, regressive barrier sand facies, submarine canyon and slope deposits typify Miocene deposition in the region. The overlying transgressive Pliocene to Early Pleistocene strata of the Delambre Formation were deposited in nutrient-enriched subtropical platform to slope environments. After the Middle Pleistocene (1 Ma) oligotrophic subtropical to tropical platform to slope conditions developed associated with the first reefal and oolitic facies. The foraminiferal evidence and absence of reefs and ooids in the Early Pleistocene and older strata suggest that the Leeuwin Current initiated after 1 Ma. Indeed, the planktonic foraminiferal assemblage in strata from 1 Ma to 450 Ky typically have a higher tropical component than the modern plankton assemblages from 18 to 21S. We suggest the initiation of Leeuwin Current was associated with a more intense outflow of equatorial waters along the Western Australian coastline and sometime after 450 Ky reached it present equilibrium.

New Biostratigraphic and Seismic Correlations for the Vlaming Sub-basin, Offshore Perth Basin, Western Australia

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The Vlaming Sub-basin, which forms part of the Perth Basin on the south-western margin of Australia, is under-explored. However, with a petroleum system demonstrated by oil recovered at Gage Roads 1 and gas at Marri 1, and oil shows at Araucaria 1 and Gage Roads 2, the Vlaming Sub-basin may have significant petroleum potential. Key exploration risks in the Vlaming Sub-basin result from poor seismic data quality and the vintage and inconsistency of biostratigraphy, and hampers well correlations and prediction and mapping of seals and reservoirs.

To address these issues, Geoscience Australia has acquired, re-processed, and analysed 2,300 line kilometres of 2D seismic data and reviewed comprehensively existing biostratigraphic data. In addition, over 200 samples from cores and cuttings, from 11 wells have been analysed for palynology and organic geochemistry. Results of sampling addressed potential source rocks of the Middle to Late Jurassic Yarragadee Formation, and biostratigraphy of reservoir and seal intervals of the Late Jurassic to Early Cretaceous Parmelia and Warnbro Groups. The new study also considered the younger Cretaceous post break-up section that includes a significant unconformity, encompassing five dinoflagellate cyst zones and spans the earliest Cenomanian and Early Campanian.

New key markers and bioevent identification has resulted in more detailed and confident biostratigraphic correlations, and improved well-seismic ties through the sub-basin and across the Perth Basin. This work allows correlation with the well-established local North West Shelf biozonation and provides supplementary biostratigraphic tie points with the international Standard Stages.

Geostatistical Simulation of Electrical Double-Layer Properties of Clay Minerals in Shaly Sand Reservoirs (Cliff Heads Oil Field, Perth Basin, Western Australia)

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Characterizing the conductivity of shaly sands below critical formation water salinity can be a challenge in well log evaluation particularly when clays with large surface areas demonstrate significant volume of clay bound water compared to the total pore volume of the reservoir rock.

Via computations of the electrical double layer properties of clay minerals that relates to their expansion and parallel conductance with pore fluids, an improved understanding of their behaviour can be obtained.

This paper introduces geo-statistical methods of simulating values for double layer conduction and diffusion layer expansion, based on knowledge of formation water salinity as well as the minimum & maximum range between clay particle surface and the outer Helmholtz plane.

It is an integration of:

• Rietveld based Siroquant assay for quantitative X-ray diffraction used in determining mineral percentages and clay lattice expansion,

• Cation Exchange Capacity used to determine the quantity of exchangeable cations at the shale-water interface,

• Normal and Uniform-Continuous Random number generation techniques.

Measured laboratory data include CEC, XRD and formation water salinity on 63 core plugs from the Cliff Heads 3, 4 and 6.

Overall, the approach is useful and time saving in assessing the effect of the double layer properties of clay minerals on conductivity measurements of well logs and plots obtained depict patterns from which excess or double layer conductance of clay minerals can be distinguished from the true conductivity of pore fluids.

A Holistic Model to Describe Charge and Retention History of the Northern Bonaparte Basin, Australia

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The Northern Bonaparte Basin has proved to be a challenging region for exploration offering considerable promise but yielding more modest success. Despite more than two decades of exploration drilling and significant attention by the research community there continues to be contentious debate regarding the charge

history and likely controls on hydrocarbon retention during subsequent periods of intense Neogene fault reactivation. Disparities between the predictions derived from basin models and the nature of hydrocarbon fill have led to contrasting charge models that often ignore hard observational data. Similarly, the number of theories put forward to describe the controls on hydrocarbon retention is varied, ranging from fault facilitated leakage controlled by either stress or strain related processes to fault independent controls related to regional water-washing effects. Despite this sustained effort there remains no widely held agreement or demonstrable validation for any of these proposed mechanisms that hold true for the region as a whole. This review seeks to highlight the limitations associated with previous models and to proffer a new unified model that more effectively honours the hard observational data. Key elements of this evaluation include a comprehensive examination of the charge history of drilled traps to provide validation of existing structural models proposed for the Northern Australian Margin and a more holistic approach to integrating the key datasets. The result is a coherent interpretation of the critical observations that produces a plausible exploration model that can be used to more effectively risk the remaining drilling opportunities in this prospective basin.

East Timor: structural and tectonic history of deformed passive margin sequences

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Timor Island preserves vast tracts of the northern Australian passive margin, with the full stratigraphic record represented on the eastern side (East Timor). Striking similarities with Australian formations throughout the Permian to Jurassic of East Timor. The Timor succession would have been among the first involved in the collision between Australia and the Banda Arc during the Neogene. Despite its relatively turbulent recent history, many of the pre-Neogene sections remain remarkably relatively undeformed, preserved as thick sections in thrust stacks, with little internal deformation in some cases. The identification of previously un-recognised slices of potential oceanic crust (MORB compositions and textures, with cumulates) allows for the possibility that the oceanic material carried thick sequences of the passive margin with it during emplacement. The fact that most of the material remains un-metamorphosed and that conodont and spore-pollen indices generally indicate low temperatures, it is likely that the passive margin sequences remain shallow and protected from high strain during early stage orogenesis. The presence of oil and gas seeps along the southern coast of Timor attests to the presence of a petroleum system at some point in the recent past, and perhaps the present day.

This paper presents a comparison of the structural style of the Timorese sections and their (undeformed) Australian equivalents, and explores models for the preservation of an Australian petroleum system in East Timor. In addition the effects of significant mud-diapirism on the petroleum potential will be explored.

The Mentelle Basin - A Deep-water, Frontier Gondwanan Basin

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The Mentelle Basin is a deep-water, offshore basin located on the southwest Australian continental margin to the southwest of Perth. The Mentelle Basin formed near a triple junction between Australia, Antarctica, and India during the breakup of eastern Gondwana in the Middle Jurassic to Early Cretaceous. The basin has rank frontier status with no petroleum wells drilled.

In order to improve the level of geological understanding and petroleum prospectivity of the basin, Geoscience Australia has acquired 1450 km of regional 2-D seismic together with sub-bottom profiler, and swath bathymetry data. Dredge and core material were also collected. These datasets form the basis of a new regional-scale basin framework from which petroleum systems elements are assessed.

Seismic interpretations suggest that the main depocentres in the western part of the basin contain at least 5 km of sedimentary section. These half graben host a relatively thick syn-rift section that is inferred to be Middle Jurassic to Early Cretaceous in age. A thin, Late Cretaceous to Recent post breakup section blankets the region. The shallower-water eastern parts of the Mentelle Basin contain a thinner section, within a series of tilted fault blocks related to Valanginian breakup of the western margin. There is also potential for Permo-Triassic rocks to be present at depth.

The Mentelle Basin is likely to have petroleum systems elements akin to the southern Perth Basin, with potential for similar generated hydrocarbons. Regionally, Mentelle Basin architecture favours eastward migration from a western source kitchen updip into structural and stratigraphic traps.

Chronostratigraphy of the Late Permian Dongara Sandstone, Northern Perth Basin

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Recent oil and gas discoveries in Late Permian reservoirs of the Northern Perth Basin (Cliff Head, Jingemia, Hovea, Eremia, Tarantula, Evandra and Centella fields) have highlighted the need for improved understanding of its depositional history. Existing published geological interpretations are lithostratigraphic-dominated and do not adequately address the spatial and temporal facies complexity of the onshore Late Permian.

A new high-resolution chronostratigraphic study has subdivided the Late Permian units into four retogradational parasequences (Palynological Zones: D.ericanus - D.parvithola) with coeval fluvial, deltaic, upper shoreface, lower shoreface, and carbonate facies. Sediments were deposited during a relative marine transgression and represent a conformable transition from a Late Carboniferous glacial lacustrine setting (Carynginian Formation) to a Late Permian marine setting (Kockatea Shale). Siliciclastic sediment provenance is interpreted to be predominantly from the north.

Best quality reservoirs are associated with the upper shoreface sands (Dongara Sandstone). This prospective hydrocarbon-prone facies is mapped as a series of discrete backstepping packages and not, as previously thought, a single regional coastal marine deposit. Reservoir quality reduces dramatically in the adjacent lower shoreface facies (Wagina Sandstone), as evident from recent appraisal drilling in the Jingemia oil field.

The sequence stratigraphic interpretation used biostratigraphic, wireline and core data from forty-two onshore

and offshore wells. Handheld spectral gamma was recorded over the core to assist with facies recognition and correlation. Anomalously high thorium readings in association with a ratty gamma log motif were interpreted as a beach or ravinement surface. Poor seismic resolution prevented a detailed seismic stratigraphic interpretation, but isopach maps were used to define the regional palaeogeographical setting.

Basement and Crustal Controls on Hydrocarbons Maturation on the Exmouth Plateau, NW Australian Margin

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A consistent approach to the assessment of basement and crustal controls on hydrocarbons maturation in mature exploration area of the Exmouth Plateau is justified by the availability of high quality refraction seismic data recorded in the area during two major ocean bottom seismograph (OBS) projects undertaken by Geoscience Australia, and jointly by the Scripps Institution of Oceanography, USGS, Lamont-Doherty Earth Observatory and the University of Hawaii's.

The tectonic elements of the Exmouth Plateau, which contains the largest oil-producing fields in Australia, developed as a result of rift tectonics initiated in the Early Jurassic and continuing until the Late Jurassic, preceding the final continental separation of Greater India from Australia. The Palaeozoic evolution and stratigraphy of the area is poorly known but it seems to be increasingly important for petroleum geology.

Measurements of radioactive elements contents in rock samples taken from outcrops of Pilbara Craton allow an estimation of heat production in the Exmouth basement and crust below it. These estimates and presence in the area of several wells for which geohistory was modelled using Winbury software (Brigadier 1, Jupiter 1, Sirius 1) allows advanced burial and thermal geo-history modelling to be carried out using Fobos Pro modelling software without relying on default or inferred values such as heat flow or geothermal gradient. Estimates of total crustal thickness (only 30-34 km) prior to rifting were derived from onshore refraction work in the Pilbara Craton. Crustal thickness and composition underneath major depocentres of the Exmouth Plateau were constrained by results of OBS studies in the area indicating that total crustal thickness (excluding up to 18 km of sediments) is reduced to just 4 km. The effect of possible underplating in the lower crust of the Exmouth Plateau on hydrocarbon maturation needs to be accounted for in geohistory modelling.