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Yampi Shelf Tie (YST) Basin Study and Interpretation Report:

Yampi Shelf, Browse Basin, Northwestern Australia.

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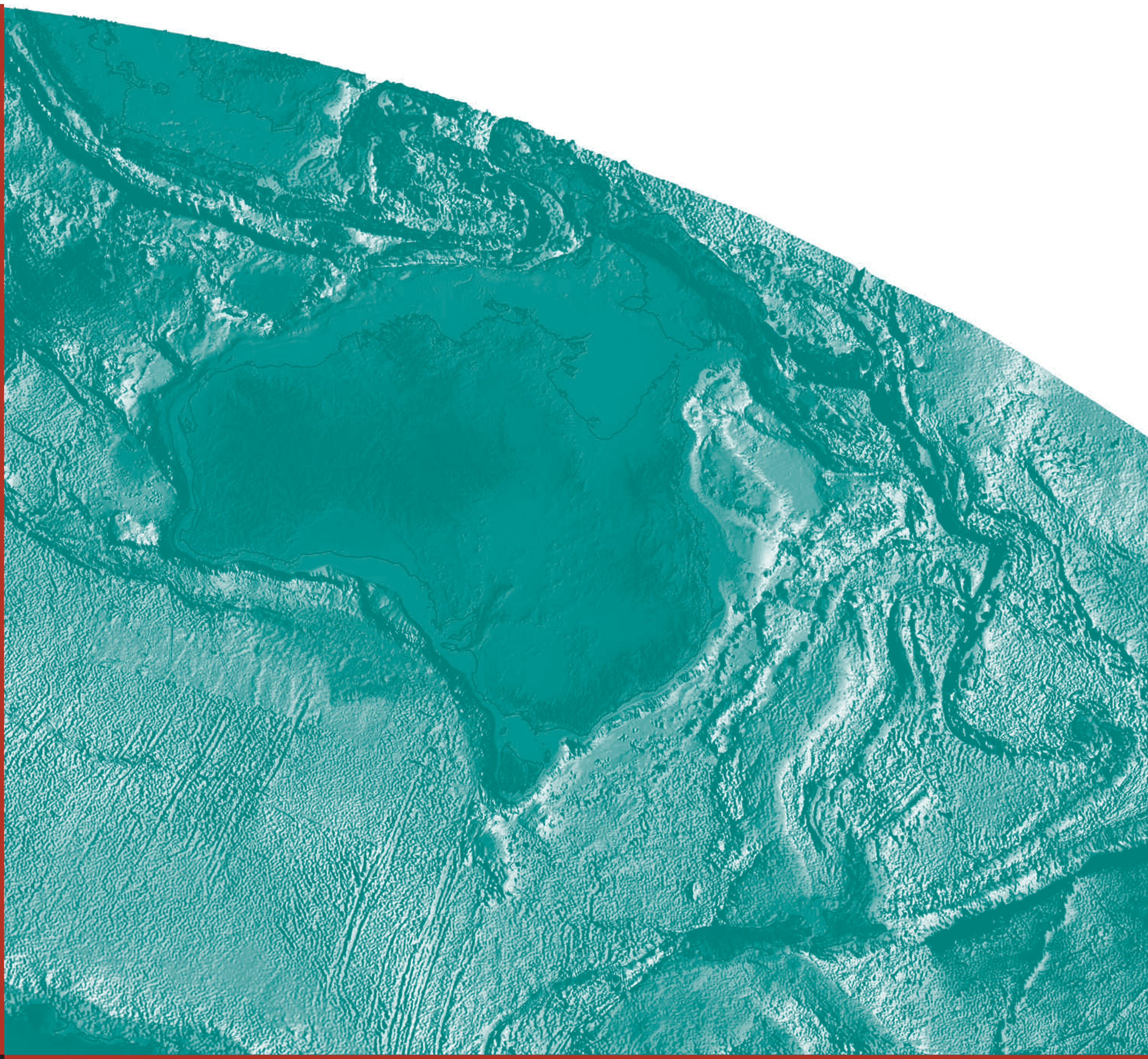

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Summary

The Yampi Shelf-Tie (YST-95) seismic survey was acquired during September 1995 by AGSO in the northeastern Browse Basin, northwestern Australia. The survey ties the key wells of Gwydion 1, Rob Roy 1, Buccaneer 1, Londonderry 1, Copernicus 1, and Productus 1. It comprises 2000 kilometres of high resolution seismic data along eighteen dip-lines and two strike-lines. An interpretation report, the Yampi Shelf Tie Basin Study, was undertaken by Jennifer Baird and Greg Blackburn of Terra Australis Cognita Pty Ltd, and Geoffrey O'Brien of AGSO, using the YST data, well data, as well as AGSO sniffer and World Geoscience Corporation (WGC) and AGSO aeromagnetic data.

The study provides a detailed evaluation and integration of geological and geophysical data along the Yampi Shelf and Prudhoe Terrace, and its relationship to the Browse Basin and Kimberley Block. Its goal is to provide a better understanding of the petroleum prospectivity of this largely unexplored region.

The Yampi Shelf has developed over relatively shallow, highly structured Proterozoic basement. Basement structure appears to have controlled at least the major components of rift segmentation, with the most obvious example being the loss of fault throw, and the attendant change in structural style, across the NW 1 lineament, the outboard extension of which acts to separate the Vulcan Sub-basin from the Browse Basin.

The principal extensional episode which is evident across the Yampi Shelf was in the Late Carboniferous/Early Permian. Well-developed Early Permian half-grabens, such as those within which the Rob Roy 1 well lies (Figure 107), are common on the outboard parts of the shelf. The Yampi Shelf, because of its inboard position, provides one of the best locations along the Western Australian margin to see the effects of this extension. These Early Permian extensional structures developed during a period of intense glaciation, and it is clear that a combination of the pre-existing basement grain (which controlled extensional development and silici-clastic input), the rift structures themselves, and glacial sedimentary environments, have all strongly shaped the Yampi Shelf. Landward-dipping tilt blocks, generally with small fault displacement, dominate the inboard part of the shelf. More outboard, the structural architecture can range from horst and graben, such as around the Londonderry 1 well (within the large displacement province) to flexural basement ramp, inboard from the Vulcan Sub-basin.

There is little evidence of fault reactivation from the Early Permian until the Callovian, when some reactivation is evident. Similarly, some Mio-Pliocene fault is evident but this appears very mild throughout the Yampi Shelf, particularly in comparison to the Vulcan Sub-basin.

The interpretation of the Yampi Shelf Tie (YST) seismic data and the associated geological review, and their integration with geochemical sniffer and aeromagnetic data sets, have resulted in a number of new conclusions regarding the prospectivity of the Yampi Shelf, Prudhoe Terrace and Caswell Sub-basin.

Biostratigraphic revisions have highlighted an older section underlying the Rob Roy Graben (and possibly also the Prudhoe Terrace) of Late Carboniferous to Early Permian in age. This interval, which relates to a major extensional episode along the entire Western Australian margin, has also been identified as having favourable source rock characteristics and maturity across much of this area. It could be an alternative source for the recent Gwydion 1 discovery oil, which would negate the need for long distance migration of Jurassic sourced oil from the Caswell Sub-basin.

Various play types have been recognised from the YST seismic grid, ranging from the conventional horst block plays on the Prudhoe Terrace and Caswell Sub-basin, to stratigraphic pinchouts and drape features around basement highs and tilted fault blocks on the Yampi Shelf. Amplitude anomalies and possible direct hydrocarbon indicators are associated with some of these plays. In particular, structures within the Rob Roy Graben have amplitude anomalies in the Echuca Shoals and Jamieson Formations (traditionally seen as sealing lithologies) which are interpreted to occur within the distal parts of sands being shed from the Yampi Shelf high.

Inner shelf sands are interpreted from the lower part of the Jamieson Formation to lie within gazetted areas of the Yampi Shelf, and have associated amplitude anomalies. These seem to be best developed around the 'headland' feature behind Londonderry 1. Other amplitude anomalies are seen within this formation on various lines of the Yampi Shelf Tie survey.

From a regional perspective, the northernmost part of the Yampi Shelf, inboard from the Vulcan Sub-basin, appears to be the least prospective. The relaying of Early Permian fault displacement across a major, NW-trending Proterozoic lineament has produced a gently dipping, flexural basement ramp, whereas outboard, along the Vulcan Sub-basin boundary zone, the attendant (matching) increased fault displacement has produced a potential barrier to hydrocarbons migrating to the northeast, onto the flexural ramp margin.

Within the central part of the Yampi Shelf, around the Londonderry 1 well location, a horst and graben structural style predominates. Here, amplitude anomalies are common throughout the sedimentary section. Hydrocarbons are actively seeping from this area, with methane values in excess of 300 ppm being measured in the water column. This seepage is very dry, however, which suggests that it originated from a dry gas source. The sniffer results, when combined with the distribution and nature of the amplitude anomalies, suggest that the central part of the Yampi Shelf is experiencing significant gas charging at the present day, which presents a significant exploration risk.. It may be, however, that decreased seal integrity through this area is contributing to the presence of shallow amplitude anomalies, though this is not considered to be a primary, causal factor. However, it should be considered that if seal integrity is indeed lower in this area, it may be a positive factor, since it might allow any later gas charge to progressively bleed off, rather than displacing any pre-existing oil accumulation. Fault displacement through this province decreases to the northwest, across (and as a result of the presence of) the northwest trending NW 1 Proterozoic lineament; this results in NW 1 being a cross-basinal high, which actually extends right across the Vulcan Sub-basin (O'Brien et al., 1996a). As such, a natural migration fairway exists which could funnel hydrocarbons from the horst and graben province northeast, towards and along the strike of NW 1. If traps are present in this zone of decreasing fault displacement, this might represent an attractive play.

Amplitude anomalies are present to the south, but these appear to be principally deeper in the sedimentary section. As this region displays no present day hydrocarbon seepage, and given the presence of oil (and some gas) in Gwydion 1, then it appears likely that a combination of a less gas-prone charge, and perhaps higher seal integrity, might characterise this region.

- The ***northern Yampi Shelf*** has significant risks on ***migration, trap and seal***.
- The ***central Yampi Shelf*** is characterised by ***a significant risk of gas flushing***, with a possible risk on ***seal***. Traps are well-developed.
- The ***southern Yampi Shelf*** appears to possess a more oil-prone charge, combined with ***higher trap integrity*** (no leakage). Given that gas was co-produced with the oil from the Gwydion 1 well, and considering the trap integrity appears relatively high, then ***some risk of gas flushing of pre-existing oil accumulations*** by later gas is present.

Introduction

This interpretation report of the Yampi Shelf Tie Seismic Survey has been undertaken by Jennifer Baird and Greg Blackburn of Terra Australis Cognita Pty Ltd as part of a cooperative study between the Australian Geological Survey Organisation (AGSO) and PGS Nopec Pty Ltd. Aeromagnetic and sniffer interpretations were made by AGSO (GWOB) and World Geoscience Corporation. Geoff O'Brien (AGSO) was the project manager.

Data set

The Yampi Shelf-Tie (YST-95) seismic survey was acquired during September 1995 by AGSO in the north-eastern Browse Basin, north-western Australia (Figure 1). The survey ties the key wells of Gwydion 1, Rob Roy 1, Buccaneer 1, Londonderry 1, Copernicus 1 and Productus 1. It comprises 2000 kilometres of high resolution seismic data along eighteen dip-lines and two strike-lines (Figure 2; Enclosure 1). The data were processed by Simon Petroleum Technology Australia, and is being marketed through PGS Nopec Pty Ltd on a non-exclusive basis, as part of AGSO's Continental Margins Program (CMP). The survey was acquired by AGSO using the *R V Rig Seismic*.

Additional seismic coverage, including AGSO's Browse Basin Tie (BBT), Browse Basin Tie Infill (BBTI) and Vulcan Tertiary Tie (VTT) seismic surveys were used to tie the wells of Heywood 1, Maret 1, Echuca Shoals 1, Prudhoe 1 and Bassett 1 (Figure 2).

Scope of report

The basic data used in this study were derived from the following well completion reports: Asterias 1, Bassett 1, Brewster 1, Buccaneer 1, Copernicus 1, Discorbis 1, Echuca Shoals 1, Gryphaea 1, Heywood 1, Katers 1, Kalyptea 1, Londonderry 1, Productus 1, Prudhoe 1, Rob Roy 1, Tahbilk 1 and Yampi 1 & 2. The present study has attempted to provide a detailed evaluation and integration of geological and geophysical data along the Yampi Shelf and Prudhoe Terrace, and its relationship to the Browse Basin and Kimberley Block, in order to improve our understanding of the prospectivity of the region.

In June 1996, eight blocks (W96-1 to -8) along the Yampi Shelf of the offshore Browse Basin were gazetted by the Bureau of Resource Sciences (BRS) in association with the Western Australian Department of Minerals and Energy, as part of the 'Release of Offshore Petroleum Areas, Australia'. In addition, the BRS in association with the Northern Territory Department of Mines and Energy has released gazettal area AC96-6 (Figure 2).

This release has arisen as a result of renewed interest in the region following the discovery of migrated hydrocarbons in the Gwydion 1 well. The current study considers the prospectivity of the shelfal area and provides a compilation of much of the related open-file basic well data.

Previous Exploration History

Exploration in the greater Browse Basin area has resulted in the discovery of several major gas-condensate fields (Scott Reef, North Scott Reef, Brecknock and Brewster), while oil shows have been recorded in Arquebus 1, Asterias 1, Buccaneer 1, Caswell 1 & 2 and Yampi 1 & 2.

Browse Basin exploration was initiated as early as 1963 with an aeromagnetic survey conducted by Aero Services Ltd, on behalf of Woodside (Lakes Entrance) Oil N.L. To the north, in the southern part of the Vulcan Sub-basin, the Arco-Aquitane-Esso group commenced exploration in 1965. In 1967, a consortium consisting of B.O.C. of Australia Ltd. (operator), Woodside Oil N.L., Mid-Eastern Oil N.L., Shell Development Pty Ltd and B.P. Petroleum (Australia) Pty Ltd, conducted the extensive Scott-Cartier seismic survey across the region. This group was later modified to include BHP Co. Ltd and became North West Shelf Development Pty Ltd which continued exploration in the area. More than 20 seismic surveys have been conducted in the area since 1963, with recent AGSO acquired surveys providing good quality, long, regional well tie lines across the basin.

This report covers acreage currently under gazettal and also held under the following permits:

WA-241-P	Shell Development Aust	50%	
& WA-35-P	Chevron	25%	
	Cultus Petroleum NL	25%	
WA-239-P	BHP Petroleum PL		45%
	ITOCHU Corp.	25%	
	Teikoku Oil Co. Ltd		20%
	Santos Ltd		10%

Geological Framework

Regional geology and tectonic framework

The Browse Basin (Gentilli & Fairbridge, 1951, Challinor, 1970) occupies an area of approximately 140,000 km^2 (Figure 1), and extends northwest from the Precambrian Kimberley Basin to oceanic crust west of the Scott Sub-basin, between the Roebuck Basin (Offshore Canning Basin) and the Vulcan Sub-basin (Hocking, Mory & Williams, 1994). It forms part of the dominantly Mesozoic basin complex of the Westralian Superbasin of Bradshaw *et al*. (1988) and Cockbain (1989), and contains Late Devonian-Early Carboniferous to Recent sediments (Symonds *et al*, 1994) which may be up to 17 kms thick in some areas.

Structural Elements

The various elements of the Browse Basin and surrounding areas are shown in Figure 3, which is based on the terminology of Elliott (1990), Willis (1988) and Mory (1988). The southeastern margin of the basin begins where the Yampi and Leveque shelves flank the Kimberley Block (Figure 1).

Kimberley Block

The Kimberley Block dominates the onshore area to the east of the Yampi Shelf, and extends offshore, where it underlies, and has formed the extensional substrate for, the Yampi Shelf (O'Brien et al., 1996a). It is a cratonic province composed of metasediments, basic intrusives and granites dating from the Proterozoic (1,800 Ma), when crustal extension resulted in the development of the Kimberley Basin (Etheridge & Wall, 1994). This basin formed as a result of approximately NE extension and continued out under much of the present day Timor Sea, including the Petrel Sub-basin. The rift faults in the Kimberley Basin trended at approximately 300-310^o (WNW to NW); a conjugate set trended NE (Etheridge and Wall, 1994).

Regional aeromagnetic and Landsat data across the Kimberley Block demonstrate that this structural grain still dominates the geology of northern Australia (O'Brien et al., 1996a). Two very prominent, aeromagnetically-defined, NE-trending fracture systems cross the entire Kimberley Block, and extend from the Canning Basin in the south to the Petrel Sub-basin in the north. These fractures represent fundamental, through-going crustal fractures and as such can be considered to be basement hard links (O'Brien et al., 1996a). O'Brien *et al*. (1996a) proposed that these 'basement hard links' have strongly controlled the development of the rift architecture of the Palaeozoic and Mesozoic extensional systems throughout the Timor Sea.

Landsat data show that the NE- and NW-trending fracture systems have clear surface expression, which, in the case of HL 0, is actually significantly wider than its magnetically-defined expression (O'Brien et al., 1996a). Basement hard links across the Kimberley Block often act to localise fluviatile systems, an observation consistent with their behaviour in the East African Rift (Lambiase and Bosworth, 1995).

The extreme heterogeneity of the Kimberley Block would clearly be expected to significantly affect the type and location of the extensional structures which were superimposed on it during the Palaeozoic and Mesozoic .

Yampi Shelf

The Yampi Shelf is a generally unfaulted, flexural ramp formed over Proterozoic rocks of the Kimberley Block (O'Brien *et al*, 1996a), and onlapped by Carboniferous to Early Cretaceous sediments. The boundary between the Yampi and Leveque shelves follows the offshore extension of a Kimberley Block lineament which runs along the Prince Regent River (Hocking, Mory & Williams, 1994). The shelves then step down towards the central deep of the Caswell Sub-basin via the intermediate Prudhoe Terrace (Figure 3).

The Caswell Sub-basin contains several broad anticlinal trends: Brewster, Caswell, Scott Reef and Buffon (Willis, 1988), and merges into the Vulcan Sub-basin in the northeast, and the Barcoo and Roebuck (formerly Offshore Canning Basin) basins to the southwest (Figure 1). The western sides of the Caswell and Barcoo sub-basins become the Scott and Seringapatam sub-basins where they cross a faulted hingeline which is imaged on gravity maps of the area (Hocking, Mory & Williams, 1994), (see Figure 1).

Geological History Of The Yampi Shelf Region

The generalised major tectonic features of the Browse Basin are shown in Figure 3, as well as the major lineaments of the basement and Kimberley Block which have been interpreted from aeromagnetic data (see later).

Palaeozoic Extensional History

The Browse Basin has been interpreted to have been initiated as an intracratonic basin during the Late Carboniferous to Early Permian (Bradshaw et al, 1988), although the presence of earlier Palaeozoic rocks beneath the Caswell Sub-basin has been suggested by Allen *et al*. (1978). For example, the adjacent Petrel Sub-basin, and parts of the Vulcan Sub-basin, experienced significant (probably ~NNE) extension in the Late Devonian to Early Carboniferous, during the formation of the Petrel Rift System (O'Brien, 1993; O'Brien et al., 1996a). It is possible, but as yet unproven, that this extensional event did in fact lead to structuring and deposition within the Browse Basin.

The Late Carboniferous to Early Permian tectonism that (?) initiated the Browse Basin was part of a much wider extensional event that led to the development of the Westralian Superbasin and was critical in establishing the present day architecture of almost the entire Western Australian margin. It is likely that the rifting began in the mid-Carboniferous (Visean), for this correlates with a major unconformities in the Carnarvon (Bentley, 1988) and Arafura Basins and the Petrel Sub-basin (Bradshaw *et al*., 1992). Furthermore, fission track data from the Amadeus, McArthur, Canning, Arafura and Pilbara Basins (Bradshaw and Vizy, 1990) show that this unconformity corresponds to a major thermal event which significantly affected the maturation of Palaeozoic source rock units. The proposed inception age for rifting correlates with the peak of the Alice Springs Orogeny.

This extension event continued until the Early Permian, and was characterised by massive (?approximately north-west) extension which dramatically thinned the crust (O'Brien et al., 1993). Whilst most of the thinning was concentrated under what is now the outer shelf and continental slope, localised graben developed over thinned regions on the inboard parts of the margin. The Yampi Shelf was located on the extreme inboard part of the Browse Basin during the development of this major Early Permian extensional system, and was essentially a gently dipping, flexural basement ramp. Faults within such basement ramps are characteristically of small displacement, with a strong landward-dipping component (O'Brien et al., 1996a). As a result of the low total extension within the ramps, pre-existing basement grain, such as that evident within the Kimberley Block, can play a key role in controlling rift segmentation and facies distribution (O'Brien et al., 1996a).

Palaeozoic Climates & Sediments

Sediments deposited during this time are likely to have been influenced by a combination of the active extensional environment and the prevailing glacial conditions. For example, ground moraines, interpreted as fills within glacial U-shaped valleys on the Yampi Shelf (Figure 4), have been interpreted. The Early Permian also saw the melting of glacial ice and isostatic rebound of land masses such as the Kimberley Block.

The climate of the (post-rift) Late Permian had ameliorated compared to the preceding glacial phase, and temperate conditions prevailed across the Browse Basin (Dickins, 1978). Block faulting, interpreted to be due to Late Permian tensional movements, have been interpreted in the Caswell Sub-basin (Powell, 1976).

Post-Rift Phase

Following cessation of this extensional phase, approximately 10-15 kms of flat-lying, largely unstructured, Permo-Triassic sag phase sediments were deposited over the entire Westralian basin system, including the central and outer parts of the Browse Basin. During this time interval, the Yampi Shelf would have experienced strong flexural stresses associated with the down-to-the-basin subsidence. Such stresses could have resulted in minor fault reactivation above the Early Permian faults.

Late Triassic Tectonism: Inversion or Extension?

The 'layer-cake', post-rift depositional phase was terminated by major tectonism along the entire North West Shelf during the late Hettangian (O'Brien, 1993; Labutis, 1994). This tectonism, which produced an Early Jurassic unconformity at the top of the Triassic section (Figure 6), resulted in broad regional arching ('sags and arches') and obvious compression of the northwest-trending, intra-cratonic, Palaeozoic basins such as the Arafura, Bonaparte and Canning basins (O'Brien, 1993; O'Brien et al., 1993; Etheridge & O'Brien, 1994; O'Brien et al., 1996a). The overall effects of this mild compression, which typically involved about 1-2% shortening from a north to north-northwest direction, and 1,000-2,000m of uplift, (O'Brien et al., 1996a), was the reactivation of the older Early Permian, Late Devonian and Proterozoic structures (O'Brien et al., 1993).

Whilst the effects of this compression are unequivocal within the Palaeozoic intra-cratonic rifts, its effect outboard, through the region of the younger Mesozoic rifts, is more problematical. Indeed, the spatial and temporal relationships between the Late Triassic compression and the (?younger) inception of the Mesozoic extensional systems outboard, are very poorly constrained. It may be that both are related, with extension in the outboard Mesozoic elements inducing compression in the intracratonic provinces, which trended sub-parallel to the Mesozoic extensional vector. Given that the Late Triassic is a period of major tectonism in eastern Australia (Etheridge & O'Brien, 1994), and a period of major plate readjustment worldwide, a more likely explanation is that the Late Triassic compression and the subsequent 'rifting' along the Western Australian margin, are different processes, though perhaps both are ultimately related to the same driving mechanisms.

Mesozoic Extensional History

The easterly basins along the present day coastline of the North West Shelf are the preserved 'failed rift' component of Veever's (1984, 1988) East African Rift analogy. The 'active rift' area ran along the northwestern margin of the Exmouth Plateau, Scott Plateau, Ashmore Platform and Sahul Platform blocks. Break-up along this 'active rift' was not time synchronous across its entire length. Areas to the north of the Exmouth Plateau (the Argo Abyssal Plain) experienced the continental break-up of Australia and Argoland during the Late Callovian-Early Oxfordian, no later than ~155 Ma (Ludden & Gradstein, 1991). Further south, breakup northwest of the Exmouth Plateau and the Cape Range Fracture Zone occurred from the Valanginian-Hauterivian (~132 Ma), and was related to the separation of Australia and Greater India.

The exact age given to the onset of seafloor spreading (i.e. the age of earliest oceanic crust production) is the subject of some debate throughout these areas. In particular, the attributed relationships between rift onset, continental breakup and the unconformities and tectonic events within the Timor Sea, in particular, have varied widely between different workers. For example, O'Brien (1993), O'Brien et al. (1993) and Etheridge & O'Brien (1994) have argued that the reported 155 Ma age for the initiation of seafloor spreading in the Argo Abyssal Plain (which is relevant to the Yampi Shelf), necessitates that much of the Jurassic tectonism within the Timor Sea took place within a *post-rift setting*. In contrast, Patillo & Nichols (1990) ascribed a middle Valanginian breakup age for the Timor Sea. Other workers, such as Woods (1994), have attempted to reconcile these disparate observations by proposing that the Oxfordian 'extension' within the Vulcan Sub-basin may have been related to detached faulting over salt, rather than genuine crustal extension associated with rifting.

Irrespective, north of the Exmouth Plateau, the mid-Callovian unconformity represents a reactivation of rifting associated with continental breakup (Figure 5). Most of the fault movement occurred along the western edge of the rift (Labutis, 1994), and resulted in significant widening across the entire rift complex. In the Timor Sea, accommodation space was clearly created in the Early Oxfordian (Woods, 1994), with rapid subsidence taking place within the Swan and Paqualin Grabens. A coincident sealevel high resulted in the formation of deep water, restricted depocentres, which favoured source rock deposition and preservation, particularly during deposition of the Lower Vulcan Formation (O'Brien et al., 1993)

The mid-Oxfordian also experienced renewed faulting, resulting in a fairly regional unconformity. The intra Kimmeridgian event in the Timor Sea is interpreted by Patillo & Nicholls (1990) to represent the final extensional (syn-rift) phase prior to middle Valanginian seafloor spreading. In contrast, O'Brien et al. (1993) and Etheridge & O'Brien (1994) regard the Tithonian-Berriasian event as post-rift (ie., post Argo breakup) tectonism, perhaps driven by intra-plate stress associated with the slowing and possible cessation of the Middle-Late Jurassic seafloor spreading (preserved in the Argo Abyssal Plain) and/or the change in geometry of extension along Australia's southern margin (Wilcox & Stag, 1990).

The Valanginian unconformity was produced by the last significant structural event of the Mesozoic (Figure 5). It has been attributed to a switch in the direction of adjacent seafloor spreading (Etheridge & O'Brien, 1994), and was accompanied by significant subsidence. Further south, it also coincides with the breakup of Australia and Greater India and the attendant initiation of seafloor spreading in the Cuvier and Gascoyne Abyssal Plains.

After the Valanginian, tectonism largely ceased and progressive, non fault-related (?thermal) subsidence was accompanied by major marine transgression and inundation. The Scott Block and those to the south experienced subsidence during the Late Cretaceous, and reached abyssal depths after the Late Miocene (Labutis, 1994). It represents the growth stage of the Timor Sea region which commenced with marine transgression in the Valanginian which moved progressively to the southeast.

Since subsidence within the Browse Basin was rapid outboard from the Yampi Shelf throughout the Cretaceous and Tertiary, it is likely that the Yampi Shelf would have experienced substantial flexural stresses during this period. These stresses could result in some fault reactivation over the larger displacement faults throughout the area.

Mio-Pliocene Reactivation

The most recent stage in the tectonic development of the area occurred in the Late Miocene-Early Pliocene, with the collision of the Australian plate with southeast Asia, although some Oligocene structuring and uplift is also evident in areas. The North West Shelf is still being influenced at present by compressional and transpressional stresses associated with this oblique collision of plates. This late event has reactivated many of the earlier rift related faults in a reverse sense, and associated compressional features can be seen at the sea floor.

In the south of the Browse Basin, the Trochus and Lynher anticline is truncated at the seafloor, where it appears to be still growing. To the north in the Vulcan Sub-basin, the collision resulted in significant tectonism. Principally flexural extension, perhaps resulting from the down-warping of the Australian plate and the associated formation of the Timor Trough between 5-3 MaBP, resulted in the dilatation of the major Jurassic and older extensional faults which defined the petroleum traps in this area. Contemporaneously, small displacement (50-200 msecs) Mio-Pliocene fault sets formed which often, but not always, linked with, and were controlled by, the deeper faults.

The dilatation on the deeper faults, and the associated Mio-Pliocene faults, decreased trap integrity significantly in some structures (particularly where the rift and reactivation faults were highly oblique [O'Brien & Woods, 1995; O'Brien et al., 1996b]), led to the breaching of many traps. In general, fault reactivation increases progressively towards the Timor Trough; as such, the northern Yampi Shelf is likely to be slightly more reactivated than the southern Yampi Shelf.

Stratigraphy

The Browse Basin does not have a formally described stratigraphic nomenclature, but is generally referred to in terms of the nearby Vulcan Sub-basin scheme (eg. as used in Patillo & Nicholls (1990)). This report also draws stratigraphic equivalents from the Bonaparte Basin (Morey, 1988) for the

Permian and Carboniferous sections, where revisions have been made to the time range previously believed to have been intersected by Browse Basin wells. A simplified summary of the lithostratigraphy of the Yampi Shelf and greater Browse Basin is shown in Figure 6.

The traditional lithostratigraphy has been put within a sequence stratigraphic context via a 'hybrid' approach based on the work of Labutis (1994) and his discussion of sequence stratigraphy on the North West Shelf, and Barber (1994). The area has quite sparse biostratigraphic control because of the relatively small number of wells. This makes detailed sequence stratigraphy impossible, though hopefully the basis of a framework can be provided by this study.

Late Carboniferous/Early Permian (Kulshill Group equivalent)

Late Carboniferous and Early Permian sedimentation from the Perth to the Bonaparte Basins was influenced by the meltout of an extensive continental ice sheet that formed in the Namurian and lingered on into the earliest Permian times (Baillie, Powell, Li & Ryall, 1994). This resulted in thick glacial outwash deposits in the Carnarvon Basin, with several cycles of boulder beds attributed to the Late Carboniferous (Veevers & Powell, 1987). Permian coals of the Perth and Collie Basins are part of a large outwash fan fringing highlands in East Antarctica, where the coals would have been deposited in swampy parts of the braidplain. This area, from the Carnarvon Basin down to Perth Basin, would have received sediment outwash from melting of the main ice sheet that covered the western part of the continent. Australia remained at quite high latitudes throughout the Permian and Triassic, and it has been suggested by Conaghan (1984) that the present day moss covered slopes and aapamire bogs of northern Scandinavia are a possible modern analogue for Australian high latitude Gondwanan coals.

The Browse Basin, however, received glacial influenced sediments from a much more limited area of ice cover on the Kimberley Block (Figure 1), and as such, has more similarities to age equivalent sediments in the Bonaparte Basin and the northern margin of the Canning Basin. The Upper Carboniferous Kulshill Group sediments are coarse grained (initiated by hinterland fault movements and sustained by glaciation), while the overlying Kinmore Group reflects generally more stable conditions on the hinterland (Mory, 1988). Kulshill Group sediments in the Bonaparte Basin were deposited in shallow marine, glacial and fluvial environments (Gunn, 1988).

Recent reappraisal of the biostratigraphic data from the Browse Basin has suggested that the lowest sediments encountered in Rob Roy 1 (see Figure 7) extend down to the *S. yberti* Zone of the Late Carboniferous (Serpukhovian). The section up to approximately 1900 mKB. is most likely equivalent to the Kuriyippi Fm and overlying Treachery Shale (of the Kulshill Group) of the Bonaparte Basin (Mory, 1988). The shale in particular represents a glacial outwash deposit. The top of this unit is marked by a possible unconformity which is evidenced more in the marked change in %VR values than lithological differences (Figure 8). The uppermost unit from the Kulshill Group in the Bonaparte Basin is the Keyling Fm which is a thick fluvio-deltaic, silici-clastic sequence deposited as a result of isostatic rebound of the hinterland (Mory, 1988). Despite the limited well penetrations of this group, there is also seismic evidence for this period of glacial sedimentation and erosion. Figure 4 illustrates a section of line YST-07 showing the erosional features of the basement which characterise the Yampi Shelf and Prudhoe Terrace. U-shaped valleys, hanging valleys, aretes and fans shed from the valley flanks are typical features, often with moraines. Glacial U-shaped valleys occur across large areas of the shelf, and in some cases contain a seismically bland fill at the base, interpreted as glacial ground moraine on the outwash plain (Figure 10). In the northeastern area basement topography is more subdued, probably due to the action of an ice sheet.

Hyland Bay Formation

Yampi 1, Echuca Shoals 1 and Prudhoe 1 intersect Early Permian aged sediments referred to as 'Upper Sakmarian to Kungurian' in the well completion reports. These siltstones, claystones, limestones, sandstones and minor coals are probably age equivalent to the lower part of the Hyland Bay Fm., while an 8 m thick bed of recrystallised limestone at the top of this sequence in Prudhoe 1 is more typical of the Late Permian section of the Hyland Bay Fm The only positive identification of Late Permian sediments is in Productus 1, where interbedded limestones and claystones represent the upper parts of the Hyland Bay Fm (Figure 11).

Triassic

The Triassic section intersected in the Browse Basin wells is typical of the rest of the section in not being well documented or formally subdivided. As such only some of the more recent wells subdivide the Triassic section. In fact, most of the earlier penetrations of the Triassic do not have conclusive biostratigraphy which would allow accurate subdivision of the penetrated sections.

The earliest Triassic unit present in the Vulcan Sub-basin is the Mt. Goodwyn Fm., however, this does not seem to have been penetrated by a well in the Browse Basin to date. It is best developed in the Bonaparte Basin to the northeast. Osprey and Pollard Fm equivalents were penetrated in Buccaneer 1, which are described as marginal marine sandstones, siltstones and calcilutites (Figures 11 & 12).

The only unit confidently assigned to the Vulcan Sub-basin nomenclature is the Middle Triassic Pollard Fm which was intersected in Copernicus 1. It is represented by interbedded claystones, sandstones and minor limestones, deposited in a terrestrial setting with a minor brackish influence in the upper part (indicated by spinose acritachs). Brecknock 1, Echuca Shoals 1, Lynher 1, Scott Reef 1, North Scott Reef 1 and Barcoo 1 also contain similar Triassic aged sediments, while North Scott Reef 1 and Scott Reef 1 were the only wells to encountering hydrocarbons in these sandstones (gas bearing).

Plover Formation

The Plover Fm was initially described by Mory (1988) from the Bonaparte Basin. It is represented by quartzose fluvio-deltaic and nearshore marine sandstones which have been the target of much exploration in the Browse Basin to date. Sandstones from this formation are gas bearing in Brecknock 1, Brewster 1, Heywood 1 and Scott Reef 1. The variable nature of this lithology is difficult to predict with the limited well penetrations, which indicate it is only partially preserved on the Yampi Shelf. To the north in the Vulcan Sub-basin, three depositional sequences have been identified by Patillo & Nichols (1990) within the Plover Fm. The basal Hettangian to Toarcian facies is characterised by fluvio-deltaic, massive, medium to coarse grained submature quartzarenites. This is succeeded by transgressive marine carbonaceous shales interbedded with sandstones and minor ironstones. A Toarcian age is given for this major marine transgression across the area. The overlying sequence comprises delta front quartzarenites (with excellent reservoir characteristics) and minor claystones.

Within the Browse Basin, Plover Fm has been encountered in Rob Roy 1, where it has nearshore marine indicators, and good source rock characteristics (Figures 7 & 11). Buccaneer 1 also encountered marine influenced Plover Fm (Figures 11 & 12). Yampi 1 lacked diagnostic environmental indicators within the Plover Fm., however the red-brown claystones and siltstones are possibly correlateable within the second marine sequence from the Vulcan Sub-basin, and also exhibit favourable source rock characteristics. Plover Fm from Yampi 2 was attributed to a lower delta plain environment on the basis of absent dinocysts and the presence of spinose acritarchs. Yampi 2 also encountered a basaltic flow immediately below sediments assigned to the *Dictyosporites complex* Zone, which had undergone significant alteration.

Lower Vulcan Formation and Montara Formation equivalent

These represent the initial syn-rift fill sediments within the Browse Basin and Vulcan Sub-basin, and ranges in age from the Callovian to the Kimmeridgian It is not present on the Yampi Shelf, but is restricted to the base of wide grabens which had formed across the rest of the Browse Basin. As in the Vulcan Sub-basin, the lowermost unit (Montara Fm.) is best developed along the eastern edge of the basin where sediments shed across the Yampi Shelf and down the Prudhoe Terrace (see Figure 14). The lower boundary between the Montara Fm and the underlying Plover Fm is unconformable, and is represented by the Callovian unconformity. The upper surface of this unit seems to be conformable with the overlying Lower Vulcan Fm., with the transition being marked by a major flooding event. In surrounding basins the Oxfordian unconformity is placed at this boundary.

Montara Fm equivalents are also encountered in the more basinal areas (Buccaneer 1, Heywood 1 and Yampi 2), where they are interpreted to have been deposited in marginal marine and marine inner shelf environments respectively (Figure 15). Close to the eastern margin, it is interpreted that these coarse sands would display excellent reservoir characteristics, as in the Vulcan Sub-basin, however, in Yampi 2 only moderate reservoir characteristics were noted with low permeabilities. The Montara Fm is interpreted to be a prograding deltaic system sourced from the south, and locally off the basin margin scarp to the east. An account from the Tahbilk 1 well completion report in the Vulcan Sub-basin divides the formation into four discrete cycles. The first comprises high energy fluvio-deltaic sandstones, conglomerates and volcanic detritus, with the top of the cycle marked by a marine transgression. The second transgressive marine cycle is represented by basal volcanic detritus and fining upwards channel fill sandstones. Overlying this is the third cycle comprising regressive deltaic sandstones, which is succeeded by the final cycle of marine transgressive shoreface sand units.

The overlying Lower Vulcan Fm is characterised by restricted marine shales deposited within the main graben axis of the Vulcan Sub-basin. This unit in the Browse Basin is generally silty and more sand prone, perhaps as a function of elevated hinterland to the east (i.e. Kimberley Block), and has less favourable source rock characteristics. This unit in Yampi 2 and Buccaneer 1 is interpreted to have been deposited under inner shelfal marine conditions (Figure 15).

The boundary between the Upper and Lower Vulcan formations is conformable in the central deep of the Caswell Sub-basin, however, the Lower Vulcan Fm is missing from the shelfal wells, where it has been removed by the Kimmeridgian unconformity event (Figure 13).

Upper Vulcan Formation

Sediments from the Upper Vulcan Fm range in age from Tithonian to early Valanginian, and represent the most intense period of rift tectonism and associated vulcanism (i.e. in the Vulcan Sub-basin). In high areas on the Yampi Shelf, the Kimmeridgian unconformity which marks the base of this unit is coincident with the Callovian unconformity. In the limited well penetrations of this unit, it is dominated by sands with minor mudstones (Figures 7 & 15). The depositional environment for these sediments is interpreted as marginal to intermediate marine. In more southerly areas (near Yampi 1) this unit is interpreted as being deposited in a shelfal to open marine environment. Lowstand inner shelf sands are noted at Prudhoe 1, Heywood 1, Buccaneer 1 and Asterias 1 (Figure 15).

Echuca Shoals Formation

The Echuca Shoals Fm (Patillo & Nicholls, 1990) is characterised by a strongly transgressive, condensed glauconitic claystone facies in the Vulcan Sub-basin. The base of this unit is marked by the intra-Valanginian unconformity (often a disconformity in the Browse Basin), and the top by the Late Aptian unconformity (Figure 15). The unit thickens overall towards the south, and becomes sandy towards the east on the Yampi Shelf. The Late Aptian unconformity is interpreted (Patillo & Nichols, 1990) to represent a regional lowstand event of limited duration. Lowstand fans in the deeper bathyal areas are present at Asterias 1 and Caswell 1 (Figure 15). The Echuca Shoals Fm geometry is clearly seen on seismic line YST-02 (Figure 16), with a distinct shelf break and slope. The low frequency negative (red cycle) immediately beneath the Late Aptian unconformity between SP. 4000 - 5200 probably represents a low stand fan similar to that intersected at Asterias 1 (Figure 16).

Jamieson Formation

The Jamieson Formation was deposited in response to the first northwestern progradation across the developing passive margin. It is characterised by non-calcareous claystones deposited in sediment starved, deep water environments. The upper boundary of this formation is marked by the intra-Albian disconformity, recognised by Patillo & Nichols (1990) in the Vulcan Sub-basin. In this study, the upper surface of the Jamieson Fm is better marked by the Turonian disconformity, as the intra- Albian event is difficult to follow. This unit is dominated by a series of stacked highstand units (Figure 19). Highstand inner shelfal sands are present at Rob Roy 1 and Londonderry 1 (Figure 17 & 18) and are interpreted to be present as the high amplitude events around 950 msecs. between SP. 3500 - 5500 on Figure 20.

Woolaston Formation, Gibson Formation and Fenelon Formation

Hemipelagic slope sedimentation characterises this sequence, and resulted in regionally distributed lithologies of marked uniformity, produced by three carbonate-marl depositional cycles. A global anoxic event during the Turonian is correlated to the North West Shelf (Patillo & Nicholls, 1990) and is marked by a claystone within the Woolaston Formation, which represents a disconformity. In northwestern parts of the Browse Basin, this surface is overlain by calcilutites (see Asterias 1 in Figure 17) which were deposited in the deepest water conditions developed in the area. Inner shelfal sands were deposited on the Yampi Shelf (Rob Roy 1 and Londonderry 1) at this time (Figure 21), and the prograding inner shelfal sands are clearly present on the seismic (Figure 22). These sands are likely to be encased in shales, as these units transgressed onto the Yampi Shelf

Puffin Formation

Deposition of the regressive Puffin Sands (Figure 23) was characterised by periods of regional lowstand (during the Campanian/Maastrichtian), during which time much of the Yampi Shelf would have been emergent and undergoing erosion. Basin floor fans were deposited during these lowstands within the Vulcan Sub-basin, however the Yampi Shelf/Prudhoe Terrace area was dominated by inner shelf sands (Figure 21). Channel cuts are noted on seismic from the Vulcan Sub-basin to the north, where channels come into the graben off the Yampi Shelf/Londonderry High. Coarse grained clastics were directed across the shelf, towards the central basin deep. The top of this formation is marked by a regional unconformity (Base Tertiary unconformity). Sea level falls at around 67 and 68 Ma. Have not been recorded in the wells, as the area was emergent at this time (Figure 21). The thin sand immediately beneath the 71 Ma. sequence boundary in Figure 21 probably represents a basin-floor fan which formed during the 75 Ma. sea level fall. Slope fans, which formed during the early stages of deposition of the Puffin Fm., are likely to be encased in deep water shales and may be an attractive target in the area (Figure 24).

Bassett Formation

Early Tertiary fluvio-deltaic sediments of the Bassett Fm are interbedded with shallow marine carbonates and marls which extend across the west of the Browse Basin. To the north in the Vulcan Sub-basin, a thick carbonate wedge developed (Johnson Formation), and prograded towards the northwest through the Tertiary.

Grebe Formation, Prion Formation and Oliver Formation

These three formations were deposited during the main phase of passive margin growth this and surrounding areas. The Grebe Formation is dominantly sandy along the eastern margin of the Browse Basin, but pinches out in the centre of the basin, which is dominated by carbonates.

Barracouta Formation

Initial deposition of the Barracouta Formation is marked by the tectonic event of Australian and Southeast Asian plates colliding. It's deposition was and still is being influenced by compressional tectonics. An unconformity at the base of this unit is recognised across much of the North West Shelf. On higher parts of the Yampi Shelf this event truncates much of the earlier section.

Well Validity

Table 1 shows the validity of most wells in the northern half of the Browse Basin. It is shown that most of the wells to date have drilled the traditional Jurassic/Triassic faulted or drape anticlines. No stratigraphic plays have been tested, and only one well has encountered hydrocarbons on the Yampi Shelf in an 'unconventional' basement drape feature (Gwydion 1). This well was not included in the well validity table as the information is still closed file to date. Commentaries on the well have been made on the basis of scouting information, as with that published in PESA News (April/May 1996) by Paul Cartwright. He gives an account of the well as containing three separate pay zones (two gas, one oil) within Late Jurassic to Early Cretaceous reservoirs.

Table 1: Well Validity

Well name	Spud date	Oper-ator	TD (m.)	Objectives	Validity & status
Asterias 1	June 1987	BHPP	4383	Early Cretaceous sands and Upper Vulcan Fm sands.	Invalid - inadequate trap development, no hydrocarbon shows (PA).
Bassett 1A	June 1978	Wside.	2706	Maastrichtian-Campanian sands in a faulted anticline	Invalid - no closure, no hydrocarbon shows (PA).
Brewster 1	May 1980	Wside.	4695	Middle - Late Jurassic	Valid - gas discovery
Buccaneer 1	Feb. 1990	Shell	3574	Plover Fm sands	Invalid - primary objective not encountered, no closure, no top or lateral seal. Oil shows were noted in the Vulcan Fm and Triassic (PA).
Caswell 1	1977	Shell	4089	Early - middle Jurassic sands in a drape anticline	Flowed oil from Early Cret. fractured shale, but did not reach objective due to technical problems.
Caswell 2	1983	Shell	4983	Early - middle Jurassic sands in a drape anticline	Invalid - Reservoir and oil in Campanian sandstone, but outside of closure at objective level.
Copernicus 1	Sept. 1993	Mobil	2750	Late Jurassic sands in a low side fault trap.	Invalid - No Jurassic present. Lack of HC's in Triassic reservoir possibly due to sands at base of top seal, or a lack of charge to Triassic (PA).
Echuca Shoals 1	Nov 1983	Wside.	4384	Jurassic - Perm. Drape anticline	Valid - Jurassic gas discovery, reached T.D. in Permian.
Heywood 1	Apr. 1974	Wside.	4572	Middle Jurassic sands within horst block.	Invalid - no closure, low permeability reservoir, high gas readings and minor oil shows in Jurassic and lower Cretaceous section (PA).
Londonderry 1	Sept. 1973	Wside.	1145	Stratigraphic test	No hydrocarbons encountered (PA).
Maret 1	Dec. 1991	Norcen	3560	Early Cret. sands	Invalid
Productus 1	Oct. 1991	Mobil	2590	Permian sands within the Hyland Bay Formation	Invalid - no reservoir, tight carbonates and shales intersected, minor hydrocarbon shows (PA).
Rob Roy 1	Jan. 1972	Wside.	2286	Stratigraphic test	No hydrocarbons encountered (PA).
Yampi 1	June 1973	B.O.C.	4163	Triassic	High gas readings and residual oil, invalid, no closure, prognosed objective was wrong (Permian).

Reservoir

Potential reservoir lithologies in the Browse Basin exist within the Carboniferous to Tertiary section. Most of the core data available is, however, for Jurassic to Cretaceous reservoirs. Table 2 shows the range and average for porosity and permeability values according to formation. Figures 25 & 26 show the porosity versus permeability data for the Browse Basin, and porosity versus depth data from both log and core derived samples (Figures 27, 28 & 29). In general, it is only the Montara and Puffin Fm (and minor Plover Fm.) which have porosity values over 15% and corresponding permeabilities over 30 Md. The limited core data and well completion reports suggest that despite the shallow depth of burial of the Permian and Carboniferous section on the Yampi Shelf, reservoir potential of both limestones and sandstones is limited by a lack of permeability and low porosities.

Figure 25 shows the basin-wide trend for porosity and permeability when averaged across all formations. In general, permeabilities fall below 10 Md. at porosities of less than 13%, which (on a basinal scale) can be expected at depths of around 2800 mSS in the Browse Basin.

Table 2: Reservoir data for Browse Basin wells.

Formation	Porosity Range (%)	Porosity Average (%)	Perm. Range (Md.)	Permeability Average (Md.)
Echuca Shoals Fm (basal sands)	1 - 32	20.3	-	-
Puffin Fm.	7 - 30	19.5	18 - 5806	3290.2
Upper Vulcan Fm.	0.8 - 27	9.7	0.1 - 22	1.9
Lower Vulcan Fm.	0.7 - 26	13.8	0.12 - 311	47.7
Montara Fm.	6 - 30	18.8	0.12 - 1.82	0.6
Plover Fm.	1 - 33	11.4	0.2 - 1050	27.5
Kulshill Fm.	2.1 - 13.0	9.8	0.2 - 2.5	0.7

Puffin Formation

Puffin Formation sandstones represent some of the best reservoir characteristic yet encountered in the Browse and adjacent basins. Porosities range from 7 - 30% (average 19.5%), with permeabilities between 18 - 5805 Md. (average 3290.2 Md.). It can be seen from Figure 26 that the Puffin Formation values plot as a separate group at the very high porosity and permeability end of the diagram. These sands were deposited during a period of regional lowstand in the Campanian, when some of the Yampi Shelf may have even been emergent. Coarse grained sands would have spilled over towards the west and northwest, depositing significant fans on the Prudhoe Terrace and deeper parts of the basin.

Jamieson Formation

On the eastern side of the Browse Basin, sandstones are developed within the Cenomanian and Albian sections of the Jamieson Fm.; no reservoir data is, however, available for these sands. Londonderry 1 has a 30 m sandstone within approximately 130m of overlying claystone. The well completion report describes it as a dominantly fine grained sandstone, becoming argillaceous towards the base, unconsolidated and good porosity. Interpreted transgressive shoreface sands within this sequence on the Yampi Shelf are proposed as a potential target. Detailed mapping within this sequence should better define the high amplitude events (Figures 30 & 31) which are correlated with shoreface sands, overlain by claystones of rather bland seismic character.

Echuca Shoals Formation

Along the eastern side of the Browse Basin, sands occur at the base of the otherwise shaley Echuca Shoals Fm., and occasionally within as thin interbeds. A sandy Echuca Shoals Fm seal is postulated as the reason for failure of the Copernicus 1 well. Porosities within these sands range from 1 - 32% (average 20.3%), and had no permeability data available. In the middle of the basin, Caswell 1 encountered a submarine fan sandstone deposited in response to the significant lowstand which occurred towards the end of the Aptian.

Vulcan Formation and Montara Formation

From the limited well completion data available, it seems that sands within the Lower Vulcan Formation have quite good reservoir characteristics (average porosity 13.8% and average permeability 47.7 Md.), however they are generally thinly bedded within this overall shaley and/or silty unit. The only well intersection of Montara Fm sands in the Browse Basin with reservoir data, was from Yampi 2 where permeabilities are quite low (average 0.6%). Shelfal sands of the Upper Vulcan Fm are a more reliable reservoir objective as they are often quite thick (beds >10m thick), and have average porosities of 9.7% (range 0.8 - 27%) and permeabilities averaging around 2 Md.

Plover Formation

A relatively large amount of data exists for the fluvio-deltaic and nearshore marine sandstones of the Plover Fm., which have been the main exploration target over much of the Browse Basin. In deeper parts of the basin, diagenetic processes (including quartz overgrowths) have reduced porosities, however, data from the Yampi Shelf wells indicates that this area is not affected to any great extent. The Plover Fm displays a large variation in porosity and permeability values. Porosity values range from 1 - 33% (average 11.4%), with permeabilities between 0.2 - 1050 Md. (average 27.5%). Plover Fm gas bearing sands have been encountered in Brecknock 1, Brewster 1A, North Scott Reef 1 and Scott Reef 1 & 2.

Triassic

Upper Triassic sandstones and carbonates may have potential as good reservoirs along the Yampi Shelf where their depth of burial does not preclude them having favourable porosities and permeabilities. Scott Reef 1 intersected Triassic gas bearing sandstones, while Copernicus 1 encountered Pollard Fm non-marine sandstones which occasionally displayed fair to good visual porosity, and minor show indications (sample and crush/cut fluorescence). Buccaneer 1 encountered log porosities of between 2 and 24% (average 17%) in the Pollard and Osprey Fm sandstones. No wells in the area have intersected the better quality Late Triassic Nome Formation sands. The major risk with this type of reservoir on the Yampi Shelf is the lack of favourable sealing lithologies between the Triassic and overlying Jurassic reservoirs.

Hyland Bay Formation

Favourable Permian reservoirs were prognosed prior to drilling Productus 1, however, the well encountered a succession of tight carbonates and shales with no significant reservoir quality sandstones. Prudhoe 1 encountered an 8 m limestone with no visual porosity, and an interbedded sequence of claystone, sandstone and calcilutites with poor reservoir characteristics in the sands.

Sandstones and limestones of the same age in Echuca Shoals 1 were also devoid of any visual porosity. The Hyland Bay Fm in the Bonaparte Basin represents an important reservoir unit, where the upper part of the sequence is sandier than the Browse Basin, and was deposited by a major Permian delta complex (Lavering & Ozimic, 1988). The clayey sands of this facies retain their porosity better than clean sands at similar depths, as the clay inhibits certain diagenetic processes (Bhatia *et al*., 1984). The Hyland Bay Fm in the Vulcan Sub-basin, however, relies on fractured limestones as a possible reservoir facies, with little if any reasonable sandstone.

Kulshill Group equivalent

A few data points from Rob Roy 1 are available for sandstones within this group. Six data points show porosities of between 2-13% (four points between 11-13%) at around a depth of 1790 mSS, however, the corresponding permeabilities are mostly around 0.2 Md. It is interesting to note that above 1770 mSS the Rob Roy 1 well completion report states that visual porosity estimates increase to around 15%, and the log porosity values are greater than 12%. This is around the same depth that the %VR trend (see Figure 8 and discussion in maturity section) indicates that there would have been considerable uplift corresponding to the melting of glacial ice. It is possible that the porosities and permeabilities of the upper part of the Kulshill Group equivalent (including the Keyling Fm equivalent) may have better reservoir characteristics than the younger Hyland Bay Fm., or the underlying Kulshill Group equivalent which would have previously been at greater depths than at present.

Seal

Sealing lithologies within the Browse Basin may be found from the Permian through to the Late Cretaceous. The unit which has historically been termed the regional seal in the Browse Basin is the Echuca Shoals Fm., which may be up to 450 m thick in some areas. Towards the base of these transgressive marine claystones there are sands, which reduce its effectiveness as a seal, but may provide a favourable reservoir if sealed by the rest of the overlying Echuca Shoals Fm
Intra-formational seals occur within the Upper and Lower Vulcan formations, however, these are better developed off the Yampi Shelf, towards the deeper parts of the basin. Shales of the Hyland Bay Fm may seal the Kulshill Fm equivalent sandstones, but as yet there have been no well intersections with these units juxtaposed.

For plays on the Yampi Shelf, the presence of an effective seal is probably the crucial element. In general, this area has intra-formational sands in the Echuca Shoals and Jamieson formations, however, adequate sections of claystone are notoriously difficult to map.

Source

Source Intervals, Type and Potential

Potential source intervals in the Browse Basin range in age from Carboniferous/Permian to Cretaceous, and parts of the entire section presently lie within the oil window at various locations across the basin.

The oldest potential source interval is the Late Carboniferous and Early Permian Kulshill Group equivalent which occurs within the Rob Roy Graben at relatively shallow depths. Figures 32, 33 & 34 show that where this section is within the oil window, it has good oil and gas potential, particularly within the Early Permian Keyling Fm equivalent. At present it is not possible to estimate the aerial extent of this formation, but it is not unreasonable to assume that it underlies at least a large area of the Yampi Shelf and Prudhoe Terrace around the Rob Roy Graben, where it would currently be within the oil window. The Kulshill Group in the Bonaparte Basin has excellent potential as an oil source in isolated beds throughout the group, while overall the entire formation has fair to good potential for both oil and gas (Laws & Brown, 1976).

Most of the Triassic section has very limited source potential, with very low TOC and HI values, and is usually only gas prone at best.

The Plover Formation, by comparison, shows good potential for oil and gas (Figure 33), and covers a large area of the Caswell Sub-basin, Vulcan Sub-basin and Prudhoe Terrace. Hydrogen Index versus Oxygen Index and *T*max versus Hydrogen Index plots characterise the Plover Fm as a Type II source rock, largely derived from terrestrial organic matter (Figures 32 & 34).

The Vulcan Formation is well documented as a good to excellent oil source (in particular the Lower Vulcan Fm.), with high TOC and HI values. The Upper Vulcan Fm also shows excellent oil potential, however these shales are somewhat limited by the high percentage of sand within this formation.

The Early Cretaceous Echuca Shoals Formation has favourable source characteristics for both oil and gas, and covers an extensive area across the basin. Much of this lies within the oil window in the central deep area of the Caswell Sub-basin.

Source Affinities of hydrocarbons

Well completion report data is used as the source of the following information:

Two oil types were encountered within the Montara Fm reservoirs of Yampi 2. The lower samples were interpreted to be locally migrated or *in situ* oil generated by the Lower Vulcan Fm They are early mature (VR=0.74%), deposited in an oxic, marginal marine environment, with a land plant derived organic facies. The upper oil is derived from an unknown source which is mature (VR=1.09%), and is characterised by clastic sediments deposited in a moderately oxic marine environment, and a mixed suite of organic facies (significant percentage of land plant derived material).

Condensate samples from Tahbilk 1 were analysed, and found to be derived from highly mature source rocks. The organic matter of these source rocks is interpreted to be predominantly aquatic in origin, with a minor terrestrial plant input, and deposited in a moderately oxidising environment.

A source rock characterisation study of samples from the Lower Vulcan Fm in Katers 1 suggested that it was deposited in transitional anoxic - oxic/anoxic conditions within a marine environment, which received a significant amount of terrestrial material.

Residual oils extracted from Buccaneer 1 appear to be geochemically similar. They are all interpreted to have been generated from a source containing algal/bacterial kerogen which was deposited in anoxic marine conditions.

Maturity

Figure 35 shows the vitrinite reflectance trend for wells used in this study. Overall, the oil window in the Browse Basin is interpreted to lie between 3700 - 4800 mSS (%VR 0.67 - 1.2, Figure 35). This has been derived from pre-Permian aged sediments, as it is believed that these are less influenced by tectonic uplift. Willis (1988) suggests that significant hydrocarbon generation in the Browse Basin begins at %VR = 0.7, although useful biomarker maturity indicator data was unavailable for the wells examined in this study.

A jump is seen in %VR values for the Permian and Carboniferous section which may be related to isostatic rebound of the hinterland after glacial ice melt (Figures 8 & 35), or tectonic uplift associated with initiation of rifting (Figure 36). Data from Rob Roy 1 (Figure 8) suggest that there may still be large areas of Early Permian - Late Carboniferous which are currently within the oil window underlying the Prudhoe Terrace. The S1/TOC & S2/TOC plot for Heywood 1 shows a more typical VR trend for areas less influenced by tectonics of major basin bounding faults (Figures 37 & 38).

Seismic interpretation

Seismic coverage and vintages

Primarily data from the YST- survey were used for the interpretation, although additional regional lines were used to provide extra well control (Figure 2).

Data quality

The YST- survey consists, in the main, of very good quality broadband data. The interpreted data set was processed to be minimum phase.

Well ties

Composite well logs for Rob Roy 1 (Figure 7), Londonderry 1 (Figure 18), Buccaneer 1 (Figure 13), Productus 1 (Figure 12), Asterias 1 (Figure 16) and Heywood 1 (Figure 38) show the interpreted horizons, the well logs and lithologies. Appendix 1 contains a list of all the depths and seismic times for each of the wells. Synthetic seismograms were made for Rob Roy 1 (Figure 39), Londonderry 1 (Figure 40), Buccaneer 1 (Figure 43), Productus 1 (Figure 45) and Asterias 1 (Figure 47). Unfortunately digital well logs were incomplete or of poor quality, and it was difficult to get good ties to the wells.

Rob Roy 1 (Figures 58 & 39)

The Mid Callovian Unconformity at Rob Roy 1 is based on information contained within the Well Completion Report. However, recent biostratigraphic reinterpretation suggests that this event is in fact deeper, and a tentative pick has been made on Figure 8. Check shot information was available only at four key horizons, and the sonic log has not been accurately calibrated with the actual check shot information. The seismic wavelet has been extracted over an interval of 500 - 1600 msecs. (Figure 39) and applied to generate the synthetic seismogram. There is good agreement between synthetic and seismic data at the well. The mapped horizons are marked on the synthetic. Note that the lithology column shows only the dominant lithology, and does not include the finer details as illustrated on well correlations (Figures 11, 15, 17 & 21). The well logs and mapped horizons are overlain on the seismic data (Figure 5).

Londonderry 1 (Figures 18, 40 & 42)

No velocity survey was shot at Londonderry 1, and the sonic log was datumed using the seismically derived two-way time for the basement event. Due to the poor quality of the logs (resulting from well bore washout), the seismic wavelet was extracted over a window of 700 - 980 msecs. (Figure 40), where the logs were generally of reasonable quality. The extracted wavelet (Figure 41) has a broad flat frequency spectrum.

Copernicus 1

No well logs or check shot surveys were available for Copernicus 1, however, a table in the well completion report allowed ties to the Base Miocene unconformity, Base Tertiary unconformity, Turonian disconformity and Mid Callovian unconformity to be established.

Buccaneer 1 (Figures 13, 42 & 43)

Buccaneer 1 has poor quality logs especially within the Tertiary section. The wavelet was extracted over the interval of 1600 - 2100 msecs. within the shaley Jamieson Formation, where hole conditions were reasonable, and applied over the whole log. Unfortunately, the false reflectivities within the Early Tertiary sands dominate the synthetic seismogram, however, there is a reasonable match where the log character is good. The extracted wavelet is relatively broad banded considering the narrow depth range over which it was extracted, and is minimum phase in character (Figure 41).

Productus 1 (Figures 12, 45 & 46)

The sonic log is well controlled by check shot data, and the wavelet was extracted over the range of 1400 - 1800 msecs.

Asterias 1 (Figures 16, 47 & 48)

These logs are of poor quality, and the wavelet (Figure 41) was extracted over the range of 1900 - 2300 msecs. This resulted in reasonable agreement between the seismic and synthetic data.

Interpreted Horizons

Ten horizons were interpreted on the YST- data set, mostly as zero crossings due to the minimum phase data set. In general, the character of the events is variable, as they are nearly all representing erosional surfaces (i.e. sequence boundaries). In higher areas on the Yampi Shelf, the entire section is quite sand prone, and detailed resolution of the condensed seismic events can be difficult. The events all change in character moving down into deeper parts of the basin, thus we rely not only on well ties, but also the character of events within the sequence above and below the marker (sequence boundary).

Sea-floor

The sea-floor was picked as a zero crossing from a peak to a trough across much of the area, although in some places the response becomes somewhat diffuse, possibly in response to the sea-floor becoming 'softer'.

Early Miocene unconformity

The Early Miocene unconformity erodes any earlier events which persist across to the eastern side of the Yampi Shelf. It marks the major collision of the Australian and Southeast Asian plates. It is mapped as a zero crossing which can be variable, but generally occurs as a crossing from a peak to a trough.

Base Tertiary unconformity

This event is mapped as a zero crossing which is quite variable both on and off the Yampi Shelf high. It also loses its character towards the far south of the grid (i.e. YST-03 and the southern ends of lines YST-01 & -02), where it is difficult to map. High up on the east of the Yampi Shelf the event is eroded out by the Base Miocene unconformity. Channelling can be seen at the level of this horizon on the Prudhoe Terrace and Yampi Shelf.

Turonian disconformity

The Turonian disconformity is mapped as a maximum flooding surface in areas of Northern Australia (ZOCA), and is likely to be a similar event in basinal parts of the Browse Basin. However, in higher parts of the Prudhoe Terrace and Yampi Shelf it seems to be associated with some significant channelling. In deeper areas to the west (i.e. near Asterias 1), the Turonian Disconformity is overlain by a calcilutite which provides a marked change in acoustic impedance, and thus a reliable event to map.

Late Aptian unconformity

In many places on the Yampi Shelf, the Late Aptian unconformity (mapped as a zero crossing) sits almost directly on basement. Across the Prudhoe Terrace and into the deeper parts of the basin, the Late Aptian to Turonian sequence (Jamieson Fm.) downlaps onto the Late Aptian unconformity. In shelfal areas, a sand lies on this surface, whereas deeper parts of the basin are shale dominated. At the very southern limit of the YST- grid, the event loses its character somewhat and becomes mappable only on the character of the underlying sequence.

Middle Valanginian unconformity

The Middle Valanginian unconformity is mapped as a zero crossing at the top of a dominantly sandy sequence. The overlying shales of the Echuca Shoals Fm have traditionally been viewed as the regional seal, however, on higher areas of the Yampi Shelf this is also sand prone. Thus the character of this event changes as we move down into the basin, although it can be mapped as the zero crossing from a trough to a peak where the overlying Echuca Shoals Fm is dominantly shaley. In areas of the Yampi Shelf where it is preserved, the event merges with the Callovian and Early Jurassic unconformities.

Middle Callovian unconformity

The Middle Callovian unconformity is recognised primarily on its character as a reactivation of rifting across the Browse Basin, but producing a more localised graben system than the preceding initial rift event in the Hettangian. Again it is mapped as a zero crossing, but is only preserved as a relatively continuous section in the very deepest parts of the basin, or localised deep areas such as the Rob Roy graben.

Early Jurassic / Late Triassic unconformity

This event marks the onset of rifting along the North West Shelf, and underlies a broad area from the Yampi Shelf out across the basin. The event is mapped as a variable character zero crossing, with the underlying Plover Fm providing a zone of rather bland character beneath the localised rift-fill sands of the overlying sequence. Due to time constraints and limited well ties, it was not mapped across much of the YST- seismic grid.

Basement

The basement pick across the Yampi Shelf is represented by a major increase in acoustic impedance as the signal passes into the crystalline basement of the Kimberley Block. The event is picked at the zero crossing from a trough to a strong peak, which is a relatively easy event to follow across much of the Yampi Shelf and Prudhoe Terrace. On the higher parts of the shelf, the basement has a marked relief which is interpreted to be produced by the action of glaciers. The basement event becomes obscured in deeper parts of the Browse Basin, and also in areas believed to have a glacial ground moraine fill in some of the glacial U-shaped valleys.

Mapped Horizons

Two-way time maps were made of seven horizons across the area of the YST- seismic grid, as well as a depth map of the sea floor derived from a depth converted interpretation of the sea floor reflector across the grid.

Sea-floor (Figure 49)

A depth map was made at this level from the seismic interpretation of the sea floor reflector on the YST- data set using a grid increment of 1000 m. This map is dominated by northwest-southeast and northeast-southwest trends, with isolated highs which probably represent carbonate buildups at the sea floor surface. The sea floor topography was probably formed during the most recent glacial lowstands, with the northwest-southeast trending low immediately to the north of Londonderry 1, as an extension of the northwest-southeast trending river systems (eg. Prince Regent River) on the Kimberley Block, when the sea level was lower.

Early Miocene unconformity (Figure 50)

The map of this horizon was grided with faults at 1000m grid increment. Although hydrocarbon shows have been recorded from this level within the Vulcan Sub-basin, there is likely to be a lack of seal at or about this level over the Yampi Shelf. Possible areas of interest are likely to be near the intersection of lines YST-01 and YST-18 & -19, where four way dip closures have been mapped, and also in the vicinity of lines YST-10, -11 & -12 immediately to the east of YST-01 where a large rotational fault block could provide a possible trap (Figure 50).

Base Tertiary unconformity (Figure 51)

The Early Tertiary fluvio-deltaic sand of the Bassett Formation overlies the Base Tertiary unconformity resulting in a low likelihood of seal at this level. The Base Tertiary unconformity dips gently to the west-northwest, with a re-entrant immediately to the southwest of Rob Roy 1 over the underlying Rob Roy Graben. The high to the southwest of the re-entrant may provide an attractive target at this level. The map was not grided with a detailed fault interpretation, except the important basin edge fault in west and grided at a 500 m grid increment

Turonian disconformity (Figure 52)

This horizon dips to the northwest more steeply than the overlying Base Tertiary unconformity reflecting the thickening of this interval to the west. Stratigraphic plays between lines YST-07 & 12, may be possible where the Turonian disconformity pinches out against basement. This map was not grided with detailed fault interpretation, except the important basin edge fault in west, and was grided at a 500 m grid increment.

Late Aptian unconformity (Figure 53)

This horizon dips more steeply to the northwest than the Turonian disconformity. Sands within the Jamieson Formation are likely to be sealed intra-formationally by the overlying Gibson and Fenelon formations (dominantly shaley). Pinchout plays against basement are plentiful, especially in the area around Londonderry 1 from seismic lines YST-06 to -13. It is in this zone that basement topography resulting from Late Carboniferous glaciation is most intense. Mapping at this scale, and with such a coarse seismic grid does not enable the fine detail of the glacial topography to be preserved on the map, however, the general trend and play type is obvious.

The surface was grided initially with faults at a 500 m grid increment. This was then merged with values from the basement grid where they are higher (i.e. up on the shelf) to produce a surface which represents the Late Aptian and its pinchout around the high basement areas.

Middle Valanginian unconformity (Figure 54)

This steeply northwesterly dipping event pinches out against the basement edge of the Londonderry High. Potential targets include low side rollover along the Buccaneer/Prudhoe fault system, and stratigraphic pinchouts against basement to the southeast of Londonderry 1. The surface was grided at a 500 m grid increment

Middle Callovian unconformity (Figure 55)

The mapped area of this horizon looks somewhat misleading on the area portrayed in this report. The horizon is mostly restricted to the Caswell Sub-basin, and steps west as we move towards the Vulcan Sub-basin. Potential targets include stratigraphic pinchouts against basement, especially in the area immediately to the east of Rob Roy 1, and low side rollovers along the Buccaneer/Prudhoe fault systems (although these may be rather deep). The surface was grided at a 500 m grid increment

Basement (Figure 56)

Overall, the basement dips steeply towards the northwest along the Prudhoe Terrace, and is more gently dipping along the Yampi Shelf. Basement is characterised by three main regions: an area to the northeast where the basement topography is relatively subdued, and which probably represents the location of part of the Late Carboniferous ice sheet. The next region is deeply incised and faulted, and is located in the central/northern area. The third region is to the southwest, and is characterised by more subdued topography where it is interpreted that a glacial outwash plain existed.

The second region (central/northern area) shows the greatest evidence of intense glaciation, and is quite prospective with drapes over the basement highs, and pinchout of the overlying section against basement within the valleys. Due to the coarse line spacing of the YST- grid, and the relative narrow nature of the glacial valleys, the true rugosity of the basement marker is not properly reflected in the map which was grided at a 500 m grid increment.

Isochronous maps

Isochron maps were made of the following intervals

Seafloor to Base Miocene unconformity (Figure 57)

This interval thickens in the west and northwesterly directions.

Base Miocene to Base Tertiary unconformity (Figure 58)

This unit thickens to the north and northwest, reflecting the dominant provenance of the fluvio/deltaic Bassett sands from the south, and to a lesser extent, shedding from the east.

Turonian disconformity to Base Tertiary unconformity (Figure 59)

The thickening to the northwest of this unit reflects the dominant northward progradation of the Puffin sands from the south as well as input from the east.

Late Aptian unconformity to Turonian disconformity (Figure 60)

The Jamieson Formation is represented by this isopach, which shows an overall thickening towards the west. The formation is dominated by a prograding unit which builds out to the north and northeast from the Yampi Shelf high (east of Londonderry 1), and thickens markedly towards the west (Caswell Sub-basin). Lines to the north and northeast of Londonderry 1 clearly show the prograding nature of this sequence, as well as the eventual pinch out of the unit northwards along the eastern edge of the Vulcan Sub-basin. An initial prograding unit at the base of the Jamieson Fm is interpreted along the eastern edge of basement highs along the Yampi Shelf. Sands within this lower unit have been intersected at Londonderry 1 where they are fairly thin and encased in shale. Updip from this well (Figures 30 & 42), sands are interpreted to be somewhat thicker (with amplitude anomalies) and may be sealed against basement highs. Possible inner shelf sands at the top of this prograding unit (Figure 31) are interpreted to wrap around the basement 'headland' behind Londonderry 1, and also show associated amplitude anomalies. Sands are interpreted within this unit at the proximal ends of these prograding units to the northeast of Londonderry 1.

Middle Callovian to Middle Valanginian unconformities (Figure 61)

This interval represents both source rocks and reservoir facies of the Vulcan Formation. The distribution of this interval is restricted to the deeper parts of the Browse Basin (i.e. Caswell Sub-basin) and Vulcan Sub-basin. Within the limits of the seismic grid which was mapped, sands of the Montara Formation occur on the flanks of the Prudhoe Terrace, and then cross to deeper parts of the Vulcan Sub-basin across the Rob Roy Graben. The imprint of the underlying Rob Roy Graben is apparent neat Rob Roy 1. By far the greatest volume of source rocks within this interval are restricted to the Caswell and Vulcan sub-basins, where they are also mature. These areas were not mapped in detail by the present study.

Basement to Late Aptian unconformity (Figure 62)

This interval was chosen to show the overall isopach between the basement and the base of the 'regional seal'. Proximal inner shelf sands are likely to be present where this unit pinches out against basement, and thus many potential stratigraphic traps are present.

Prospectivity

A hybrid approach to the traditional lithostratigraphy combined with sequence stratigraphy (where adequate well control permits) has highlighted new areas of prospectivity on the Yampi Shelf within units seen previously as having only potential as seals for example. The prograding Jamieson Fm is an example of this, where interpreted shoreface sands are seen as having associated high amplitudes in areas along the Yampi Shelf.

Amplitude Anomalies - Gwydion 1

Cartwright (1996) in the PESA News gives an account of three separate pay zones (two gas, one oil) within the Late Jurassic to Early Cretaceous reservoirs at Gwydion 1. While the well information for Gwydion 1 is still closed file, these three zones are readily apparent as distinctive seismic amplitude anomalies (Figures 63 & 64) with the upper zone likely to be spread over a number of separate reservoirs. It is apparent from these distinctive signatures that hydrocarbons (both oil and gas) may be detectable by direct hydrocarbon indicator techniques (i.e. seismic attribute analysis).

Play types

The YST- data set has displayed numerous examples of amplitude anomalies across the Yampi Shelf and within the greater Browse Basin. The following discussion explores examples of these anomalies which are illustrated on various lines, which have contributed to the formation of a number of play types within the area. As the data set concentrates mainly on the Yampi Shelf, then charging any traps relies only on migration of oil up to the shelf. As has been discussed in the previous section, oil migration onto the shelf has been proven by Gwydion 1, and there is a range of source rocks throughout the section. Older potential reservoirs such as those in the Permian may still be adequately sourced by the Kulshill Fm equivalent, which is known to be present in the Rob Roy graben (and probably underlies a considerably larger area across the shelf).

Basement drapes

The Yampi Shelf has recently become the focus of some considerable attention with the well Gwydion 1 proving oil migration up to a basement drape feature relatively high on the shelf. Four way dip closed drapes over basement highs are thus an attractive target given this recent encouragement. Given the proposed glacial nature of the basement topography, many high features may be missed due to the coarse seismic grid. Numerous possible basement drape features can be seen on the YST- seismic grid, some of which have accompanying seismic amplitude anomalies, although most of these are quite small (Figures 65 - 69).

Compressional features

Within the Rob Roy Graben reactivation and possible lateral movement along the faults has resulted in compressional features, some of which have associated amplitude anomalies (Figure 76).

Stratigraphic traps

The stratigraphic trap is a somewhat difficult play to characterise, and potential may exist at numerous levels on the Yampi Shelf, where older sandy sections are truncated beneath overlying transgressive shales. There is the potential to develop these plays at numerous levels in the sequence, and a few examples from the YST- data set are discussed below.

Potential stratigraphic targets within the Kulshill Group equivalent include the moraines within the glacial U-shaped valleys (Figures 9 & 10), and alluvial fans shed from the adjacent highs (Figure 71). A stratigraphic pinchout play developed in possible Kulshill Group equivalent, is illustrated in Figure 72, which shows line YST-06. High amplitudes can be seen in the units adjacent to the basement high of the palaeo-shelf edge. They are truncated by the merged unconformities of the Early Jurassic, Callovian, Oxfordian & Valanginian, and top sealed by the Echuca Shoals Formation claystones. Laterally, it is not possible to define whether this particular feature would form a trap, although it is has the best potential within any embayments which may exist along the palaeo-shelf edge. These could be developed at many levels, but have the best potential for top seal beneath the Jamieson or Echuca Shoals formations.

Similar stratigraphic pinchouts against basement within the Berriasian shoreface sands are possible, as is shown on the seismic line downdip from Gwydion 1 (Figure 73). There is also the potential in higher shelfal locations for stratigraphic traps of sands within the otherwise sealing lithologies of the Echuca Shoals and Jamieson formations. Figure 24 shows a possible flat spot within an interpreted sand in the Echuca Shoals Fm., updip from Rob Roy 1 on line YST-05. Figure 75 illustrates an amplitude anomaly over a basement high within the Jamieson Formation, and stratigraphic pinchout traps against basement updip from Londonderry 1 (Figure 76) which have been discussed earlier. Figure 77 illustrates amplitude anomalies and a flat spot interpreted within inner shelfal sands of the Jamieson Formation. Seal for a localised sand such as this would be the surrounding Jamieson Formation claystones.

Traps which have a large stratigraphic component to them may exist within the Puffin Formation. Any plays at this level in the Browse Basin are at risk due to poor sealing capacity of the overlying Johnson Fm Intra-formational seals within the Puffin Formation may provide a seal for four way dip-closed plays. Figure 78 shows an amplitude anomaly within the Puffin Formation where an interpreted reservoir sand is juxtaposed with shaley channel fill.

Low side fault plays

An interpreted alluvial fan can be seen on line YST-07 in Figure 71, coming off a narrow faulted basement high. An age of Permian is given to this unit which is truncated below the Late Aptian unconformity. The fan itself, consists of high amplitude events within an otherwise bland zone. The sands within the alluvial fan would have a base seal provided by the ground moraine (tillites) left within the U-shaped glacial valley. Lateral seal would be provided by distal shale prone equivalents of the alluvial fan facies, and sealed against the crystalline basement of the upthrown basement (Kimberley Block). Top seal would be claystones of the overlying Jamieson Formation.

A low side fault play is also interpreted updip from Londonderry 1 on line YST-08. Sands are postulated within the Jamieson Fm on the low side of a narrow basement block Figure 70 shows that amplitude anomalies are developed on the basinal sides of two horst features up dip from Londonderry 1. Figure 79 illustrates a distinct amplitude anomaly within interpreted inner shelfal Berriasian sands sealed by intra-formational shales. A similar low side fault play is present within the Puffin sands (Figure 80).

As with the stratigraphic traps, lowside closures of sands have the best potential to be closed within embayments at the palaeo-shelf edge. Figure 14 shows a fan within the Vulcan Fm (probably the Montara Fm equivalent), which could be sealed against the basement.

High side fault plays

A combination of fault seal and stratigraphic entrapment is proposed for the play illustrated in Figure 81 on line YST-03. Amplitude anomalies exist on the high sides of two landward dipping faults on the Yampi Shelf, updip from Gwydion 1. The sands are within the Echuca Shoals and Jamieson formations, and are probably sealed laterally by intra-formational claystones, and by clay smear on the faults.

Rollover on the high side of a fault on line YST-06 has associated amplitude anomalies and possible ‘flat spots’ within the Echuca Shoals and Jamieson formations (Figure 82). These two units consist almost entirely of claystone further downdip at Buccaneer 1, however, it is postulated that discontinuous sands could be developed closer to the Yampi Shelf in the vicinity of these anomalies.

Further updip again on line YST-06 (Figure 83) is another feature with an associated amplitude anomaly and possible flat spot. This is developed within the Vulcan Fm and would probably rely partly on fault seal, as well as top seal by claystones of the overlying Echuca Shoals Fm.

Inverted fault block play

Figure 84 shows a section of YST-02 which has inverted faults and associated compressional rollover. An amplitude anomaly is seen within the pre Callovian section, possibly sealed by shales within the overlying Vulcan Fm.

Horst blocks

Figure 85 illustrates a horst block with weak amplitude anomalies within the pre-Callovian section.

Shallow Amplitude Anomalies

In addition to the deeper amplitude anomalies, which were discussed above, a cursory attempt was made to determine the distribution of anomalies shallow within the sedimentary section as well. For the purposes of mapping, ‘shallow’ amplitude anomalies were those shallower than approximately 500 msecs. Given that hydrocarbon-related diagenetic zones within the Grebe Formation sands are an important indicator of both hydrocarbon charge and trap integrity in the Vulcan Sub-basin, to the immediate north of the Yampi Shelf, the presence of possible HRDZs was also noted.

Examples of shallow amplitude anomalies are provided in Figures 86-90, whereas combinations of shallow amplitude anomalies and possible HRDZs/HRDZ-like features are shown in Figures 91-93.

The areal distribution of all amplitude anomalies and HRDZs is presented on Figure 94 and Enclosure 16. Two trends are apparent:

1. Firstly, amplitude anomalies are much more common in the central and southern part of the survey area than in the northern part.

2. Secondly, shallow amplitude anomalies are much more common in the central part of the survey area, between the Rob Roy 1 and Londonderry 1 wells than in the south, near Gwydion 1.

Possible reasons for these observations will be discussed in the section below.

Sniffer Program: Central And Southern Yampi Shelf

The central part of the survey area, which is characterised by numerous shallow and deeper seismic amplitude anomalies and some HRDZ-like features, was selected for limited geochemical sniffer acquisition. In addition, some acquisition was also carried out to the south, in the vicinity of the Gwydion 1 oil field.

The reasons for selecting these two areas were as follows:

- The southern area appears to be principally characterised principally by deeper amplitude anomalies, with little evidence for shallow seepage.
- The central area was characterised by the co-occurrence of a number of factors, including the presence of numerous shallow and deeper amplitude anomalies and HRDZ-like features, the presence of a major aeromagnetically-defined, Proterozoic basement lineament which runs right through the focus of the shallow anomalies, and importantly, the fact that potential Cretaceous reservoir sands pinchout against a basement 'headland' in this area.

Results

Southern Yampi Shelf

Sniffer acquisition in the southern area, in the vicinity of Gwydion 1 well, did not reveal the presence of any hydrocarbon seepage within the water column. The conclusion drawn from this is that the integrity of the traps within this area is relatively high, at least in terms of the hydrocarbon charge (be it oil or gas) which has been received.

Central Yampi Shelf

Sniffer acquisition through this region revealed the presence of a very large and intense gas seep, located approximately 20 kms east of the Londonderry 1 exploration well (Figures 95 & 96; Enclosures 17 & 18). The region of strongest seepage extended over 5-6 kms, with methane values of almost 300 ppm (~75 times background) being measured. Ethane peaked at over 2 ppm.

Overall, the composition of the seep gas is quite 'dry', and averaged about 0.8% 'wet' over the full range of methane concentrations (Figure 97). This observation, combined with other molecular compositional information (such as the ethane/ethylene ratio etc), demonstrate the seep is of thermogenic origin, and was probably sourced from a dry gas, rather than oil, source. Carbon isotopic work on the methane within the seep is presently being undertaken (available December 1996) to determine whether the gas is of Permian (carbon isotopic composition of ~-26), Jurassic (~-38-42) or mixed, origin.

Implications Of Sniffer Results

Migration Risk

These observations are clearly of significant relevance to petroleum exploration in this area. From a positive viewpoint, they demonstrate that hydrocarbons have migrated all the way to the inboard part of the central/northern Yampi Shelf, thereby establishing some similarity with the area around the recent Gwydion 1 discovery to the south. As such, *migration is probably not an issue within the central Yampi Shelf* .

Likely Charge: Gas Or Oil?

From a negative viewpoint, the seep is dry, which *may suggest that the region is gas-prone*. In particular, if the gas is shown to be of Permian age, then the prospectivity of any *pre-Cretaceous* traps would be significantly down-graded, for very early gas charging would be likely. If the seep gas is shown to have been sourced from the Jurassic, then other factors, such as source quality, maturation and migration will need to be evaluated before the full implications of the recognition of this seepage can be appreciated.

The differences in apparent present day seepage between the southern and central Yampi Shelves may explain the observed differences in the abundance of shallow amplitude anomalies. In the southern area, around Gwydion 1, it appears as though oil has been the dominant hydrocarbon charge. Given the fact that the gas seep measured in the central Yampi Shelf is very dry (and also very large), it may be that relatively more gas is migrating into this region, and, being more mobile, is reaching higher into the sedimentary section. The fact that Mio-Pliocene fault reactivation generally increases towards the Timor Trough may also assist the migration of gas to shallower levels.

Within the Central Yampi Shelf, *the area of gas seepage correlates exactly with the region in which the shallow amplitude anomalies, a major basement lineament and the pinchout of the Cretaceous sands all co-occur*. (see Figure 91). It may be that this part of the Yampi Shelf has received very considerable gas charge from deeper in the basin, and that this charge has been focused via the Cretaceous reservoir sands.

Effects Of Lineaments And Seal Quality?

The presence of the lineament could have facilitated the presence of shallow amplitude anomalies in two ways: either by decreasing fault displacement across itself, by inducing fault relaying (O'Brien et al., 1996a) or by decreasing trap integrity in the shallow section. This could be particularly important in the Mio-Pliocene, when the presence of a NW-trending under-pinning lineament would assist trap failure under a mild NNW extensional regime.

Another important consideration in the interpretation of the amplitude anomalies and seafloor seepage *is the quality and thickness of the sealing facies*. In particular, variations in the sealing quality of the Echuca Shoals Formation along and across the Yampi Shelf could also produce the distribution of amplitude anomalies noted. As discussed earlier, the Echuca Shoals Formation thickens overall towards the south, and becomes sandy towards the east on the Yampi Shelf. *A greater abundance of poor quality sealing facies over the central Yampi Shelf (near Londonderry 1 for example) compared to the region around Gwydion 1 would certainly favour a greater number of amplitude anomalies within the shallow sedimentary section.*

Overall, however, *seal quality certainly cannot be the sole, or even most important factor in controlling* the distribution of the amplitude anomalies. Shallow anomalies are rarer to the south, but this is also consistent with the proven (by Gwydion 1) oil-prone nature of the region. Moreover, the region around Gwydion 1 shows no evidence of present day hydrocarbon seepage, again consistent with a lack of gas. Similarly, the abundance of shallow amplitude anomalies around Londonderry 1 is in accord with the sniffer results, namely that the hydrocarbon charge in this area is dry, thermogenic gas.

On balance, *the preferred interpretation is that the abundance of amplitude anomalies, both shallow and deep, around the Londonderry area is due to an abundant dry gas charge, rather than poor quality seal.* It could be argued, as has been done in the Vulcan Sub-basin (O'Brien & Woods, 1995; O'Brien et al., 1996b), *that relatively lower trap/seal integrity might assist in the preservation of oil columns within this area, by allowing later gas charge to progressively bleed off, rather than displacing the oil.*

Aeromagnetic Data: Yampi Shelf & Timor Sea

In 1995, World Geoscience Corporation (WGC) of Perth, Western Australia, carried out a high resolution aeromagnetic acquisition program over the Yampi Shelf. Data were acquired at a 400 m traverse spacing in a north-south flight direction. Tie-lines were flown east-west, at a 1,200 m spacing. The flying height was 100 m. The location of these data, in relation to the YST seismic survey data, is shown in Figure 98.

Other aeromagnetic data available for the Yampi Shelf and surrounds includes a regional AGSO survey acquired in 1990 over the Vulcan Sub-basin (2,500 m line spacing; see Wellman & O'Brien, 1991; O'Brien et al., 1992; O'Brien, 1993; O'Brien et al., 1993) and AGSO regional data (800 m line spacing) which were acquired during the last three years over the onshore Kimberley Block and its immediate offshore extension.

For the purposes of this study, the WGC Yampi Shelf data, plus the regional AGSO data sets, have been integrated in a general manner with the YST seismic interpretation, to provide a framework for establishing a better understanding of the regional seismic grid. *This integration is only meant to be cursory*; a more detailed study is presently being undertaken as part of AGSO's ongoing Timor Sea studies. The results of these detailed studies will be forwarded to all entitled companies as they become available (first and second quarter, 1997).

The aeromagnetic images presented in the report are as follows:

- A digital merge of the onshore and offshore regional data sets with the high resolution Yampi Shelf data (Colour; NW illumination; Reduced To Pole [RTP]). Figure 99; Enclosure 19.
- Total magnetic intensity (Grey scale; NW illumination; Reduced To Pole [RTP]). Figure 100.
- Total magnetic intensity, Pseudo Depth Slice 3 (Grey scale; NW illumination; Reduced To Pole [RTP]). Figure 101.
- Total magnetic intensity, Pseudo Depth Slice 2 (Colour; NW illumination; Reduced To Pole [RTP]). Figure 102.
- Total magnetic intensity, First Vertical Derivative with YST seismic positional data (Colour; NW illumination; Reduced To Pole [RTP]). Figure 103.

Aeromagnetic Observations

The digital magnetic merge (Figure 99; Enclosure 19) summarises much of the regional information in the magnetic data set. Prominent, NE-trending Proterozoic fracture systems are evident within the

Kimberley Block in the southern part of the image. The most prominent of these corresponds to 'HL 0' of O'Brien et al. (1996a) and appears to be responsible for the 'flipping' in the polarity of the Late Devonian/Early Carboniferous Petrel Sub-basin Rift System to the north-east.

The conjugate set to HL 0 is evident within the high resolution magnetic data on the Yampi Shelf. There, narrow, high frequency, NW-trending lineaments extend out from the Kimberley Block . It is clear that these NW-trending lineaments often, but not always, separate zones of quite different total magnetic intensity (O'Brien et al., 1996a). Magnetic modelling work (Nash & Belford, 1996) indicate that the high frequency nature of these lineaments is due to the presence of dolerite dykes along their length (within the Proterozoic succession). The fact that total magnetic intensity can change dramatically across these lineaments, such is the case with 'NW 0', suggests that they some are essentially deep-seated, through-going features, even though the dolerites themselves probably occur within 2,000 m of the surface. The deep-seated nature of many of these major fracture systems is supported by recent work on the onshore Kimberley Block (Peter Gunn; AGSO pers. com. 1996).

A very prominent series of NW-trending lineaments, with associated intrusions, extends from the northern Yampi Shelf out across the Vulcan Sub-basin. O'Brien (1993) and O'Brien et al. (1993) designated this fracture system and proposed that it was a fundamental Proterozoic fracture system which acted to separate the Vulcan sub-basin from the Browse Basin to the south. This fracture system has been designated as 'NW 1' on Figure 99/Enclosure 19, which is the same nomenclature previously used by O'Brien (1993) and O'Brien et al. (1993) for this feature.

Prominent NE-trending fractures are also evident in the Yampi Shelf aeromagnetic data. These probably represent the (Proterozoic) conjugate set to the north-west trending set, though these may also have been reactivated as normal extensional faults in the Palaeozoic and Mesozoic.

The complexity of the basement fabric and composition within the Yampi Shelf area is highlighted in Figures 100-103. The NW-trending grain is obvious on the two grey-scales (Figure 100, 101). Note the prominent intrusive (here informally designated the 'Hamlet' intrusive), which forms part of the NW 1 fracture and intrusive complex, on Figures 101 and 102 (north-western part of image). Note also that the definition of the high frequency fractures decreases rapidly along strike in either direction from the Hamlet intrusive. This loss of resolution is due to the fact that basement is rapidly faulted down to the north-west through this area, and consequently the intra-basement sources become too deep to be reliably imaged (at that frequency). Importantly, this observations shows that NW 1 is actually located at the intersection of a NW-trending basement lineament and a NE-trending, major extensional fault system. Similarly, another major intrusive is present to the north-west, where NW 1 intersects the bounding fault on the south-eastern flank of the Vulcan Sub-basin (O'Brien, 1993; see also Figure 99/Enclosure 19). A similar correspondence between fracture systems/accommodation zones and igneous activity is well-documented from the East African Rift (Lambiase and Bosworth, 1995).

Basement lineament NW 1 appears to be the most fundamental in this area. Reasons for this include:

- The high frequency lineaments which in part define NW 1 are strong.
- NW 1 is characterised by igneous intrusions along its length.
- It separates two basin provinces, namely the Browse Basin and the Vulcan Sub-basin, which have quite different extensional and subsidence histories (O'Brien, 1993; O'Brien et al., 1993).
- Examination of seismic tie line YST 001 shows that the area of relatively high, rugose basement relief actually terminates through the vicinity of NW 1. The south-western boundary of this basement feature is located outside the area covered by the Yampi Shelf magnetic data.

Lineament NW 0 separates two regions with quite different total magnetic intensities, which implies that it is deep-seated. Nevertheless, no major intrusives are present along NW 0.

Implications For Exploration

The Proterozoic basement rocks which underpin the Yampi Shelf are extremely heterogeneous and are dominated by a strong, north-west trending fracture/lineament system. From an exploration standpoint, determining the location of these lineaments is important, particularly given the relatively widely-spaced seismic line spacing presently available for the Yampi Shelf. Recent work on the control that basement composition and fabric exerts on the development of extensional structures (O'Brien et al., 1996a) has shown that even very subtle, pre-existing basement discontinuities (or 'hard links') can act to strongly relay fault displacement, or even cause polarity flips along strike. Since *hard links often result in fault throw increasing progressively away from them, they always produce cross-basinal highs* which are important from a migration and drainage viewpoint (O'Brien et al., 1996a). Similarly, the Proterozoic (~1,700 Ma?) dolerites within the fractures systems would have weathered out quickly, resulting in the formation of topographic lows along their length (eg. HL 0, HL 1, the Prince Regent River; O'Brien et al., 1996a).

Thus, particularly during the Early Permian (terrestrial) extensional phase, individual hard links would have potentially helped to localise both silici-clastic input into the rift systems, as well as the position of the relay zones/ramps which would have carried the sediment down into the rift axis.

The YST seismic grid is too broad to allow such concepts to be fully tested. Fault displacements over much of the shelf, particularly in the inboard regions, are generally small, with a strong landward-dipping component. As such, it is impossible to reliably 'carry' many of these faults between adjacent seismic lines:- these faults could either relay across the basement lineaments, or pass straight through them (though relaying seems more likely). Nevertheless, some of the larger, more basinward faults can be 'carried' between lines with some confidence, which allows the influence of the basement grain and composition to be established.

An attempt to carry a few of the more significant faults is shown on Figure 104/Enclosure 20. It is clear from Figure 104/Enclosure 20 that a region of relatively well-defined, large displacement faults, which are evident on lines YST 007-012, die out rapidly across NW 1. Along strike from these faults, across NW 1, only a few scattered, and apparently largely discontinuous, small displacement faults are present. A fundamental change in structural/basin style accompanies the transition across NW 1. Through the vicinity of the large displacement faults (YST 007-012), a well-developed series of grabens and horsts is present (Figure 105). Across NW 1, however, the decreasing fault displacement produces a seaward-dipping ramp geometry (Figure 106).

It is likely that the Early Permian fault displacement which has been 'lost' across NW 1 was taken up within the very large displacement, southern compartment of the proto-Vulcan Sub-basin (Figure 104/Enclosure 20), particularly along the south-eastern fault zone. The fault displacement probably simply 'jumped' approximately 40 km to the north-west in order to balance the extension across the extensional system.

The transition between the large displacement and small displacement rift segments on the Yampi Shelf effectively takes place between seismic lines YST 012 and -013. Interestingly, this also effectively marks the northern limit of the common seismic amplitude anomalies (Figure 94; Enclosure 16). Almost no amplitude anomalies were mapped through the small displacement rift segment, whereas numerous anomalies were present along the large displacement fault system. Possible explanations for this are as follows.

Case I: Palaeozoic Source

The small displacement rift segment is effectively a flexural basement ramp which is 'open' to the north-west. Consequently, it is likely that any Permian or Carboniferous source rocks through this rift segment would be of relatively poor quality. As such, the potential for *local generation* of hydrocarbons might well be low, which could explain the lack of amplitude anomalies. Moreover, *the lack of significant basement relief and/or structuring through this region means that the potential to trap any hydrocarbon is also low* .

If the hydrocarbons present across the Yampi Shelf (including both those producing amplitude anomalies and sniffer anomalies) *migrated long distances* from more basinward positions, then the large displacement fault which is present along the south-eastern margin of the Vulcan Sub-basin (ie. the Anderdon trend) may have effectively prevented hydrocarbon migration up onto the Yampi Shelf. Effectively, the relayed fault displacement (to the north-west) across NW 1 may have produced its own migration 'shadow' zone for the more inboard Yampi Shelf. This is in spite of the fact that the Yampi Shelf through this area appears as a basement ramp, which, simplistically, would appear to favour long distance migration.

In contrast, the abundance of amplitude anomalies within the large displacement rift segment could be due to the presence of favourable conditions for Permian or Carboniferous source deposition and preservation in the faulted grabens (assuming local generation), or the fact that fault displacement is more 'evenly distributed' across the extensional system, which facilitates long distance migration. A combination of both processes would appear likely.

Case II: Mesozoic Source

If the hydrocarbons responsible for the amplitude anomalies and present day seepage are Jurassic in age, then similar arguments apply. It is likely that the very large displacement faults along the Anderdon Trend on the south-eastern margin of the Vulcan Sub-basin would prevent hydrocarbon migration across the basement ramp to the south-east. Similarly, the more distributed nature of the extension within the large displacement rift segment between Rob Roy 1 and Londonderry 1 might facilitate migration from the Jurassic (or Triassic?) depocentres to the north-west.

Hydrocarbon Migration Into NW 1?

Since fault displacement decreases to the northwest, across, and as a result of the presence of, the NW 1 Proterozoic lineament, this results in NW 1 being a cross-basinal high. This high extends right across the Vulcan Sub-basin (O'Brien, 1993; O'Brien et al., 1993; O'Brien et al., 1996a). As such, the decreasing fault displacement produces a natural migration fairway/gradient which could funnel hydrocarbons from the horst and graben province in the central Yampi Shelf (ie. around Londonderry 1) northeast, towards and along the strike of NW 1. If traps are present in this zone of decreasing fault displacement, this might represent an attractive play.

Summary Of Structural Development: Yampi Shelf

The Yampi Shelf has developed over relatively shallow, highly structured Proterozoic basement. Basement structure appears to have controlled at least the major components of rift segmentation, with the most obvious example being the loss of fault throw, and the attendant change in structural style, across the NW 1 lineament.

The principal extensional episode which is evident across the Yampi Shelf was in the Late Carboniferous/Early Permian. Well-developed Early Permian half-grabens, such as though within which the Rob Roy 1 well lies (Figure 107), are common on the outboard parts of the shelf. The Yampi Shelf, because of its inboard position, provides one of the best locations along the Western Australian margin to see the effects of this extension. These Early Permian extensional structures developed during a period of intense glaciation, and it is clear that a combination of the pre-existing basement grain (which controlled extensional development and silici-clastic input), the rift structures themselves, and glacial sedimentary environments, have all strongly shaped the Yampi Shelf. Landward-dipping tilt blocks, generally with small fault displacement, dominate the inboard part of the shelf. More outboard, the structural architecture can range from horst and graben, such as around the Londonderry 1 well (within the large displacement province) to flexural basement ramp, inboard from the Vulcan Sub-basin.

There is little evidence of fault reactivation from the Early Permian until the Callovian, when some reactivation is evident. Similarly, some Mio-Pliocene fault is evident but this appears very mild throughout the Yampi Shelf, particularly in comparison to the Vulcan Sub-basin (see O'Brien & Woods, 1995; O'Brien et al., 1996b).

Summary Of Findings

The interpretation of the Yampi Shelf Tie (YST) seismic data and the associated geological review, and their integration with geochemical sniffer and aeromagnetic data sets, have resulted in a number of new conclusions regarding the prospectivity of the Yampi Shelf, Prudhoe Terrace and Caswell Sub-basin.

Biostratigraphic revisions have highlighted an older section underlying the Rob Roy Graben (and possibly also the Prudhoe Terrace) of Late Carboniferous to Early Permian in age. This interval, which relates to a major extensional episode along the entire Western Australian margin, has also been identified as having favourable source rock characteristics and maturity across much of this area. It could be an alternative source for the recent Gwydion 1 discovery oil, which negates the need for the proposed long distance migration of Jurassic oil from the Caswell Sub-basin.

Various play types have been recognised from the YST seismic grid, ranging from the conventional horst block plays on the Prudhoe Terrace and Caswell Sub-basin, to stratigraphic pinchouts and drape features around basement highs and tilted fault blocks on the Yampi Shelf. Amplitude anomalies and possible direct hydrocarbon indicators are associated with some of these plays. In particular, structures within the Rob Roy Graben have amplitude anomalies in the Echuca Shoals and Jamieson Formations (traditionally seen as sealing lithologies) which are interpreted to occur within the distal parts of sands being shed from the Yampi Shelf high.

Inner shelf sands are interpreted from the lower part of the Jamieson Formation to lie within gazetted areas of the Yampi Shelf, and have associated amplitude anomalies. These seem to be best developed around the 'headland' basement feature behind Londonderry 1. Other amplitude anomalies are seen within this formation on various lines of the Yampi Shelf Tie survey.

From a regional perspective, the northernmost part of the Yampi Shelf, inboard from the Vulcan Sub-basin, appears to be the least prospective. The relaying of Early Permian fault displacement across a major, NW-trending Proterozoic lineament has produced a gently dipping, flexural basement ramp, whereas outboard, along the Vulcan Sub-basin boundary zone, the attendant (matching) increased fault displacement has produced a potential barrier to hydrocarbons migrating to the northeast, onto the flexural ramp margin.

Within the central part of the Yampi Shelf, around the Londonderry 1 well location, a horst and graben structural style predominates. Here, amplitude anomalies are common throughout the sedimentary section. Hydrocarbons are actively seeping from this area, with methane values in excess of 300 ppm being measured in the water column. This seepage is very dry, however, which suggests that it originated from a dry gas source. The sniffer results, when combined with the distribution and nature of the amplitude anomalies, suggest that the central part of the Yampi Shelf is experiencing significant gas charging at the present day, which presents a significant exploration risk. However, it should be considered that if seal integrity is indeed lower in this area, it may be a positive factor, since it might allow the later gas charge to progressively bleed off, rather than displacing any pre-existing oil accumulation. Lower seal integrity could, however, assist It may be, however, that decreased seal integrity through this area is contributing to the presence of shallow amplitude anomalies, though this is not considered to be a primary, causal factor. Fault displacement through this province decreases to the northwest, across (and as a result of the presence of) the northwest trending NW 1 Proterozoic lineament; this results in NW 1 being a cross-basinal high, which actually extends right across the Vulcan Sub-basin (O'Brien et al., 1996a). As such, a natural migration fairway exists which could funnel hydrocarbons from the horst and graben province northeast, towards and along the strike of NW 1. If traps are present in this zone of decreasing fault displacement, this might represent an attractive play.

Amplitude anomalies are present to the south, but these appear to be principally deeper in the sedimentary section. As this region displays no present day hydrocarbon seepage, and given the presence of oil (and some gas) in Gwydion 1, then it appears likely that a combination of a less gas-prone charge, and perhaps higher seal integrity, might characterise this region.

To summarise:

- The ***northern Yampi Shelf*** has significant risks on ***migration, trap and seal***.
- The ***central Yampi Shelf*** is characterised by ***a significant risk of gas flushing***, with a possible risk on ***seal***. Traps are well-developed. Lower trap integrity might also act to reduce risk of gas flushing.
- The ***southern Yampi Shelf*** appears to possess a **more oil-prone charge**, combined with ***higher trap integrity*** (no leakage). Given that gas was co-produced with the oil from the Gwydion 1 well, and considering the trap integrity appears relatively high, then ***some risk of gas flushing of pre-existing oil accumulations*** by later gas is present.

Recommendations For Further Work

The following recommendations are a suggestion of areas where additional work could be directed to expand, or provide additional clarification to, the conclusions of the interpretation report presented here.

- A thorough biostratigraphic review of wells in the vicinity of the Yampi Shelf Tie seismic survey would provide additional control for a more detailed sequence stratigraphic investigation of the Yampi Shelf and associated areas.

- Further investigation (i.e. AVO work) of the various amplitude anomalies detailed in the report may provide some clarification as to whether these are direct hydrocarbon effects or produced as a result of tuning effects.

- A clarification of the stratigraphy of the Browse Basin is long overdue, but specifically the Late Carboniferous - Early Permian interval encountered in Rob Roy 1 warrants particular attention due to its identification as a potential source interval.

- Resampling of the lower intervals from the Rob Roy 1 well for geochemical analysis in light of the limited data points available at present, would provide additional characterisation of this interval.

- Additional sniffer and perhaps Airborne Laser Fluorescence (ALF) acquisition along the length of the Yampi Shelf, to further characterise the nature/phase of the leaking hydrocarbons, and the integrity of the various provinces.

- Integration of high density seismic surveys with the aeromagnetic data, to determine whether the Proterozoic lineaments always, often, or rarely, induce fault relaying.

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Appendix 1:

Time - Depth data for wells used in interpretation

Asterias 1

Mapped Horizon	Depth (m.K.B.)	Depth (m.S.S.)	Calibrated Two Way Time (msecs.) [Seismic time]
Sea Floor	195	178	240 [261.4]
Base Miocene	928	911	814 [808.9]
Base Tertiary	1913	1896	1420 [1415.4]
Turonian unc.	2945	2928	2024 [2025.1]
Albian/Aptian unc.	3395	3378	2300 [2305.3]
Valanginian unc.	3647	3630	2431 [2435.4]
Kimmeridgian unc.	-	-	-
Callovian unc.	-	-	-
Top Permian	-	-	-
Basement	-	-	-
T.D.	4402	4385	2771 [2770.9]
Summary Info:	Operator	BHPP	
	Lat. & Long.	-13:09 06.84”	X: 621 387
		124:07 11.64”	Y: 8 545 746
	K.B. (m.)	17	
	Sea floor (m.)	178	
	Spud date	15 Jun. 1987	
	Compl. Date	16 Sep. 1987	
	Status	P & A	

Buccaneer 1

Mapped Horizon	Depth (m.K.B.)	Depth (m.S.S.)	Calibrated Two Way Time (msecs.) [Seismic time]
Sea Floor	171	155.8	209.8 [205.3]
Base Miocene	731	715.8	668.7 [677.0]
Base Tertiary	1525	1509.8	1244.9 [1247.8]
Turonian unc.	1899	1883.8	1520.7 [1495.0]
Albian/Aptian unc.	2597	2581.8	2006.3 [2013.7]
Valanginian unc.	2825	2809.8	2132.2 [2129.4]
Kimmeridgian unc.	3100	3084.8	2280.0 [2281.0]
Callovian unc.	3524	3508.8	2352.6 [2340.3]
Top Triassic	3395	3379.8	2424.3 [2424.3]
Basement	-	-	-
T.D.	3574	3558.8	2506.0 [2506]
Summary Info:	Operator	Shell	
	Lat. & Long.	-13:39 44.65” 123:57 20.70”	X: 603 366 Y: 8 489 402
	K.B. (m.)	15.2	
	Sea floor (m.)	156.1	
	Spud date	24 Feb. 1990	
	Compl. Date	12 Apr. 1990	
	Status	P & A	

Heywood 1

Mapped Horizon	Depth (m.K.B.)	Depth (m.S.S.)	Calibrated Two Way Time (msecs.) [Seismic time]
Sea Floor	35	25	
Base Miocene	808	798	
Base Tertiary	1410	1400	
Turonian unc.	2278	2268	
Albian/Aptian unc.	3093	3083	
Valanginian unc.	3198	3188	
Kimmeridgian unc.	4240	4230	
Callovian unc.	-	-	
Top Permian	-	-	
Basement	-	-	
T.D.	4572	4562	
Summary Info:	Operator	B.O.C.	
	Lat. & Long.	-13:27 45.66”	X:
		124:04 00.21”	Y:
	K.B. (m.)	10	
	Sea floor (m.)	35	
	Spud date	7 Apr. 1974	
	Compl. Date	14 Jun. 1974	
	Status	P & A	

Londonderry 1

Mapped Horizon	Depth (m.K.B.)	Depth (m.S.S.)	Calibrated Two Way Time (msecs.) [Seismic time]
Sea Floor	103	90	121.2 [123.8]
Base Miocene	529	516	478.5 [473.5]
Base Tertiary	707	694	632.3 [625.6]
Turonian unc.	769	756	688.6 [678.1]
Albian/Aptian unc.	1005	992	896.5 [894.3]
Valanginian unc.	-	-	-
Kimmeridgian unc.	-	-	-
Callovian unc.	-	-	-
Top Permian	-	-	-
Basement	1135	1122	988.0 [984.9]
T.D.	1145	1132	991.6 [991.7]
Summary Info:	Operator	Woodside	
	Lat. & Long.	-13:36 53.17”	X: 663 562
		124:30 42.59”	Y: 8 494 363
	K.B. (m.)	13	
	Sea floor (m.)	90	
	Spud date	28 Sep. 1973	
	Compl. Date	6 Oct. 1973	
	Status	P & A	

Productus 1

Mapped Horizon	Depth (m.K.B.)	Depth (m.S.S.)	Calibrated Two Way Time (msecs.) [Seismic time]
Sea Floor	164	141	191.3 [191.2]
Base Miocene	694	671	630.1 [631.6]
Base Tertiary	1153	1130	954.6 [949.3]
Turonian unc.	1703	1680	1350.9 [1355.9]
Albian/Aptian unc.	2003	1980	1577.3 [1576.8]
Valanginian unc.	-	-	-
Kimmeridgian unc.	-	-	-
Callovian unc.	-	-	-
Top Permian	2013	1990	1583.3 [1587.8]
Basement	-	-	-
T.D.	2590	2567	1842.1 []
Summary Inf.:	Operator	Mobil	
	Lat. & Long.	-13:16 38.21”	X: 647 614.8
		124:21 45.54”	Y: 8 531 792.4
	K.B. (m.)	23	
	Sea floor (m.)	142	
	Spud date	12 Oct. 1991	
	Compl. Date	15 Dec. 1991	
	Status	P & A	

Prudhoe 1

Mapped Horizon	**Depth (m.K.B.)**	**Depth (m.S.S.)**	**Calibrated Two Way Time (msecs.) [Seismic time]**
Sea Floor	175	145	
Base Miocene	784	754	
Base Tertiary	1208	1178	
Turonian unc.	1797	1767	
Albian/Aptian unc.	2333	2303	
Valanginian unc.	2715	2685	
Kimmeridgian unc.	2888	2858	
Callovian unc.	-	-	
Top Permian	-	-	
Basement	-	-	
T.D.	3322	3292	
Summary Inf.:	Operator	Bocal	
	Lat. & Long.	-13:44 55.75”	X:
		123:51 51.13”	Y:
	K.B. (m.)	30	
	Sea floor (m.)	175	
	Spud date	13 Sep. 1974	
	Compl. Date	8 Nov. 1974	
	Status	P & A	

Rob Roy 1

Mapped Horizon	Depth (m.K.B.) [ft]	Depth (m.S.S.)	Calibrated Two Way Time (msecs.) [Seismic time]
Sea Floor	111.5 [366]	102.1	137.5 []
Base Miocene	568 [1859]	558.6	530.0 []
Base Tertiary	700 [2296]	690.6	640.8 []
Turonian unc.	762 [2500]	752.6	704.0 []
Albian/Aptian unc.	1155 [3789]	1145.6	1055.0 []
Valanginian unc.	1343 [4406]	1333.6	1200.1 []
Kimmeridgian unc.	-	-	-
Callovian unc.	1450 [4854]	1440.6	1290.1 []
Top Permian	1571 [5159]	1561.6	1354.0 []
Basement	2256 [7400]	2246.6	1680.4 []
T.D.	2286 [7498]	2276.6	1689.6 []
Summary Info:	Operator	Woodside	
	Lat. & Long.	-13:58 15.58”	X: 629 524
		124:11 57.13”	Y: 8 455 167
	K.B. (m.)	9.4	
	Sea floor (m.)	111.5	
	Spud date	27 Jan. 1972	
	Compl. Date	25 Feb. 1972	
	Status	P & A