U. S. Department of the Interior

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A TOTAL PETROLEUM SYSTEM OF THE BROWSE BASIN, AUSTRALIA: LATE JURASSIC, EARLY CRETACEOUS-MESOZOIC

by

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FOREWORD

This report was prepared as part of the World Energy Project of the U.S. Geological Survey. In the project, the world was divided into 8 regions and 937 geologic provinces. The provinces have been ranked according to the discovered oil and gas volumes within each (Klett and others, 1997). Then, 76 "priority" provinces (exclusive of the U.S. and chosen for their high ranking) and 26 "boutique" provinces (exclusive of the U.S. and chosen for their anticipated petroleum richness or special regional economic importance) were selected for appraisal of oil and gas resources. The petroleum geology of these priority and boutique provinces is described in this series of reports.

The purpose of this effort is to aid in assessing the quantities of oil, gas, and natural gas liquids that have the potential to be added to reserves within the next 30 years. These volumes either reside in undiscovered fields whose sizes exceed the stated minimum-field-size cutoff value for the assessment unit (variable, but must be at least 1 million barrels of oil equivalent) or occur as reserve growth of fields already discovered.

The total petroleum system constitutes the basic geologic unit of the oil and gas assessment. The total petroleum system includes all genetically related petroleum that occurs in shows and accumulations (discovered and undiscovered) that has been generated by a pod or by closely related pods of mature source rock and which exists within a limited mappable geologic space, together with the essential mappable geologic elements (source, reservoir, seal, and overburden rocks) that control the fundamental processes of generation, expulsion, migration, entrapment, and preservation of petroleum. The minimum petroleum system is that part of a total petroleum system encompassing discovered shows and accumulations together with the geologic space in which the various essential elements have been proved by these discoveries.

An assessment unit is a mappable part of a total petroleum system in which discovered and undiscovered fields constitute a single relatively homogenous population such that the chosen methodology of resource assessment based on estimation of the number and sizes of undiscovered fields is applicable. A total petroleum system might equate to a single assessment unit. If necessary, a total petroleum system may be subdivided into two or more assessment units such that each assessment unit is sufficiently homogeneous in terms of geology, exploration considerations, and risk to assess individually.

A graphical depiction of the elements of the a total petroleum system is provided in the form of an event chart that shows the time of deposition of essential rock units; the time processes, such as trap formation, necessary to the accumulation of hydrocarbons took place; the critical moment in the total petroleum system; and the preservation time, if any.

A numeric code identifies each region, province, total petroleum system, and assessment unit; these codes are uniform throughout the project and will identify the same item in any of the publications. The code is as follows**:**

Example

Region, single digit	**3**
Province, three digits to the right of region code	3**162**

Total Petroleum System, two digits to the right of province code 3162**05**

Assessment unit, two digits to the right of petroleum system code 3162050**4**

The codes for the regions and provinces are listed in Klett and others, 1997.

Oil and gas reserves quoted in this report are derived from Petroleum Exploration and Production database (Petroconsultants, 1996) and other area reports from Petroconsultants, Inc., unless otherwise noted.

Figure(s) in this report that show boundaries of the total petroleum system(s), assessment units, and pods of active source rocks were compiled using geographic information system (GIS) software. Political boundaries and cartographic representations were taken, with permission, from Environmental Systems Research Institute's ArcWorld 1:3 million digital coverage (1992), have no political significance, and are displayed for general reference only. Oil and gas field centerpoints, shown on this(these) figure(s), are reproduced, with permission, from Petroconsultants, 1996.

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Petroconsultants, 1996, Petroleum Exploration and Production Database : Petroconsultants, Inc., P.O. Box 740619, 6600 Sands Point Drive, Houston TX 77274-0619, USA or Petroconsultants, Inc., P.O. Box 152, 24 Chemin de la Mairie, 1258 Perly, Geneva,

ABSTRACT

The Browse Basin Province 3913, offshore northern Australia, contains one important petroleum system, Late Jurassic, Early Cretaceous-Mesozoic. It is comprised of Late Jurassic through Early Cretaceous source rocks deposited in restricted marine environments and various Mesozoic reservoir rocks deposited in deep-water fan to fluvial settings. Jurassic age intraformational shales and claystones and Cretaceous regional claystones seal the reservoirs. Since 1967, when exploration began in this 105,000 km^2 area, fewer than 40 wells have been drilled and only one recent oil discovery is considered potentially commercial. Prior to the most recent oil discovery, on the eastern side of the basin, a giant gas field was discovered in 1971, under a modern reef on the west side of the basin. Several additional oil and gas discoveries and shows were made elsewhere. A portion of the Vulcan sub-basin lies within Province 3913 where a small field, confirmed in 1987, produced 18.8 million barrels of oil (MMBO) up to 1995 and has since been shut in.

Numerous untested structures and other prospects, along with proven oil and gas accumulations, provide for many exploration opportunities and the potential for this area to be a significant contributor to the petroleum resources of Australia. Development of infrastructure for this remote location will come with the discovery of additional reserves both here and in the adjacent Bonaparte Gulf and Timor Sea areas.

INTRODUCTION

One Total Petroleum System(TPS) involving Late Jurassic through Early Cretaceous source rocks and Mesozoic reservoir rocks has been identified in the Browse Basin Province 3913, and called the Late Jurassic, Early Cretaceous-Mesozoic TPS (Fig. 1). Major subsidence in this Mesozoic basin occurred in the Cretaceous when restricted marine conditions provided for thick and high quality source rock deposition. Maturation of this source rock is greatest in the northern portions of the area but combined vertical fault migration and long-range lateral migration have sourced discoveries in the northern, southern, central, and far eastern portions of the basin. The area is sparsely explored. One oil discovery in 1997 is estimated to double the proven reserves and has increased interest in the Browse Basin as a potentially significant petroleum province of offshore Australia. Additional hydrocarbon source rocks of Triassic and Early Jurassic age are possible. Contributions from these source rocks are not well documented.

PROVINCE GEOLOGY

The Browse Basin Province 3913 is situated offshore of Western Australia along the northern coast (Fig. 1). Most of the province lies in the Timor Sea. It includes the Territory of Ashmore and Cartier Islands, Australia (Fig. 2). The province is bounded to the north by the waters of Indonesia, to the southwest by the Northwest Shelf Province 3948, to the northeast by the Bonaparte Gulf Basin Province 3910 and to the southeast by the offshore part of the Kimberley Basin craton. Most of the province lies within the jurisdiction of offshore Western Australia; the remainder within the waters of the Territory of Ashmore and Cartier Islands (Fig. 2).

The Browse Basin covers an area of approximately 105,000 km^2 between the Scott Plateau and the Ashmore Platform to the west and north and offshore portions of the Kimberley Block to the east (Butcher 1989) (Fig. 2). The Scott Plateau covers another 80,000 km^2 (Stagg, 1978).

Main units of the province include, from the eastern edge of the Scott Plateau, the Seringapatam sub-basin or outer Browse sub-basin, the central or Caswell sub-basin, the inner Browse sub-basin, and the southern portion of the Vulcan sub-basin (Fig. 2). Along the eastern edge of the province, sediments of the Browse Basin onlap subsurface extensions of the Kimberley Block. These extensions are known as the Yampi Shelf, the Leveque Shelf to the south, and the Londonderry High (or Arch) to the north (Fig. 2). A hinge zone on the margin of the Yampi Shelf defines the edge of the Prudhoe structural terrace. Ocean crust of the Argo Abyssal Plain lies west of the Scott Plateau. The Ashmore Platform and the Timor Trough lie to the north (Hocking and others, 1994; Baillie and others, 1994; Haston and Farrelly, 1993; Willis, 1988; Stephenson and Cadman, 1994).

The Kimberley Block consists of approximately 5 to 8 km of Proterozoic basin rocks over approximately 9 km of Archaean rocks (AGSO North West Shelf Study Group, 1994). The Yampi Shelf is composed of Cretaceous and Tertiary sediments that overlie Precambrian basement of the Kimberley Block. Further west, the Prudhoe Terrace consists of steeply dipping Precambrian basement rocks that are onlapped by northeast trending block-faulted Permian sediments, which are in turn onlapped by Late

Jurassic age clastics. Total estimated thickness of Mesozoic strata is 3.5 km. Permian through Jurassic age sediments pinch out on the flanks of the Scott Plateau, which consists of Precambrian and Paleozoic rocks. A thin section of Cretaceous and Recent sediments are present on top of the plateau (Stephenson and others, 1994). The Kimberley Block and the Scott Plateau are considered to be the sources of clastics within the Browse Basin. Portions of the Ashmore Platform were emergent from Late Triassic through Cretaceous and may also have contributed sediment to the province (Bradshaw and Sayers, 1996).

This province is part of the Westralian Supersystem (Bradshaw, 1993) that reaches from the Exmouth Plateau (to the southwest), northeast to Papua New Guinea and links basins that share an history of extension, breakup and sea floor spreading during the Jurassic and Early Cretaceous (Bradshaw and others 1994). The basins of this offshore margin share an overall stratigraphy of Triassic to Cretaceous reservoirs that were sourced primarily by Jurassic rocks, sealed by Cretaceous rocks and overlain by Cretaceous and Tertiary shelf carbonates (Fig. 3).

The Browse Basin began to accumulate sediments in the Carboniferous. Sediments accumulated in the intracratonic basin or continental seaway that formed roughly along the present shelf and connecting the Paleozoic Canning rift basin with the Paleozoic Bonaparte Gulf rift basin around the seaward edge of the Kimberley Block (Stephenson and Cadman, 1994) (Figs. 3 and 4). The majority of subsidence and sediment accumulation occurred in Cretaceous time (Bradshaw and others, 1994). The region received mostly coastal plain, deltaic, and shallow water sediments during Triassic to early Late Jurassic (Oxfordian) times. It was connected north to the Tethys Sea between the Ashmore Plateau and a continental block that included the Scott Plateau (Bradshaw and others, 1994). Occasional marine connections, southwest, to the Rowley sub-basin and a persistent marine passage, north, between the Scott Plateau and the Ashmore Platform are present on maps by Bradshaw and Sayers (1996). Faulting in Triassic time followed by Jurassic rifting, resulted in the separation of a continental block from the Scott Plateau and formation of the Argo Abyssal Plain in Late Jurassic. These events produced northeast-trending tilted fault blocks, subsidence of the central basin, uplift of the Ashmore Platform and Scott Plateau, basalts, tuffs, and volcanics, and a widespread late Middle Jurassic (Callovian) to middle Late Jurassic (Kimmeridgian) breakup unconformity (Willis, 1988; Stephenson and Cadman, 1994). The subsequent drift phase resulted in extensive marine flooding of the Browse Basin that began in the central portions of the basin and eventually flooded highs and the eastern basin margin. The Scott Reef trend was covered by Upper Jurassic (Tithonian) marine claystone. Open ocean circulation occurred in middle Cretaceous with subsidence of the Ashmore Platform and the Scott Plateau. Younger tectonic events in the northern part of the basin are associated with the Timorese Tertiary orogeny.

The Browse Basin contains Permian, Mesozoic and Cenozoic rocks that reach a maximum thickness of 17 km in the central or Caswell sub-basin (Hocking and others, 1994). Approximately 8 km of Late Carboniferous-Early Permian shallow marine, deltaic carbonates, and clastics were deposited adjacent to the Prudhoe terrace. These sediments onlap basement to the southeast, and thin to the northwest. Permian sediments directly overlie eroded Precambrian basement along the eastern flank of the Browse Basin (Stephenson and others, 1994). Deposition in this area ceased with uplift that was associated with the Late Permian Bedout Movement. The Triassic section is approximately 2 km thick in the center of the basin, and consists mainly of Lower Triassic (Scythian) to Middle Triassic (Anisian) marine claystones. Sedimentary rocks on the eastern margin originated as fluvial sands, and deltaic sands and clays. Rocks in the northern areas of the basin include shelf carbonates, shales, and deltaic sandstones. Rocks to the west originated as clays, limes, sandy dolomites, and deltaic sands deposited on a marine shelf. A widespread erosional unconformity formed during Middle to Late Triassic (Ladinian-Carnian) time resulted from tectonic reactivation in the Rowley sub-basin to the south of this province. Transpressional uplift, faulting and block rotation occurred in the Late Triassic-Early Jurassic. Lower-Middle Jurassic sediments are approximately l km thick. Uplift associated with formation of the Argo Abyssal Plain is represented by a Middle to Upper Jurassic (Callovian-Oxfordian) unconformity. Middle and Late Jurassic time was marked by volcanics, which in places overlie the unconformity. A regional claystone, about 1.5 km thick, was deposited during Early to early Late Cretaceous (Valaginian-Cenomanian) time and sealed Jurassic rocks of the Scott Reef area. Regional deposition of carbonates began, in earnest, in the Late Cretaceous (Turonian) across the entire Browse Basin. These marls, calcarenties and calcilutites, deposited in the center of the basin to approximately 3.5 km thick, interfingered with clastics at the northern and northeastern margins. The present carbonate shelf edge lies approximately at the Scott Reef trend.

The southern portions of the Vulcan sub-basin are included in Province 3913. The structure of this sub-basin is traced, from seismic, under the Browse basin where resolution becomes poor (Pattillo and Nicholls, 1990). The Vulcan graben lies between the Ashmore Platform and the Londonderry High (Fig. 4b). The Permian seismic reflector indicates approximately 4,000 m of vertical fault displacement of the Vulcan sub-basin adjacent to the Londonderry High (Pattillo and Nicholls, 1990). Subsidence occurred in two adjacent half grabens in the southern Vulcan sub-basin from Middle Jurassic (Callovian) time to middle Late Jurassic (Kimmeridgian) time. Slower subsidence with widespread deposition continued to Early Cretaceous (Valanginian) time. Pattillo and Nicholls (1990) suggest that submarine fans and fan deltas were deposited along the graben flanks during Late Jurassic subsidence. Post-subsidence deposition prograded northwest from the Londonderry High across to and thinning over the Ashmore Platform.

Stratigraphic nomenclature is not well established and varies among areas and authors (Symonds and others, 1994; Maung and others, 1994). Most authors refer to rock units in time without using stratigraphic names. Nomenclature from the adjacent Bonaparte Gulf area and the Vulcan sub-basin is sometimes applied (Fig. 3).

The presence of the Browse sedimentary basin was recognized from an aeromagnetic survey in 1963. Seismic surveys followed in 1964 and the first well was drilled in 1967 on the Ashmore Platform (Butcher, 1989). Between 1971 and 1997, thirty wells were drilled in the Browse Basin. Water depths of greater than 200 m to 2000 m has impeded exploration (Maung and others, 1994). Seismic data imaging problems beneath the Cretaceous and Tertiary carbonate shelf have been encountered in the Browse Basin. There are reported drilling difficulties due to clay sensitivity, excess pore pressure, and lost circulation in the Tertiary carbonate section can be severe (Willis, 1988).

The Scott Reef giant gas discovery made in 1971, probably the largest gas field in Australia (IKODA Pty Ltd, 1997b), was only the third well drilled in the Browse Basin. Three more gas discoveries, one interpreted gas discovery, three oil discoveries, and one interpreted oil discovery have been made with only one oil discovery considered potentially commercial, Cornea (IKODA Pty Ltd, 1997a) (Table 1).

PETROLEUM OCCURRENCE

Triassic and Jurassic reservoirs account for more than 3130 million barrels of oil equivalent (MMBOE) of recoverable reserves in the Browse Basin and 77 MMBOE in the 3913 province portion of the Vulcan sub-basin. Cretaceous reservoirs account for more than 2.6 billion barrels of oil equivalent (BBOE) in the Browse Basin and 10 MMBOE in the Vulcan sub-basin.

Cornea-1, drilled in 1997, was reported to have found from 600 million barrels of oil (MMBO) to 2.6 billion barrels of oil (BBO) in place (Williamson, 1997; DPIE, 1998). This discovery is considered to be the first commercially producible oil in the Browse Basin. It confirms a new play trend located along the far eastern edge of the basin that was first indicated by Gwydion-1 drilled in 1995. The Cornea discovery proves that very large volumes of oil have been generated in the mature central portions of the basin and it confirms there has been long-range migration and charge. Gwydion-1 tested a compaction structure draped over a basement high similar to Cornea and located roughly along the same trend. Both discoveries are visible as seismic anomalies and hydrocarbons are detected in the water column at Cornea.

The Scott Reef gas discovery targeted a high fault block structure on the western edge of the Browse Basin. Gas and condensate are present in Jurassic rocks with shows in Triassic rocks. North Scott Reef-1 is an extension of the same structure and Brecknock-1 gas discovery is located to the south along the same trend. The Brecknock-1, Brewster-1A, and Echuca Shoals-1 gas discoveries are Jurassic rocks formed into drape anticlines over fault blocks.

Arquebus-1, just southwest of Lombardina, was drilled in 1991 in the southern portion of the Browse Basin. This gas discovery tested middle to upper Jurassic sandstones, which are situated in a three-way closure. Testing confirmed a 51 m gross oil column with a 45 m gross active oil column and a possible 105 m gross oil column interpreted from logs (Haston and Farrelly, 1993).

In the central Browse Basin oil shows are from Cretaceous sandstones in Caswell-1 and -2.

Several oil and gas discoveries have been made in the Vulcan sub-basin that trends southwest-northeast and continues northeast into Province 3910. O'Brien and others (1993) suggest that Vulcan sub-basin discoveries appear to be located along northwest and north-south trending faults where these trends intersect northeast/east-northeast trending structural grain. This intersection is thought to be a result of complex interactions of the Proterozoic/Late Carboniferous-Early Permian fault sets with the varying Mesozoic stress directions. Discoveries in the province portion of the Vulcan Graben are: 1) Puffin, oil in Cretaceous shallow marine sandstones; 2) Skua, oil and gas in Cretaceous and Jurassic intervals; 3) Montara oil and gas; and 4) Tahbilk, gas in Jurassic deltaic rocks.

Skua Field was discovered in 1986 and confirmed in 1987. Hydrocarbons occur in high quality, submarine fan sandstones of Early Jurassic age and are trapped in a steeply dipping fault block. The field is trapped against the bounding fault of the graben, which offsets Early Jurassic age rock against Cretaceous Santonian age rock. A gas cap of 28 m and an oil leg of 46.5 m in reservoirs of 22 % porosity was reported by Osborne, (1990). Cumulative production reported in 1995 was 18.8 MMBO and since then production facilities have been moved off site due to rising production costs (World Oil, 1997). This is the only production to date from this province.

Caswell–1, drilled in 1977, was the first recorded oil discovery in the Browse Basin. Initial production (IP) was reported as 201 barrels of oil per day (bopd) of 46° API gravity oil (Butcher, 1989). The Scott Reef-1 discovery was reported as 49°-54° API gravity hydrocarbons at an IP of 100 m^3 of gas/condensate per day (Willis, 88). Porosity at Gwydion-1 averages 26%, and 30.5° API oil was recovered (Spry and Ward, 1997). Barcoo-1 in the far southeastern part of the province, has total organic carbon (TOC)s as high as 4.7wt%, and hydrogen index (HI)s from 23-269 reported by Bradshaw and others (1994).

In the Vulcan sub-basin, Puffin oil has an API of 40° and reservoir porosity of 21.5% and Skua field oil has an API of 43.4°, reservoir porosity of 16-20% and permeability of 950 millidarcies (mD).

Migration paths to discoveries in the eastern parts of the Browse Basin are described by Spry and Ward (1997) as vertical up the marginal fault system and lateral within Cretaceous sands. Hydrocarbons migrate updip to traps draped over basement highs and stratigraphic pinchouts against basement. Migration paths within the Vulcan sub-basin would primarily be along faults to structural traps that overlie and are adjacent to mature source rocks within the graben or to sandstones within the source rock intervals. Accumulations in the western parts of the basin may have been fed across and along faults that control the structural highs of Scott Reef from source rocks in the Caswell sub-basin to the east or possibly the outer sub-basin to the west and north. If discoveries at Scott Reef are associated with possible source rocks of Permian and Triassic age (Stephenson and Cadman, 1994) vertical migration of hydrocarbons along fault would be likely.

SOURCE ROCK

In the Browse Basin Province 3913 the Late Jurassic, Early Cretaceous-Mesozoic TPS is characterized by source rocks of Late Jurassic and Early Cretaceous age and potential and proven reservoir rocks that range in age through the entire Mesozoic (Fig. 5).

Willis (1988) and Haston and Farrelly (1993) report potential source rocks throughout the Middle Jurassic to Lower Cretaceous section and speculate the source potential of the Triassic rocks is probably gas. Bradshaw and Sayers, (1996) map an extension of deep-water, anoxic, marine conditions that existed in the Late Jurassic, from the north, between the exposed Ashmore Platform and the exposed Londonderry High. A Cretaceous-Jurassic petroleum system has been suggested with hydrocarbon sources in the Jurassic upper and lower Vulcan formations and the Cretaceous Echuca Shoals Formation (DPIE, 1998). This possible petroleum system would source hydrocarbon accumulations in the Triassic Nome Formation at Scott Reef, Jurassic Plover Formation at Brecknock, North Scott Reef, and Skua, Montara Formation at Montara, and Tahbilk, Cretaceous Echuca Shoals Formation at Cornea and Gwydion, and the Cretaceous Puffin Formation at Puffin (DPIE, 1998) (Fig.3). Stephenson and Cadman (1994) suggest that Middle to Late Triassic rocks may have sourced gas accumulations at Scott Reef.

Source rocks of late Middle Jurassic (Callovian) to Early Cretaceous (Valanginian) time are mainly confined to the Vulcan sub-basin and were deposited during Vulcan subsidence in a low energy restricted marine environment (Pattillo and Nichols 90).

Scott (1994) notes two occurrences of source rocks in the Browse Basin. Marine shelf and basin sediments of Late Jurassic-earliest Cretaceous are characterized by total organic carbon (TOC) of 1-5 wt%, S_2 of 2-15 mg/g, and hydrogen index (HI) of 100-400. Estimated thickness of this source rock section varies from 100 m to more that 1000 m. Alluvial plain and deltaic facies account for another possible source rock in the Early-Middle Jurassic Plover Formation. This mixed marine and alluvial section is greater than 500 m thick with TOCs of 1-70 wt%, S_2 of 2-250 mg/g, and HI of 100-600 (Scott, 1994). Bradshaw and others, (1994) indicate the highest levels of TOC are present in rocks of Early Jurassic (Pliensbachian to Toarcian) age and Middle Jurassic (Bajocian to Bathonian) age with associated HIs of approximately 250. The Late Jurassic (Kimmeridgian) is not as thick or as rich in TOC as is found in other areas of offshore Australia, however, the interval is considered as possible source rock. A Lower Cretaceous source interval was suggested for the Browse Basin by Wilmot and others at AGSO (Bradshaw and others, 1994).

Using present-day geothermal gradients, the Upper Cretaceous claystone section may be mature in west-central and outer parts of the basin, the Lower Cretaceous (Neocomian) rocks may be mature over most of the central basin and the Lower to Middle Jurassic section may be mature across the entire basin (Fig. 6) (Willis, 1988; Butcher, 1989). The mid-Cretaceous section is shown by vitrinite reflectance data to be in the peak oil generative stage west of the Prudhoe Terrace (Bradshaw and others, 1994). Stephenson and Cadman (1994) proposed that the northern portion of the basin is mature for hydrocarbon generation and that maturity decreases to the southwest.

OVERBURDEN ROCK

During the Cretaceous, open ocean circulation was established and a passive margin style of tectonic stability prevailed where carbonate deposition built the present shelf and reef configuration. The 1,511 m thick Cretaceous section in Arquebus-1, next to Lombardina (Fig. 2), includes marine shales of open marine to shelfal marine and carbonate (Haston and Farrelly, 1993). The Tertiary section in this well is 918 m of bioclastic calcarenite interbedded with dolomite and sandstones of limited areal extent.

TRAP TYPES

Compactional drapes over fault blocks and tilted fault blocks delineate the proven trap style in the central and western portion of the Browse Basin. These tilted fault blocks are aligned in trends that are roughly parallel to and located between the sub-basin trends (Willis, 1988; Stephenson and Cadman, 1994)(Fig. 4). The drape structures appear as anticlines on figure 2. Triassic tilted strata are faulted then draped and onlapped by Jurassic strata (Fig. 4a, b). Continued faulting along these trends involved the Jurassic strata which were then overlain by upper Jurassic and younger strata. Offshore extension of lineaments and folds from the onshore Kimberley Block (PESA, 1996), are interpreted to influence accumulations on the Yampi Shelf where recent discoveries are trapped in compactional drape anticlines formed over paleo-topography and in depositional pinchout against basement.

Tilted fault-blocks formed across the basin during Late Triassic to Early Jurassic tectonics. An unconformity of Middle to Late Jurassic (Callovian-Oxfordian) age was characterized by Late Jurassic lava flows and deposition of volcaniclastic sediments. Regionally extensive Cretaceous claystones sealed traps (Fig. 3). These traps have generally been preserved since the Cretaceous. Drape anticlines and faulted anticlines result from compaction of Jurassic and Cretaceous sediments over tilted Triassic fault blocks. These traps are also found in the Vulcan sub-basin where two parallel graben formed during Middle to Late Jurassic (Callovian-Kimmeridgian) subsidence. Minor faulting related to these graben continued through the Cretaceous and some reactivation began during the Tertiary Timorese collision. Proven traps along the Yampi Shelf consist of drape over basement relief in combination with depositional onlap of Cretaceous sediments onto the Kimberley Block.

Tilted fault block traps of Scott Reef were among the earliest hydrocarbon discoveries in the Browse Basin. These traps are similar in style to earlier successful discoveries along the Northern Carnarvon portions of the Australian Northwest Shelf in Province 3948 to the southwest.

RESERVOIR ROCK

The Browse Basin was generally a low energy, shallow and narrow marine-influenced continental seaway that was open to the north, northeast and sometimes to the Rowley sub-basin in the southwest and beyond. The land mass named Argo Land, portions of the eastern Indonesian plate, other continental plates connected to the Scott Plateau, and the Ashmore Platform separated the basin from the Tethys Ocean (Bradshaw and others, 1994). Formation of the Argo Abyssal Plain in Middle to Late Jurassic (Callovian-Oxfordian) time opened the area to the ocean as a thermally subsiding passive style margin.

The main reservoir at Skua Field is the Jurassic Plover Formation. The Plover Formation is present as erosional remnants beneath the late Middle Jurassic (Callovian) unconformity in tilted fault blocks mainly in the Vulcan sub-basin. These marine to deltaic clastics are absent on the Ashmore Platform and partially preserved on the Londonderry High (Pattillo and Nichols, 1990). Coarse fan deltas of the Montara Formation fringe the sub-basin on the southeast and extend into the axis. The Vulcan Formation consists of restricted marine mudstone and deep-water fans that were derived from the graben flanks.

Late Cretaceous rocks, deposited as deep-water fans, in the central basin (PESA 1996) are the reservoir rocks in Caswell-1. This well tested oil from thin sandstone of Albian age surrounded by shale.

The main reservoir sequence in the Scott Reef field and at Brecknock-1 is described as Jurassic interbedded sandstones, shales and volcanics that were deposited in nearshore marine to fluviodeltaic environments. Porosity ranges from 11-14%. The

Triassic gas bearing interval at Scott Reef is dolomite and dolomitic sandstones (Bint, 1988).

Lower Cretaceous (Hauterivian to Barremian) oil and gas bearing reservoirs in Gwydion-1 are described as clean quartz sandstones that were deposited in high energy upper shoreface conditions and retain porosities of 24-27% (Spry and Ward, 1997). Other gas bearing strata in this well are glauconitic sandstones of Early Cretaceous (Barremian to Albian) age.

The Jurassic section drilled at Arquebus-1, next to Lombardina (Fig. 2), is 827 m thick and has an interpreted hydrocarbon column of 105 m (Haston and Farrelly, 1993). The Lower Jurassic section contains spilitic volcanics that are interpreted to have erupted along the basin margin fault into shallow marine environments where deposition of carbonates, sandstones, siltstones, claystones, and volcaniclastics occurred. The Middle Jurassic strata contains shallow marine to non marine, massive quartzose sandstone with porosity of 14%, interbedded with siltstone, claystone and carbonate. The Upper Jurassic is described by Haston and Farrelly (1993) as shallow water claystone to sandstone with porosity ranging from 6-12%.

SEAL ROCK

Jurassic intraformational shale and claystone seals are described by Bradshaw and others (1994). Local and regional seal rocks consisting of lower to upper Cretaceous (Valaginian-Cenomanian) claystones are reported to reach a thickness of 1.5 km on the highs of the Scott Reef area and thicker in the sub-basins (Stephenson and Cadman, 1994). These claystones are a result of the post breakup establishment of a passive margin continental shelf and slope of generally low energy and low sediment accumulation rate (Spry and Ward, 1997).

UNDISCOVERED PETROLEUM BY ASSESSMENT UNIT

The U. S. G. S. Browse Basin Province (3913) contains one TPS (391301) with one assessment unit (39130101) (Fig. 1). Exploration targets are numerous and are under-explored in the Browse Basin. The entire basin is underlain by either Permian or Triassic/Jurassic tilted fault blocks. Where primary porosity is preserved, reservoir quality is good, although quartz overgrowths occlude much of the porosity at some locations in the deeper sedimentary rocks. Miller and Stuart (1992) describe possible deep-water fans of Early Cretaceous (Valanginian) age, that have been identified on seismic. These fans occur in the southwestern portion of the Browse Basin and are similar to the reservoir rocks at Caswell-1. Depositional onlaps of progressively younger sediments onto the Kimberley Block, all along the Yampi Shelf and Londonderry High, are potential targets. Any traps and structures on the migration route from the mature source in the basin to the onlaps on the eastern edge are also potential targets. Valley-fill type reservoirs formed on the flanks of the Kimberley Block and the persistent high platforms could be another important stratigraphic trap. Inversion of Paleozoic basin areas and other strata by the Timorese Orogeny might be additional targets for investigation. Hour-glass structures of Tithonian reservoir sandstones sealed laterally by faults during Tertiary tectonic events are described by Maung and others (1994).

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