LOWER PALEOZOIC STRATIGRAPHY AND PETROLEUM POTENTIAL OF THE WALLAL RIFT SYSTEM, SW CANNING BASIN, WESTERN AUSTRALIA

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Introduction

The Wallal Rift System contains a series of fault-troughs (largely half-grabens) in two embayments and the Samphire Graben (Fig. 1a). The troughs contain up to 4.5 km of sediments on the magnetic basement. Their total onshore area (20,290 km^2) is larger than the onshore sector of the Willara Sub-basin (18,345 km^2). These are, however, less explored than the northwestern part of the sub-basin, within which Samphire Marsh–1 is the closest well to the rift (TD=2013m). The well intersected 775 m of the Lower Ordovician Nambeet Formation under the Lower Permian Grant Group and ended in Neoproterozoic granitic rocks on the margin of the Samphire Graben. Seismic lines tied to the well indicate that the Ordovician section thickens down-dip into the graben (Purcell and Poll, 1984, fig. 19).

Seismic exploration during the 1980s and 1990s suggested that a pre-Permian Paleozoic section is present in the northern rifts. Various types of sub-Grant leads and traps were also proposed or mapped, although none was tested. Recent studies have suggested that a Larapintine 2 petroleum system may be present in the rift (ISIS, 2007; Alavi, 2013), although pre-Permian Paleozoic sediments have not been penetrated. Here we predict the Lower Paleozoic stratigraphy and examine petroleum potential of the rift in some details.

Insert Figure 1 here.

Exploration history and previous studies

The northern Wallal Embayment and the Samphire Graben were discovered during the 1950s. The first three stratigraphic wells were drilled in the Wallal Platform to control depth to basement. The deepest well may have ended in the Grant Group (BMR 04A Mandora, TD=679 m; Mory, 2010). Three wells were also drilled in the Wallal Embayment, the deepest of which ended in Precambrian rocks under the Grant Group (Pandanus–1, TD=880m). The other two ended in the Grant Group (Chirup–1, TD=762m; Corbett–1, TD=800m). There is only one comparatively deep minerals exploration hole in the Samphire Graben (Sandfire–1, TD=760m), but there is no well in the Waukarlycarly Embayment. This is much larger than Wallal Embayment, but it was not known until the early 1990s, when Purcell attributed its associated gravity low to a graben that was confirmed by a seismic survey (Hunt Oil, 1997). The company assigned 'base Paleozoic' at the base of a bland seismic interval under the Grant Group, well above the acoustic basement (Roach et al, 2010, fig. 2.6). By comparison, Purcell interpreted five sub-Grant seismic units on the acoustic basement. The lower four units are comparable with supersequences of the Ordovician–Silurian supersequence in the Willara Sub-basin (Romine et al, 1994, fig.8). We interpret the bland unit (second unit from above) as the evaporitic Upper Ordovician–Silurian Carribuddy Group, since Bagas (2005) assigned the uppermost (first) unit to Devonian–Upper Carboniferous along the southern line (H96-01). As the Upper Devonian–Lower Carboniferous megasequence is missing (Fig. 1b); the uppermost unit may mostly belong to the Lower Devonian Tandalgoo Formation.

Line H96-01 was acquired along the Telfer Road (Fig. 1a). It extends about 20 km over the western margin of the embayment across the Vines Fault, which dips northeast at a lower angle than the Camel–Tabletop Fault Zone (CTFZ) (Alavi, 2013, pl. 1). The Vines Fault is the northern segment of a regional thrust at the boundary of the Proterozoic Paterson Orogen and the Neoarchean East Pilbara Craton. The Neoproterozoic Yeneena Basin lies between the Vines Fault and the CTFZ. Opaque seismic signature of the basin extends under the sub-

Grant seismic units, indicating that they all belong to Paleozoic. Further evidence in support of this is given in Alavi (2013).

The CTFZ strikes along the western margin of the main rift, the Waukarlycarly Embayment and the Samphire Graben. This is a geosuture that has been reactivated during the Paleozoic as a transtentional structure, controlling the orientation of initial rifting that probably took place during the Cambrian (SRK, 1998, fig.4-2; extensional D7 event of Bagas, 2005, p.15). By comparison, the Anketell–Samphire Fault System (ASFS) along the eastern margin of the rift belongs to a series of southwest-dipping, Early Paleozoic faults west of the Admiral Bay Fault Zone (ABFZ) (Fig. 1a; Romine et al., 1994). Over 4 km of cumulative vertical differential movements have taken place along the CTFZ and he AFSFS during the Paleozoic, creating a pair of en echelon half-grabens with opposite polarities within the embayment, southwest and northeast of an axial high that trends northwestward between the Telfer area basement high and the Wallal Platform (Fig. 3; Alavi, 2013).

Insert Figure 2 here.

Data and methods

Most of the rift is covered with gridded (80 m cells) high-resolution aeromagnetic and ground gravity data. We have used the data for magnetic basement modelling, image processing and enhancement for qualitative interpretations.

Vintage seismic data from twelve surveys cover the rift unevenly, except for the Corbett–1 area and northeastern margin of the Samphire Graben (Fig. 1a). Seismic stratigraphic interpretations are primarily based on data from Samphire Marsh–1, Frankenstein–1, minerals hole HAC 9201 and stratigraphic syntheses of Haines (2010) and Mory (2010), summarised in Figure 1b.

Seismic stratigraphy

The Lower Devonian Tandalgoo Formation is widely present in the southern Canning Basin and it is likely to be present within the rift directly under the Grant Group (Fig. 3). A prominent reflector-couplet at the base of this unit could be due to prolong erosion during the Prices Creek Movement. The unit thins westward, indicating either syn-depositional subsidence along the eastern margin of the Waukarlycarly Embayment—where it is overlain with a wedge of alluvial fan deposits—or less deposition in the western trough of the embayment. The wedge is interpreted as the Upper Carboniferous continental Reeves Formation, which may have been penetrated under the Grant Group in the minerals hole HAC 9201. Thus, despite the absence of the Liveringa Group and the Mesozoic section in the southern embayment, thickness of the Lower Paleozoic section overburden can be locally comparable to that of the northern Wallal Embayment (Fig. 2).

The Lower Paleozoic section comprises the oldest Paleozoic synrift (Cambrian?–Middle Ordovician) and the postrift (Upper Ordovician–Silurian) sequences (mainly the Carribuddy Group) in the region (Fig. 1b). The upper part of the synrift sequence usually appears as a series of continuous and concordant reflectors in southern Canning Basin under the Carribuddy Group (SRK, 1998). The reflectors are interpreted as alternating carbonates and clastics of the Willara, Goldwyer and the Nita formations. In contrast, reflectors are relatively weak and less continuous in the lower part of the sequence due to coastal and shallow marine transgressive facies of the Nambeet Formation and possible underlying Cambrian or latest Neoproterozoic volcanic and clastic deposits as found under the Ordovician section in Frankenstein–1. Furthermore, a package of pronounced reflectors at the base of the sequence towards the CTFZ resembles the seismic signature of Cambrian volcanic rocks in the Western Officer Basin. If this is valid, the lowest unit (fifth unit) of the synrift sequence may be of late Ediacaran–Cambrian age, deposited during the waning of the Paterson Orogeny (c. 550 Ma). This would imply that initial rifting was driven by mantle plume activities that led to the eruption of the Kalkarindji Large Igneous Province in northwest Australia.

Insert Figure 3 here.

Petroleum potential

A series of reflectors showing laterally variable higher amplitudes are present in the Lower–Middle Ordovician (synrift) sequence throughout the rift (Figs 2 and 3). These are likely to be due to high impedance contrast between alternating shale-rich and carbonate units. The overlying Carribuddy Group (postrift sequence) is up to about 500 m thick in the Waukarlycarly Embayment, assuming an interval velocity of 3.5 km/s, as there is no indication of salt-mobilisation and halite units of the group are probably thin or absent. The group; however, includes shale-rich units in the southern Canning Basin (Haines, 2010). Therefore, it may serve as the most effective seal for a Larapintine 2 petroleum system, which is prospective for conventional and tight or shale gas and oil exploration in the Canning Basin.

Deposition of organic-rich shales was probably promoted in the rift valley by restricted water circulation during maximum flooding of the basin, when the Middle Ordovician Goldwyer Formation was deposited (Romine et al., 1994). A relatively 'hot' Proterozoic, due to emplacement of high-heat producing granites during the Neoproterozoic and mantle plume activities during the Cambrian, may have promoted source rock maturity during the Early Paleozoic.

Some of the overburden must have also been removed during the Alice Springs Orogeny and the Gondwanan glaciation, indicated by pronounced relief of the basal Grant unconformity on the rift margins (Fig. 3). Thus, potential reservoirs are more likely along the rift margins and intra-rift ridges, where faults may have acted as conduits (and barriers) to fluid migration. In addition to the Nita carbonates, the cavernous or fractured carbonates of the Willara Formation may serve as reservoir. These are respectively sealed by the basal shale units of the Carribuddy Group and the Goldwyer Formation.

Although the possibility of petroleum accumulation in eolian sandstones of the Tandalgoo Formation or sandstone and shale couples of the Grant Group cannot be ruled out, there is greater risk of trap integrity and reservoir flushing by ground-water above the Carribuddy Group.

Intra-sedimentary igneous rocks may have also adversely affected reservoir quality in the Permian section, although these appear to be less common in the northern embayment and probably absent in the southern one. Basalt layers have been intersected in Sandfire–1 and Corbett–1 (Fig. 2) and they are most common in the Samphire Graben, where they are also reversely magnetised. Their dendritic pattern of magnetic anomalies indicates that lava flow may have taken place during the middle to late Permian within the early Permian paleochannels during the Kiaman period of reverse polarity. If so, the flows may have not have detrimentally affected reservoir quality.

Conclusions

Basic elements of a Larapintine 2 petroleum system appear to be in place. This needs to be confirmed by well data. Deeping of the Corbett–1 may be the preferred option.

Alternatively, a stratigraphic well at SP 1350 on the axial high of the Waukarlycarly Embayment (Fig. 3) or SP 3770 in the NE Samphire Graben may be considered (Fig. 2).

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Authors' biographies

Dr Alavi completed his research in marine geoscience at the University of London (UK) in 1980. He worked at various organisations in Australia, mostly as a marine geologist/oceanographer, before joining the Geological Survey of Western Australia in 2008, where he has been working mainly on the southern Canning Basin. He is a member of PESA.

Dr Bagas has over three decades of experience as a geologist at the Geological Survey of Western Australia and the Northern Territory Geological Survey. He is a Research Associate Professor at the Centre for Exploration Targeting of the UWA, collaborating with the Geological Survey of Denmark and the ARC Centre of Excellence for Core to Crust Fluid Systems on various projects. He is a Fellow of SEG and a Member of SGA.

Peter Purcell is an Australian geologist with an MSc from the University of Sydney. He is General Manager of P & R Geological Consultants Pty Ltd, with over 40 years experience working for international and Australian oil exploration companies in Australia, SE Asia and East Africa. He has edited several books on Western Australian geology, including the North West Shelf, and is the author of numerous articles on geology and petroleum exploration in Australia and East Africa, as well as environmental and aboriginal issues.

Irena Kivior obtained Eng. M.Sc. (1976) degree from the Academy of Mines and Metallurgy in Cracow and worked as a mathematician in Poland. In 1980 she migrated to Australia and until 1990 worked as a mineral and coal geologist. She then conducted research at the Adelaide University and was awarded a Ph.D. in 1996. Her Postgraduate Research Fellowship (1996-1998) focused on sedimentary basin and deep crustal studies using potential field data. In 1997, she founded Archimedes Consulting, providing geophysical services for the petroleum industry, using proprietary techniques from her research. Irena is a member of AAPG, EAGE and SEG.

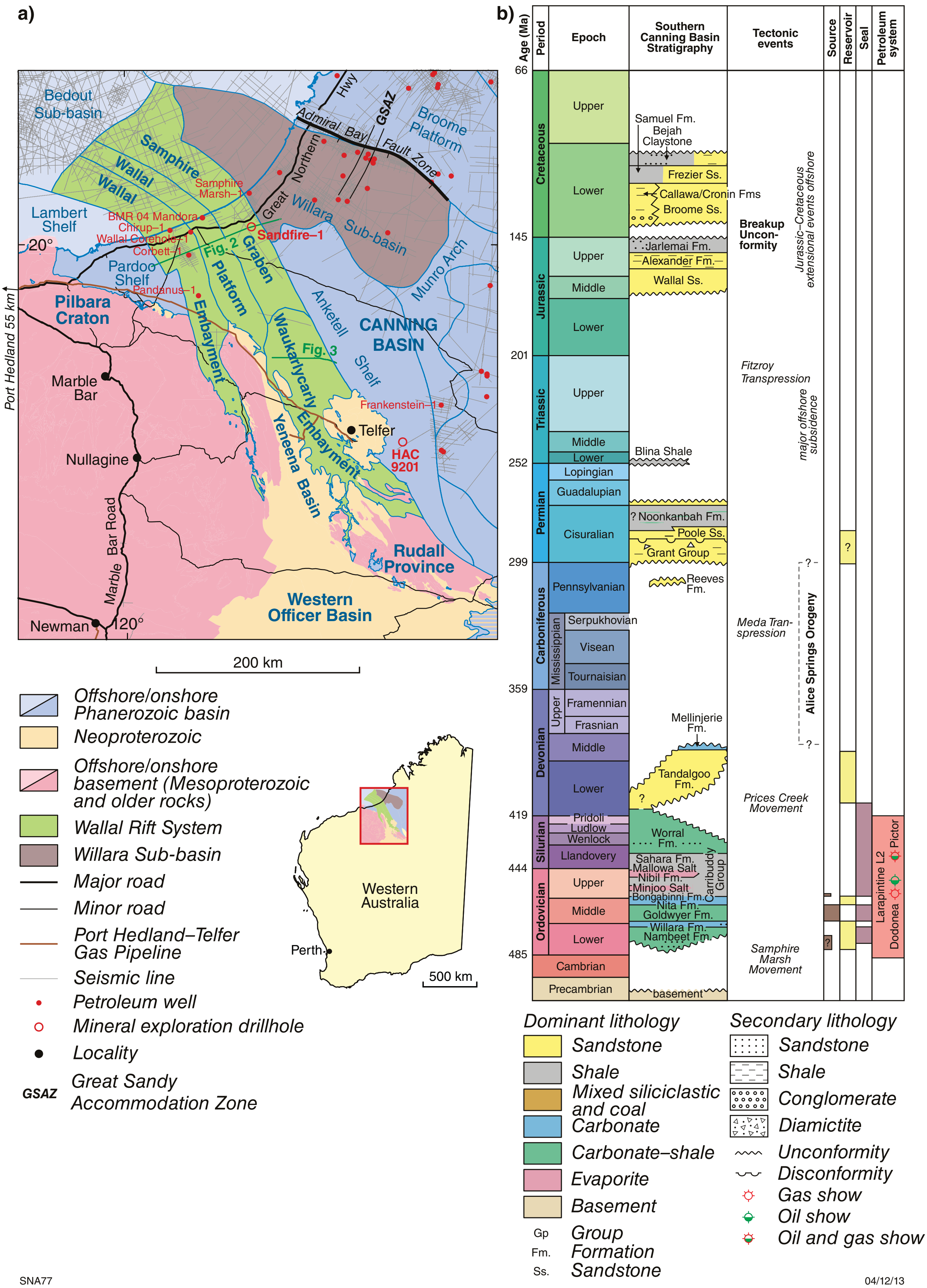
John Brett is a geophysicist with extensive exposure to airborne geophysics and gravity data processing. He graduated from University of Melbourne in 1985 and worked briefly in the petroleum industry before becoming involved with airborne geophysical data processing. He has processed airborne and ground data for a wide range of industry and government organisations. He has also conducted training courses in the use of data processing and imaging software.

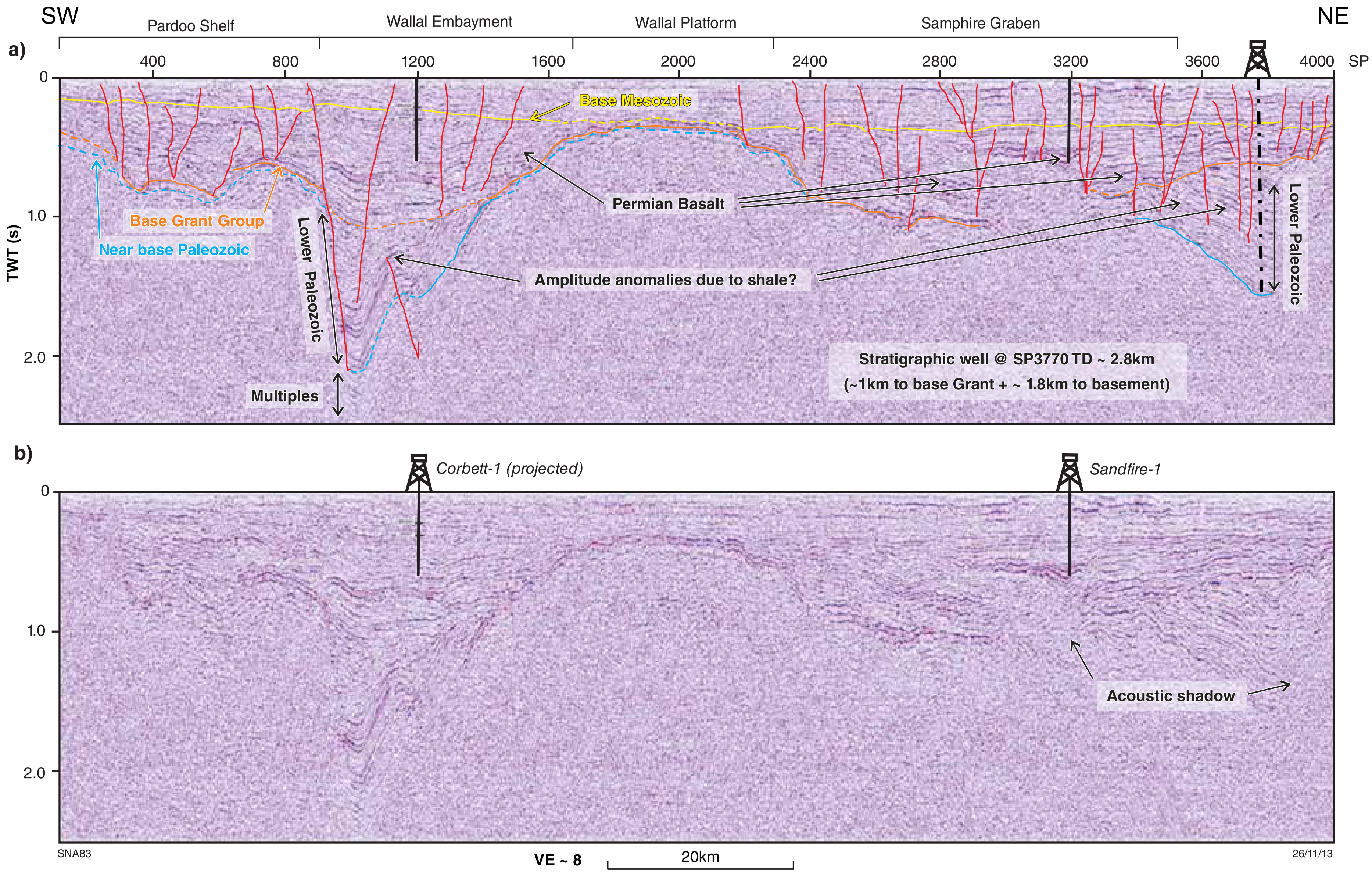
Figure Captions

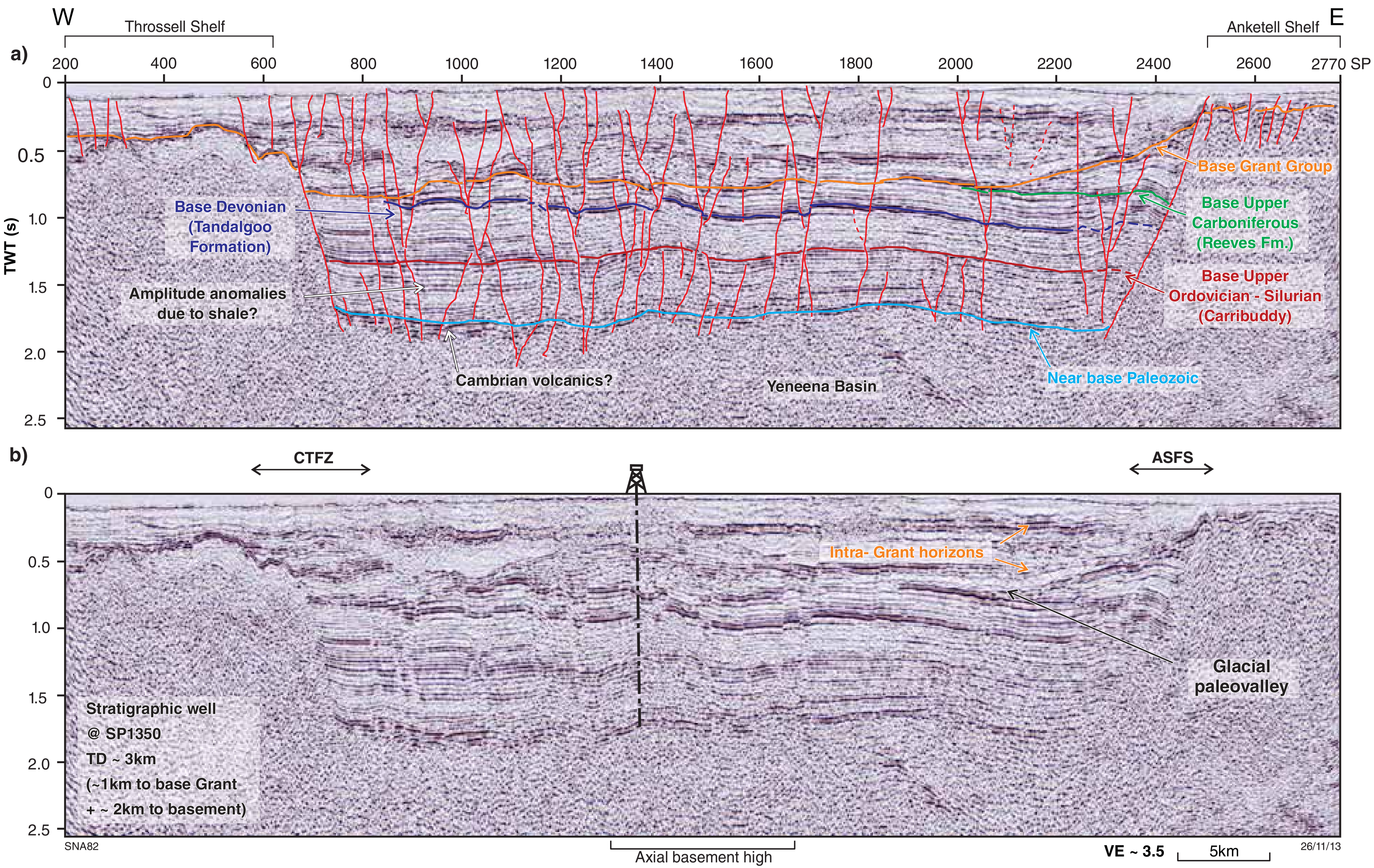
Figure 1: a) Location and structural elements of the Walla Rift System, b) generalised stratigraphy and petroleum system of the southwest Canning Basin.

Figure 2: Interpreted (a) and uninterpreted seismic line 85RH-002 (b) across the northern rifts (see Figure 1a for location)

Figure 3: Interpreted (a) and uninterpreted seismic line H96-05 (b) across the central Waukarlycarly Embayment (see Figure 1a for location)


a)
Bedout Sub-basin
Samphire
Wallal
Wallal
Lambert Shelf
20°
Samphire Marsh–1
BMR 04 Mandora
Chirup–1
Wallal Corehole–1
Corbett–1
Pardoo Shelf
Pandanus–1
Sandfire–1
Fig. 2
Graben
Platform
Embayment
Great Northern
Admiral Bay
Fault Zone
GSAZ
Hwy
Broome Platform
Willara Sub-basin
Munro Arch
Anketell
Shelf
CANNING BASIN
Fig. 3
Waukarlycarly
Embayment
Yeneena Basin
Frankenstein–1
Telfer
HAC 9201
Pilbara Craton
Port Hedland 55 km
Marble Bar
Nullagine
Marble Bar Road
Newman
120°
Rudall Province
Western Officer Basin
200 km
Offshore/onshore Phanerozoic basin
Neoproterozoic
Offshore/onshore basement (Mesoproterozoic and older rocks)
Wallal Rift System
Willara Sub-basin
Major road
Minor road
Port Hedland–Telfer Gas Pipeline
Seismic line
Petroleum well
Mineral exploration drillhole
Locality
GSAZ Great Sandy Accommodation Zone
Western Australia
Perth
500 km
b)
Age (Ma)
Period
Epoch
Southern Canning Basin Stratigraphy
Tectonic events
Source
Reservoir
Seal
Petroleum system
66
Cretaceous
Upper
Lower
Samuel Fm.
Bejah Claystone
Frezier Ss.
Callawa/Cronin Fms
Broome Ss.
145
Breakup Unconformity
Jurassic–Cretaceous extensional events offshore
Jurassic
Upper
Middle
Lower
Jarlemai Fm.
Alexander Fm.
Wallal Ss.
201
Fitzroy Transpression
Triassic
Upper
Middle
Lower
Blina Shale
major offshore subsidence
252
Permian
Lopingian
Guadalupian
Cisuralian
? Noonkanbah Fm.
Poole Ss.
Grant Group
299
Carboniferous
Pennsylvanian
Reeves Fm.
Mississippian
Serpukhovian
Visean
Tournaisian
Meda Transpression
Alice Springs Orogeny
359
Devonian
Upper
Framennian
Frasnian
Middle
Lower
Mellinjerie Fm.
Tandalgoo Fm.
419
Prices Creek Movement
Silurian
Pridoli
Ludlow
Wenlock
Llandovery
Worral Fm.
444
Ordovician
Upper
Middle
Lower
Sahara Fm.
Mallowa Salt
Nibil Fm.
Minjoo Salt
Bongabinni Fm.
Nita Fm.
Goldwyer Fm.
Willara Fm.
Nambeet Fm.
Carribuddy Group
485
Samphire Marsh Movement
Cambrian
Precambrian
basement
Larapintine L2
Dodonea
Pictor
Dominant lithology
Sandstone
Shale
Mixed siliciclastic and coal
Carbonate
Carbonate–shale
Evaporite
Basement
Gp Group
Fm. Formation
Ss. Sandstone
Secondary lithology
Sandstone
Shale
Conglomerate
Diamictite
Unconformity
Disconformity
Gas show
Oil show
Oil and gas show
SNA77
04/12/13


SW
NE
Pardoo Shelf
Wallal Embayment
Wallal Platform
Samphire Graben
400
800
1200
1600
2000
2400
2800
3200
3600
4000
SP
a)
TWT (s)
0
1.0
2.0
Base Mesozoic
Base Grant Group
Near base Paleozoic
Lower Paleozoic
Permian Basalt
Amplitude anomalies due to shale?
Lower Paleozoic
Multiples
Stratigraphic well @ SP3770 TD ~ 2.8km
(~1km to base Grant + ~ 1.8km to basement)
b)
Corbett-1 (projected)
Sandfire-1
Acoustic shadow
SNA83
VE ~ 8
20km
26/11/13


W
E
Throssell Shelf
Anketell Shelf
a)
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2770 SP
TWT (s)
0
0.5
1.0
1.5
2.0
2.5
Base Grant Group
Base Upper Carboniferous (Reeves Fm.)
Base Devonian (Tandalgoo Formation)
Base Upper Ordovician - Silurian (Carribuddy)
Amplitude anomalies due to shale?
Cambrian volcanics?
Yeneena Basin
Near base Paleozoic
b)
CTFZ
ASFS
Intra- Grant horizons
Glacial paleovalley
Stratigraphic well
@ SP1350
TD ~ 3km
(~1km to base Grant
+ ~ 2km to basement)
SNA82
Axial basement high
VE ~ 3.5
5km
26/11/13