

Review of Exploration Drilling Success Rates in the Amadeus Basin

- This position paper aims at rating existing play types by reviewing success rates for individual reservoir / seal couplets.
- On an individual well basis it is noted that 100% of the 26 dry holes in the basin failed to intersect 4WD closure at any stratigraphic level. In addition, 100% of the 7 discoveries/technical discoveries, intersected the producing reservoir/seal couplet within 4 WD closure.
- Thus 4WD closures for any particular reservoir/seal couplet are far more attractive at this stage of exploration than other play types (eg fault dependent traps) which so far have failed to yield recoverable hydrocarbons, but will become important in the future.
- A review of success rates for individual reservoir/seal couplets within 4WD closure yields the following results:

<u>Reservoir/ Seal Couplet</u>	<u>Intersections/successes in 4WD Closure</u>	<u>Success R.</u>
Heavitree/Gillen	one / one (Magee-1)	100%
Bitter Springs/ Aralka- Pertatataka- Chandler	one / none	0%
Pioneer/Pertatataka	one / one (Ooraminna-1)	100%
Arumbera/Chandler	four / two (Dingo, Orange)	50%
Intra-Goyder	Seven/ none	0%
Pacoota / HVS (no Stokes seal)	Three / one (West Walker-1)	33%
Pacoota/Stairway Stokes	two / two (Mereenie, Palm Valley)	100%

- The aforementioned success rates for target reservoir /seal couplets clearly indicate that the Heavitree/Gillen, Pioneer/Pertatataka and Pacoota-Stairway/ Stokes are primary targets in the basin recording 100% success rates for 4WD closures located adjacent to mature source kitchens. In similar geological circumstances the Arumbera/ Chandler couplet records a 50% success rate.

- **Fault dependent traps are a play for the future, especially for targets where Gillen or Chandler salt has penetrated along fault planes or where potential leaking faults dissipate into pervasive remobilised salt. Plays which employ salt related seal such as diapir flank and some “Halo” plays will also be high-graded as exploration progresses – these plays are likely to be considerably larger and more numerous than simple unaffected 4WD closures.**

Introduction

The Amadeus Basin is highly prospective but is extremely complex from a petroleum exploration standpoint. A review of exploration drilling success rates provides feedstock defining future exploration axioms for the basin. An understanding in detail of the geoscientific issues behind drilling successes and failures in all drill holes is essential to lift exploration success rates in the basin. The following data in no way prejudice new play types evolving in the basin, most of which have not been drilled to date.

There are 8 viable petroleum systems in the Amadeus Basin which are listed below:

Horn Valley Siltstone
 Middle Late Cambrian shales (Goyder Fm, Upper Shannon Fm)
 Basal shale Giles Creek Dolomite
 Intra Chandler Formation shales
 Pertatataka Formation
 Aralka Formation
 Bitter Springs Formation (Loves Creek Member, Johnny’s Creek Member)
 Gillen Member

Previous Studies: Only 33 exploration wells have been drilled over an area spanning 170,000 km². Previous studies have asserted that two wells yielded commercial fields, 5 were technical successes, 11 have previously been deemed true failed trap tests and 13 wells were drilled off structure/outside closure (Weste,1992). This yields a commercial success rate of 11% and a Technical success rate of 40%. This note disputes a number of these assertions, most notably those related to deemed “valid traps” which failed to yield hydrocarbons.

In addition, this more detailed review of success rates as they apply to individual target reservoir seal / couplets provides a markedly different picture and will direct exploration initiatives into the future in this complex basin.

A Review of Exploration Success Rates

The post mortems of 11 wells previously believed to have been drilled within structural closure, but which failed to intersect hydrocarbons, have on close

inspection failed to ratify their “valid” trap status (Appendix-1). Only Tent Hill-1 has possible structural closure but the structure warrants a seismic remap. Bluebush-1 was located within structural closure but target reservoir couplets were absent although the well terminated before penetrating the Heavitree Quartzite which remains untested in this general region.

This study enhances the existing corporate view that 4 way dip closures have a 100% success rate. The seven wells which encountered commercial discoveries (2) and technical discoveries (5) all resulted from hydrocarbon entrapment in 4 way dip closures. **It is believed that of the remaining 26 exploration wells none was located on a valid fault independent 4 way dip closure (see Appendix-1).**

The fact that 100% of 4WD closures drilled (ie 7 exploration wells) have been successful, while there is a 100% failure rate for non-4WD structures (26 exploration wells) support the notions that:

1) Nearly all 4 way dip closures within the basin are likely to be charged with hydrocarbons at any one of a number of stratigraphic levels ie traps of this type in the basin will always be hydrocarbon saturated where they occur in reasonable proximity to source “ kitchens”.

2) 4WD closures are obviously the lowest risk play type. The only mapped 4WD trap not to yield hydrocarbons was Bluebush-1 and this well was denoted by a clear absence of target reservoir/seal couplets.

3) The highest risk in the basin by far is establishing the veracity of the trap. The fact that thus far in the basin’s exploration history there has been 100% failure rate for structures other than 4WD closures confirms the need for tighter seismic control and thorough statics and velocity modelling to facilitate accurate depth mapping.

4) Structures with robust vertical closure are most attractive in terms of trapping and retaining hydrocarbons.

Review of Reservoir/Seal Couplet Success Rates

	St	Pa	IG	Ar	Pi	BS	HQ
<u>Well</u>							
Mereenie	#	#	#	#	NPe	NPe	NPe
Palm Valley	#	#	#	#	NPe	NPe	NPe
Orange	#	#	#	#	NPe	NPe	NPe
Dingo	NPe	#	#	#	NPe	NPe	NPe
W. Walker	#	#	#	NPe	NPe	NPe	NPe
Ooraminna	NPr	NPr	NPr	NPr	#	#	NPE
<u>Magee</u>	NPr	NPr	NPr	NPr	NPr	NPr	#

Gas To Surface

NPe = Not Penetrated

Oil To Surface

NPr = Not Present

Probable 4WD Closure
No Hydrocarbons

St = Stairway, Pa = Pacoota, IG = Intra-Goyder, Ar = Arumbera, Pi = Pioneer, BS = Bitter Springs, HQ = Heavitree

Discussion: Reservoir/ Seal Couplet Success Rates

1. Reservoir/Seal Couplet : Heavitree/ Gillen

The only penetration of this couplet tested small quantities of gas and Helium (Magee-1). The success rate and 4WD CLOSURE success rate is 100%. The success rate will persist through time as the overlying Chandler Salt is ubiquitous.

The success ratio for this reservoir/seal couplet in 4WD is 100%.

2. Reservoir/ Seal Couplet : Bitter Springs / Pertatataka – Aralka - Chandler.

Good oil shows were recorded in the Johnny's Creek Member in Finke 1. This fossil oil column was probably sourced from the Bitter Springs Formation and was breached during the Petermann Ranges Orogeny. A similar scenario probably occurs in the en echelon James Range structure to the east which appears to host a residual column in the Arumbera Sandstone.

The success ratio for this reservoir/seal couplet in 4WD is 0%.

3. Reservoir Seal Couplet: Pioneer Sandstone/ Pertatataka Fm.

One 4WD closure, Ooraminna-1, produced gas at low rates. The Pioneer was not penetrated in 5 4WD closures and was absent via non deposition in Magee-1 and Bluebush-1.

The success ratio for this reservoir/seal couplet in 4WD is 100%

4. Reservoir Seal Couplet: Arumbera Sandstone / Chandler Fm.

Two 4WD closures at Dingo and Orange produced gas but the unit is believed to be water saturated over the Mereenie and Palm Valley structures.

The success ratio for this reservoir/seal couplet in 4WD is 50%

5. Reservoir Seal Couplet: Intra Goyder Reservoir/ Seal couplet.

This target occasionally records HC shows and a ?residual oil column exists in Alice-1. The unit has never recovered hydrocarbons to surface.

The success ratio for this reservoir/seal couplet in 4WD is 0%.

6. Reservoir Seal Couplet: Pacoota Sandstone-Stairway ss/ Stokes

This system is productive at Mereenie and Palm Valley.

The success ratio for this reservoir/seal couplet in 4WD and where the Horn Valley Siltstone is mature is 100%.

7. Reservoir Seal Couplet: Pacoota Sandstone / HVS

The only well to show HVS seal is West Walker. Elsewhere the Stokes Siltstone is regarded the primary seal for the Pacoota/ Stairway system.

The success ratio for this reservoir/seal couplet in 4WD is 33%.

Future Potential of Fault Dependent, “Halo” and Diapir Flank Plays

There is a high likelihood that fault dependent traps will prove viable in the future, although the current drilling history has not certified this as yet. The factor that favours fault entrapment, particularly at the Heavitree / Gillen level and also at **basement levels**, is the thick, often remobilised Gillen salt seal which is pervasive and intrudes along fault planes effectively sealing off the Gillen/Heavitree petroleum system – fault traps against basement are particularly attractive. In general this play type will become increasingly viable as these traps are likely to be much larger in general than available 4WD closures, thus mitigating the risk/reward ratio.

The Pioneer Sandstone is often encased in thick tight shales of the Pertatataka Fm and Aralka Fm, a configuration which lends itself to shale smear and development of favourable shale gouge ratios needed in the case of viable fault traps. Evidence of wrenching and transpression on fault lines supports the play.

Similarly the Early Cambrian Chandler Salt offers opportunities where salt intrudes fault planes or where they dissipate into zones of remobilized salt. As seismic coverage progresses in the basin these more complex traps will become attractive at the levels of the Arumbera Sandstone, intra-Goyder Formation and the following reservoir seal couplets: Pacoota ss/ Horn Valley Siltstone, Stairway/Stokes Siltstone, Mereenie ss/Parkes Siltstone.

Appendix-1

A Review of Amadeus Basin Exploration Wells Formerly Considered Valid Traps

1) Alice 1:

Structures in this general area result from ASO folding and faulting. Structural closure is not mapped at Ordovician (Pacoota levels) and hence it is unlikely structural closure exists from this level to the base Giles Creek Dolomite. Structure maps are unavailable below this level although it is highly likely the structure spills to the NNE. A potential flushed pool in the Goyder Formation hints at structural reactivation. The results for intersected reservoir seal-couplets in the well are summarised below:

Pacoota/Stairway- Stokes Siltstone seal: NO CLOSURE
Intraformational Goyder reservoir-seal : NO CLOSURE
Arumbera ss/ intraformational seal : ? NO CLOSURE(probably wet, some salt water produced on DST)
Pioneer Sandstone : Not penetrated
Heavitree/Gillen : Not penetrated

Conclusion: Probably lacks structural closure at all levels although the Pioneer , Bitter Springs and Heavitree/Gillen were not penetrated. The trap cannot be considered as a valid trap lack of such was the main reason for the failure of the well.

2) Orange-1,2 :

The Orange structure has at least some structural closure and a new study by Central suggests the gross column at Orange-2 could exceed 100 m . A summary of target reservoir/seal couplets intersected in the well occurs below:

Pacoota/Stairway- Stokes Siltstone seal: Probable Closure – Stokes seal absent. HVS is a poor source rock.
Intraformational Goyder reservoir-seal : Probable Closure but dry – source rocks immature, HVS is a poor source rock.
Arumbera ss/ intraformational seal : CLOSURE Present, 100 m gas column
Pioneer Sandstone : Not penetrated
Bitter Springs : Not penetrated
Heavitree / Gillen : Not penetrated

The Orange structure was probably a valid trap but lack of or immaturity in the Palaeozoic source sequences was probably responsible for the lack of shows at these levels. Structural closure at the Arumbera sst level resulted in gas entrapment. The Pioneer target was not penetrated and remains untested over this structure. This structure cannot be

viewed as a valid trap which was dry, in view of the fact that the Arumbera Sandstone was gas saturated over 100 m.

3) Finke-1:

The Finke structure was not defined on seismic and structural interpretations are based on outcrop distribution. The well intersected a palaeohigh with a very thin Arumbera section. The top Bitter Springs recorded a 200 m residual oil column which probably extended into the Arumbera section. Pertatataka Fm loading of the Gillen / Bitter Springs source sequence with migration to this regional palaeohigh in Marinoan times is the most likely hydrocarbon charge scenario.

The original structure could have formed by drape and compaction but was probably breached by major uplift and erosion during the Petermann Ranges Orogeny or during a major period of uplift and peneplanation at the close of Chandler Formation time. Subsequent early Middle Cambrian sediments of the lower Giles Creek Formation transgressed the high and formed a sheet like deposit in this general area and were not influenced by the earlier palaeotopography.

A summary of reservoir/seal couplets occurs below.

Pacoota/Stairway- Stokes Siltstone seal:	Not present (eroded).
Intraformational Goyder reservoir-seal	:Not present (eroded).
Arumbera ss/ intraformational seal	:Trap breached in ? Early Cambrian
Pioneer Sandstone	: Not deposited
Bitter Springs	: 200 m residual oil column.
Heavitree / Gillen	: Not penetrated

Conclusion: The trap is an example of Marinoan charge to an early formed trap (pre-Petermann Ranges Orogeny) which was breached in Early Cambrian times. This well, together with James Range-1 are the only wells in the basin to demonstrate this particular scenario.

4) James Range-1

This is a regional play very similar to Finke. Marinoan oil charge from the Bitter Springs/ Gillen migrated to the Arumbera Sandstone which records a column of residual oil / bitumen staining about 80 m thick. James Range was lower on the palaeohigh than Finke and the Arumbera Sandstone thickness was commensurately greater with almost all of unit 1 being preserved.

The oil pool was effectively destroyed during Early Cambrian uplift and erosion which peneplaned the high prior to the Middle Cambrian marine transgression. Reservoir seal couplets encountered are described below:

Pacoota/Stairway- Stokes Siltstone seal: Not present (eroded).
Intraformational Goyder reservoir-seal :Not present (eroded).
Arumbera ss/ intraformational seal :Trap breached in ? Early Cambrian. 80 m of residual bitumen staining was recorded.
Pioneer Sandstone : Not deposited
Bitter Springs : Massive carbonates intersected but were water saturated.

Conclusion: The trap is an example of Marinoan charge to an early formed trap (pre-Petermann Ranges Orogeny) which was breached in Early Cambrian times.

5) Mt Charlotte-2:

Recent mapping indicated closure at the base Chandler salt level but the Arumbera was missing and none of the other target reservoir seal /couplets at various stratigraphic horizons were encountered in the well. The Gillen was present in the well which did not penetrate the Heavitree Quartzite. A summary of reservoir/seal couplets occurs below:

Pacoota/Stairway- Stokes Siltstone seal : NO CLOSURE
Intraformational Goyder reservoir-seal : NO CLOSURE
Arumbera ss/ intraformational seal : Not present
Pioneer Sandstone : Not present
Heavitree Quartzite : Not penetrated

Conclusion: No structural closure is present in the Palaeozoic sequence. The structure was probably closed at Precambrian levels as indicated by recent mapping. However the Pioneer and Arumbera targets were not present in the well and the Heavitree was not penetrated; thus the trap cannot be considered as a valid trap which failed to encounter hydrocarbons.

3) Tempe Vale 1:

Current mapping shows the structure as a fault controlled anticlinal structure which has been flushed by low salinity aquifers (2600 ppm) compared with ~90,000 ppm aquifers in the Mereenie Field. The older Ordovician section is exposed updip to the southeast and the trap is effectively breached.

Pacoota/Stairway- Stokes Siltstone seal: NO CLOSURE + breached
Intraformational Goyder reservoir-seal : NO CLOSURE
Arumbera ss/ intraformational seal : Not penetrated
Pioneer Sandstone : Not penetrated
Heavitree Quartzite : Not penetrated

Conclusion: No structural closure is present in the Palaeozoic. At this level the trap cannot be considered as a valid trap which failed to encounter hydrocarbons. There was no penetration of the deeper horizons.

Waterhouse-1:

The well was drilled within closure at some horizons but did not penetrate the Pioneer Sandstone which is believed to be within closure; this horizon produced gas at the nearby Ooraminna Structure which occurs immediately to the east. Waterhouse-1 was drilled within closure at the Arumbera Sandstone level but the absence of hydrocarbons is probably a function of insufficient seal. The thick Chandler salt seal is missing over the structure. A summary of reservoir /seal couplets occurs below:

Pacoota/Stairway- Stokes Siltstone seal:	NO CLOSURE + breached
Intraformational Goyder reservoir-seal	: NO CLOSURE + breached
Arumbera ss/ intraformational seal	: CLOSED but insufficient seal
Pioneer Sandstone	: CLOSED but not penetrated
Heavitree Quartzite	: Not penetrated, not imaged.

Conclusion: The Arumbera ss was wet because of insufficient seal even though the structure was closed at this level. The Pioneer is also within closure but has not been penetrated in the two near crestal wells. This well cannot be considered a valid trap which failed to be charged by hydrocarbons.

Tent Hill-1:

The Ordovician Larapinta Group was largely water saturated. A minor gas show was recorded in the lower Stairway and minor high pressure/ low volume gas was present in the HVS. Weste (1992) defines the play as a seismically defined anticlinal structure however there is some uncertainty regarding the veracity of the trap. Thick Stokes Siltstone seal was present.

Pacoota/Stairway- Stokes Siltstone seal:	? CLOSURE
Intraformational Goyder reservoir-seal	: Not Penetrated
Arumbera ss/ intraformational seal	: Not Penetrated
Pioneer Sandstone	: Not penetrated, not imaged
Heavitree Quartzite	: Not penetrated, not imaged.

Conclusion: Confirmation of trap integrity is required. In this well 150 units of gas was recorded during coring of a brecciated shale in the

HVS; minor gas and oil bled from a core. Presumably Tent Hill 1 was located on a separate structure to West Walker-1 which recorded a gas column in the top Pacoota Sandstone which initially blew out but was later tested at 0.6 mmcf. Silurian outcrop patterns suggest Tent Hill -1 was located downdip of the crest but a seismic remap is required.

West Waterhouse-1:

This structure is separated from the crestal portion of the structure by a reverse fault which may not seal. No confirmatory mapping of a 4 - way dip closure trap is available. The well flared gas for 30 minutes prior to coring in the upper Pacoota Sandstone.

West Walker-1 :

In this well there appears to be a thin gas leg on water in the uppermost Pacoota Sandstone. The Horn Valley Siltstone is assumed to have non-seal status in this well considering the overlying Stairway Sandstone is wet. The Stokes Siltstone seal is present in the well. (NB the HVS is not a seal in Palm Valley or Mereenie fields).

Pacoota/Stairway- Stokes Siltstone seal:	CLOSURE
Intraformational Goyder reservoir-seal	: Not Penetrated
Arumbera ss/ intraformational seal	: Not Penetrated
Pioneer Sandstone	: Not penetrated, not imaged
Heavitree Quartzite	: Not penetrated, not imaged.

A thin gas leg in the Pacoota Sandstone supports the notion of structural closure and the play is described in the literature as a seismically defined anticline on trend with Mereenie Field. The play was probably a valid trap but with only minor vertical closure. This well cannot be considered a valid trap which failed to be charged by hydrocarbons as a thin gas leg is recognised in the Pacoota Sandstone. The Stokes Siltstone seal was present but the trap probably has only very subtle vertical closure.

Bluebush-1:

The well was drilled inside structural closure at a number of Palaeozoic levels but the main target, the Arumbera Sandstone, was missing from the intersected sequence. Most target reservoir – seal couplets are missing in the section.

Pacoota/Stairway- Stokes Siltstone seal	: Area of non-deposition
Intraformational Goyder reservoir-seal	: Area of non-deposition

Arumbera ss/ intraformational seal : Area of non-deposition/erosion
Pioneer Sandstone : Area of non-deposition
Heavitree Quartzite : Not penetrated, not imaged.

The structure was a valid 4way dip closure but none of the target reservoir seal couplets, with the exception of the Heavitree-Gillen target, were intersected in this drill hole, being absent via non-deposition. The Loves Creek Mbr comprised tight carbonates and evaporites completely lacking permeability. The Heavitree may still be an oil/gas target in this area. Overall this well cannot be considered a valid trap which failed to be charged with hydrocarbons; it is in fact a valid trap which failed due to the complete absence of reservoir-seal couplets in the well.

Gosses Bluff-1:

The structure formed via a meteorite impact which occurred in Cretaceous times – the structure may post date the main hydrocarbon expulsion phase which is generally acknowledged to have occurred during Devonian sediment loading associated with the Alice Springs Orogeny. The fact that the Stairway Sandstone produced a small amount of gas may hint at much younger gas generation than previously envisaged. Regardless, because of the very late timing of the structure this well cannot be regarded as a valid structural test which failed to yield hydrocarbons.