The Middle Stairway Shale Member: A New Petroleum System And Unconventional Shale Gas Target

Executive Summary

- **The Lower Larapinta Group can be divided into three upward fining, transgressive marine cycles each having the potential to reservoir commercial hydrocarbons in sandstones which mark the base of each cycle. The basinal marine shales which cap each cycle have variable potential to source and seal hydrocarbon deposits.**

- **Cycle-1 (HVS) is capped by the Horn Valley Siltstone which is a proven oil and gas source rock and local seal; it is currently under consideration for shale gas and basin- centred gas. Down-flank source rock enrichment is a key driver.**

- **Cycle-2 (MSSM) is capped by the Middle Stairway Shale Member which has potential to act as a gas prone source rock and provide local seal. The shale also has potential for unconventional gas whether it be basin-centred gas or shale gas. The detail of this new petroleum system remains unassessed due to sparse data but the zone should be carefully monitored during future drilling programs and where practicable cores should be taken viz. Johnstone West-1.**

- **Cycle-3 is capped by the Stokes Siltstone which provides regional seal but lacks source rock potential. However, success ratios indicate the diminution or absence of this seal strongly increases exploration risk at lower levels.**

- **Cycle 2 (MSSM) shales have certainly sourced hydrocarbons reservoired in the overlying Upper Stairway Sandstone and may provide semi-regional seal for underlying reservoirs in the Lower Stairway Sandstone. In particular, in Mereenie field the potential for tight gas in the gross gas column from the Upper Stairway to the Pacoota Sandstone oil/water contact, may have been underestimated by the operator. For instance in East Mereenie-4 it is likely that from the base of the Stokes Siltstone seal (876 m KB) to the Pacoota gas-oil contact (1365 m KB) there is a tight gas column with a gross thickness of 489 m. The gross gas column noted in the WCR was only 170 m thick. Obviously modern stimulation and completion technology could realise this stranded gas.**

- **The large volumes of oil and gas reservoired at Mereenie and Palm Valley fields seem incongruous with the relatively low organic carbon contents in the HVS and also the MSSM. However, thin bituminous shales (TOC up to 9%) have been recorded in the former and possibly thicken into palaeo-topographic lows like the Missionary Plains Trough which is completely undrilled. Similarly, better source rock quality at the MSSM level could occur in basinal areas where anoxic conditions would have been more prevalent than over palaeo-highs such as the Mereenie high.**

- **Shale gas potential can improve with depth as at higher pressures organic kerogen within the shale loses its ability to hold methane which is displaced into shale porosity. Examples of this occur in the US where, following fracture stimulation, shale zones can flow at 30 mmcfd at depths approaching 15000 ft.**

Introduction

The Stairway Sandstone is an enigmatic sequence in that it has always resided as the poor cousin of the Pacoota Sandstone – Horn Valley Siltstone (Pa-HVS) petroleum system. As such it has not attracted as much technical study as the former nor as much exploration in its own right. This study reviews the entire Stairway sequence and its petroleum potential, but with particular emphasis on carbonaceous shales in the upper part of the Middle Stairway Shale Member (MSSM), which are investigated for their shale gas potential and also for their general propensity to form a viable petroleum system by providing a source/seal for conventional hydrocarbon plays .

A key consideration is the dearth of data away from the two producing fields ie Mereenie and Palm Valley. In a sense this adds to the play, as some very encouraging indications are present in the current sparse data set and portend well for the future as this play comes more clearly into focus.

The Stairway Sandstone is a multi-faceted Ordovician sedimentary package in the upper Larapinta Group and is up to 250 m thick ; it was originally described as comprising three members (Havord, 1991):

1) A lower sheet like sandstone member is usually referred to as the Lower Stairway Sandstone Member (LSSM). This is a producing reservoir in Mereenie and Palm Valley fields and has regional extent comprising regressive shoreface/barrier bar sandstones up to 60 m thick. Marine /lagoonal shales up to 20 m thick sometimes occur in the middle part of the sand sequence.
2) A Middle Stairway Shale Member (MSSM) comprising mainly silty shale and subordinate sandstone at the base is capped by a carbonaceous shale 20-40 m thick. Log response is indicative of carbonaceous shale (high gamma ray, high interval transit time) and several gas flows have been recorded from this shale section. There are analogies with carbonaceous shales deposited in the upper part of the HVS which form the main source rock charging the Mereenie and Palm Valley fields, but the latter contain more organic carbon. The sequence denotes a transgressive/regressive marine sequence probably deposited in an epeiric marine sea. Thin rudaceous layers are recorded in this sequence in a number of wells and present as possible fracc. targets.
3) An Upper Stairway Sandstone Member (USSM) is a regressive shoreline sandstone which is a gas producer in Mereenie and Palm Valley fields which is believed to have been sourced from the MSSM. It is sealed by multicoloured silty shales of the Stokes Siltstone.

Petroleum Geology – Ordovician Larapinta Group

The petroleum geology of the Larapinta Group centres on the source potential of the Horn Valley Siltstone (HVS) but additional source rocks occur in the Upper Pacoota Sandstone and the Middle Stairway Shale Member although there is little data relevant to the latter two units.

A review of the main sealing lithologies should recognise that seals can operate in two separate scenarios: 1) over a lengthy geological time span from original sedimentation to the current day and 2) over a much shorter time span covering the production life of the field.
The HVS is a case in point, in that over the geological time span from its inception to the current day, this shale **has not acted as a regional seal** over the Mereenie and Palm Valley

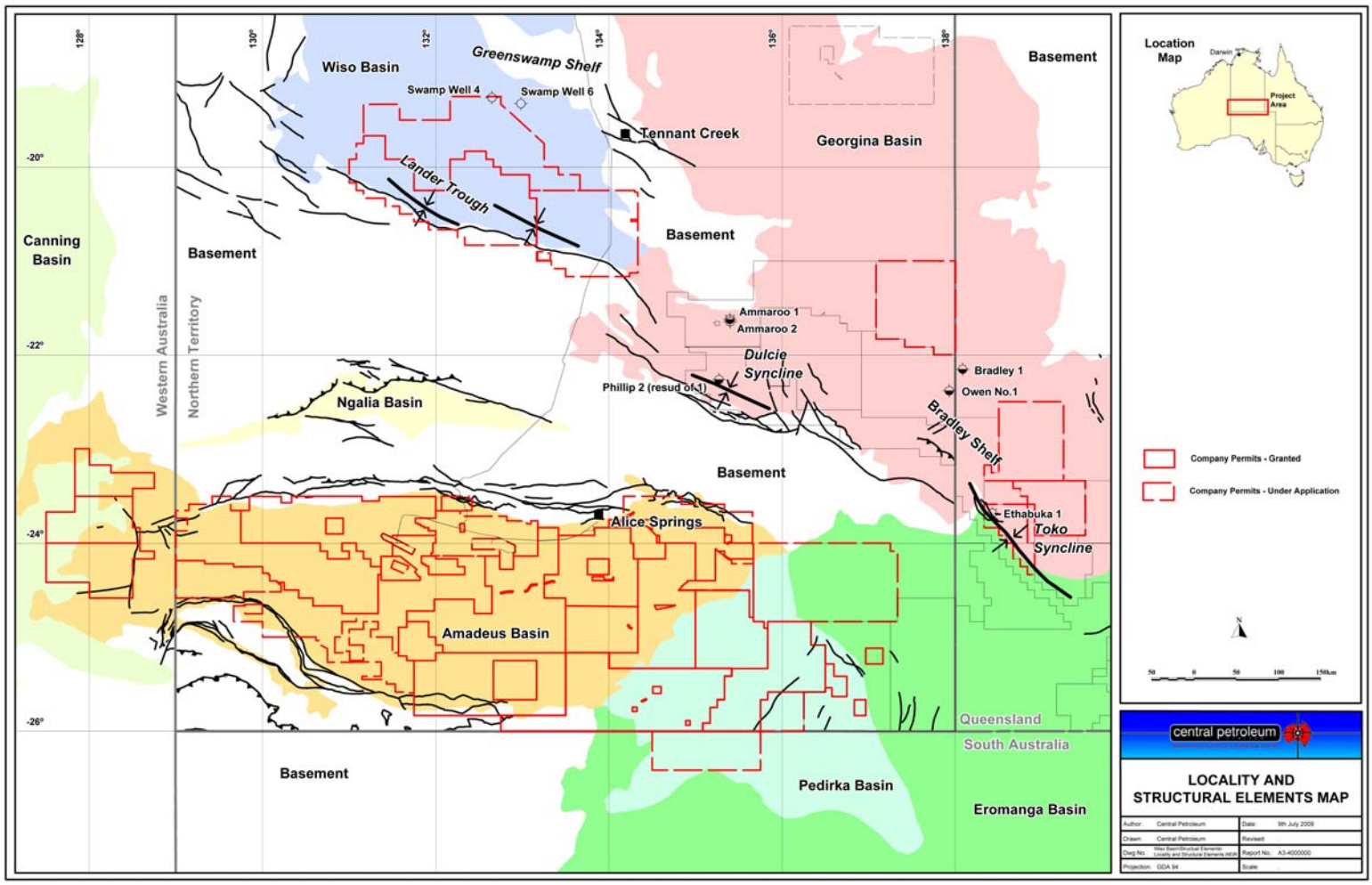


Figure-1 Amadeus Basin regional Location Diagram

fields and thick gross hydrocarbon columns are invoked for both fields. However, while this potential seal has been breached over geological time it is probably true that over the production life of the fields the HVS may locally interfere with communication of producing reservoirs above and below this shale.

In particular, the Middle Stairway Shale Member (MSSM) may in fact act as top seal to the underlying Lower Stairway Sandstone reservoir and is probably a source rock in it's own right. Certainly if the HVS is a **shale gas prospect** then the MSSM must be considered in a similar light. This unit has only been very lightly explored and has been eroded in several crestal structural wells (eg Finke-1, James Range-1, and Johnny's Creek East-1) so data is very limited.

In the following section three transgressive upward fining cycles, forming the lower Larapinta Group, are discussed in more detail. These are:

1) Cycle 1 (HVS) – productive from the Pacoota Sandstone (HVS source, local seal)
2) Cycle 2 (MSSM) – productive from the lower Stairway Sst(MSSM source,local seal)
3) Cycle 3 (Stokes) – productive from the upper Stairway Sst (MSSM source – Stokes seal but no source potential at this level).

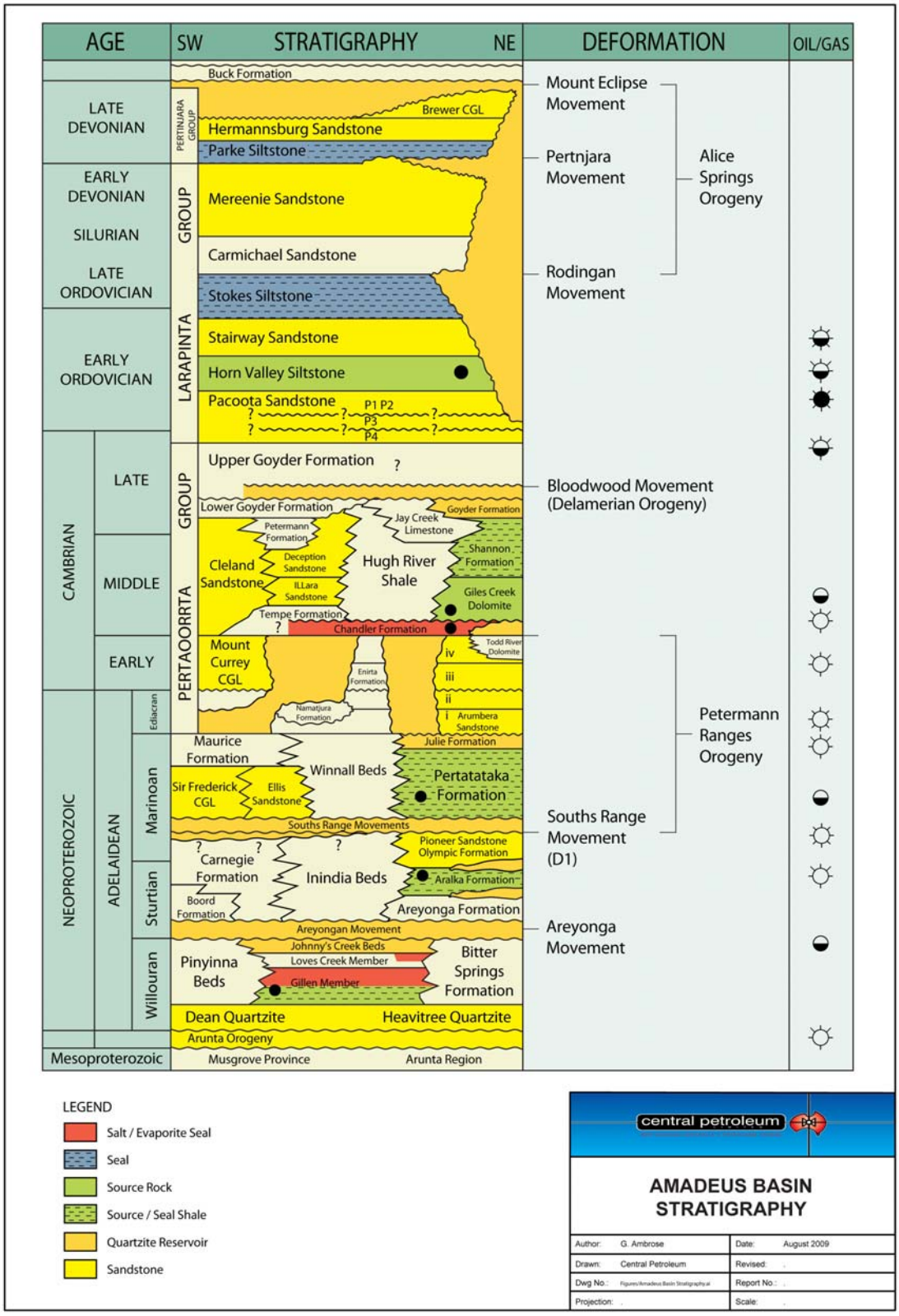


Figure 2 : Stratigraphic Column Amadeus Basin

Table-1 Data for the Middle Stairway Shale Member

Petroleum Well	MSSM – Base/Top	MSSM Isopach	HC Show/ TEST
East Mereenie-1	2700 – 2800 ft	100 ft 30 m	No shows
East Mereenie-2			
East Mereenie-4	3100 – 3185 ft	85ft 26 m	GTS@75 MCFD @3150 FT; this must indicate an indigenous source and probably seal
East Mereenie-3	4010 – 4145 ft	135 ft 41 m	GR indicates high silt content
West Mereenie-1	2795 – 2900 ft	105 ft 32 m	GTS RTSTM @2854 FT open hole test in shale. Must be local source. Gas flows from ss above and below.
Mereenie-1			
Mereenie NW-1		Absent via erosion	Stokes sits on LSSM
Tent Hill-1	939 – 967 m	28 m	No shows, but slow sonic times
West Walker-1	3775 - 3840ft	65 ft 20m	No shows
Tempe Vale-1	231 – 258 m	27m	Oil/gas shows in lower MSSM siltstone; ? local source
West Waterhouse-1	5138 – 5212 ft	74 ft 23 m	
Palm Valley-1	1425 – 1481 m	56 ft 17 m	
Palm Valley-2	5300 – 5470 ft	170 ft 52 m	
Orange-1	6327 - 6535 ft	Shale Absent	Condensed section ;sand rich
Gosses Bluff-2	6327 – 6535 ft	208 ft 63m	High GR shale;20-30 units of gas in ss at base. BG 3 units in shale
Gosses Bluff-1	1350 – 1450 ft	100 ft 30 m	Trip gas flare occurred at 3092 ft

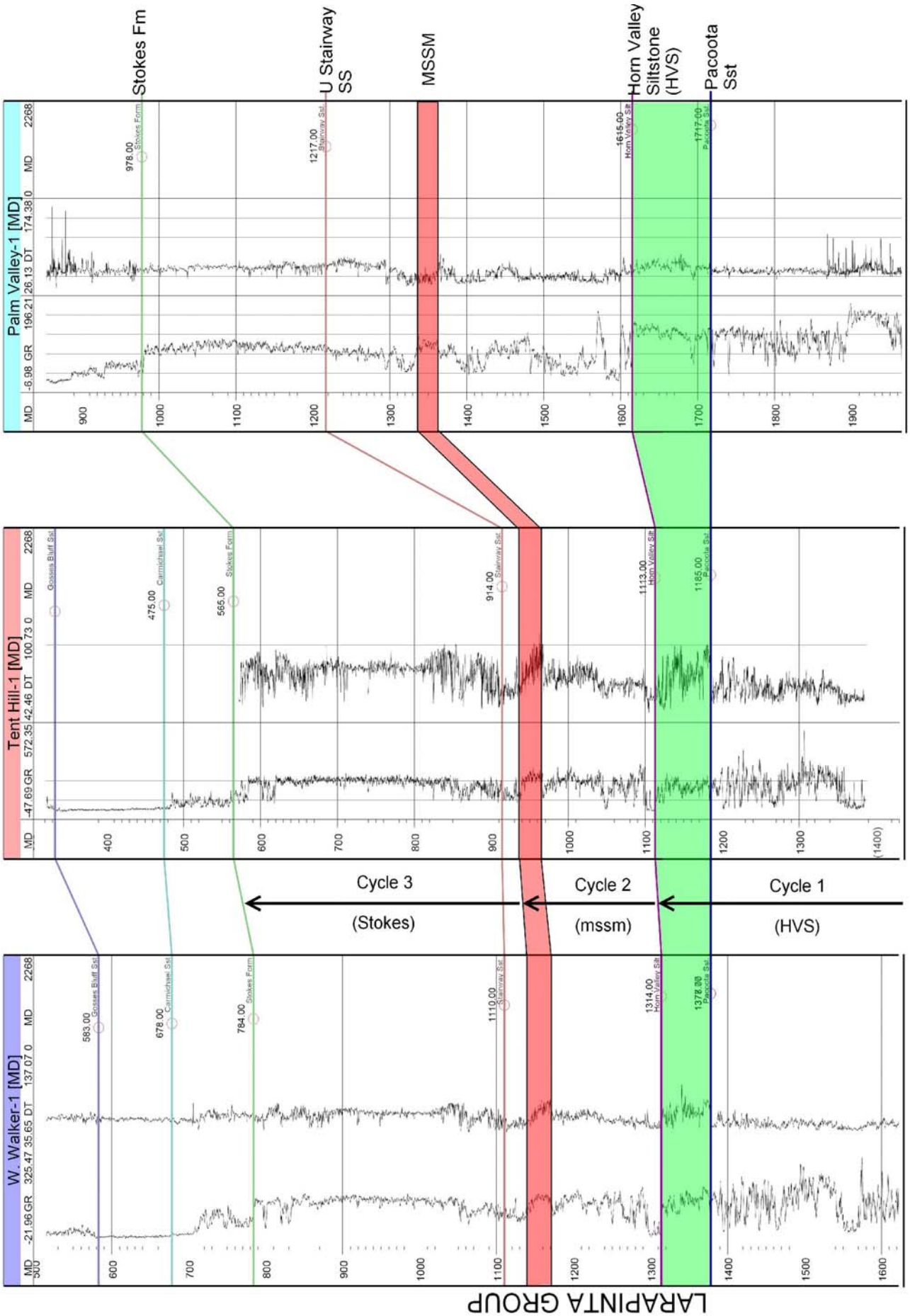
The Ordovician Larapinta Group comprises three vertically stacked, dominantly marine, transgressive cycles. The basal cycle is referred to as Cycle 1 (HVS), the second overlying cycle is referred to Cycle 2 (MSSM). The third cycle is denoted by the Upper Stairway Sandstone and overlying Stokes Siltstone which does provide regional seal but is not a source rock.. A summary of these cycles occurs below:

Cycle 1 (HVS):

Cycle-1 is an upward fining transgressive cycle defined by upper shoreface sandstones (Unit P1) at the base with channelling into the underlying Shannon Formation denoting a regional unconformity (Haines, 1982). Braided fluvial sandstones with subordinate shale disconformably overlie this unit and provide the most productive reservoirs in the Mereenie field (Deckleman,1991). Gradual deepening of the basin is denoted by a transition to higher shale:sand ratios in beds which were deposited in lower shoreface to offshore marine environments. In particular the shales beds, which are lagoonal to marine in origin, thicken thicken up through the section. They are multicoloured in the lower section and become more carbonaceous upwards as the latter was preserved in basinal/lagoonal anoxic environments. The marine transgression culminated in deposition of the HVS which caps Cycle1 (Fig.3) and includes a maximum flooding surface.

The HVS is a pyritic sequence of black anoxic shales with subordinate limestone, siltstone and occasional fine sandstone. This is the dominant source rock of the Amadeus Basin and was probably deposited in a deep epeiric marine basin which was anoxic at the base of the water column but also included a mid-water oxygen minimum zone above an oxygenated zone. Where the latter intercepted the ocean bottom, organic rich sediments accumulated.

Figure 3


Stokes Fm
U Stairway SS
MSSM
Horn Valley Siltstone (HVS)
Pacoota Sst
Palm Valley-1 [MD]
Tent Hill-1 [MD]
W. Walker-1 [MD]
Cycle 3
(Stokes)
Cycle 2
(mssm)
Cycle 1
(HVS)
LARAPINTA GROUP

Interbedded pale bioclastic limestones were probably deposited by gravity driven turbidity currents (Elphinstone and Gorter, 1991) feeding off the shelf break. These basinal shales of the HVS record TOC's of up to 9% (most wells average 0.4-1.0%) and provide a pivotal source sequence; in some places these shales may provide regional seal (eg West Walker-1) but this is not the case at Mereenie and Palm Valley fields.

Cycle-2 (Middle Stairway Shale Member-MSSM)

Cycle-2 is a regional upward fining cycle similar to Cycle-1 (HVS) but generally displaying about half the vertical extent of the latter. The sequence has attracted relatively little attention largely because the target reservoir(s) have poor deliverability and also because the Middle Stairway Shale was overlooked as a significant source rock. The key to unlocking the potential of the petroleum system resides in 1) fracture stimulation of thick tight gas columns in existing fields (Mereenie field) and 2) exploration for similar targets in conventional traps, and 3) definition of unconventional shale gas plays. Analogies between the HVS petroleum system and this second, largely unexplored system in the upper Larapinta Group are summarised below (Figure 3):

Cycle 2 (MSSM) is analogous to Cycle-1 (HVS) in that:

- Both cycles represent broad upward-fining transgressive sequences culminating in deposition of carbonaceous basinal marine shales (Cap Shales) viz. HVS shales in the case of Cycle 1 and Middle Stairway Shales in the case of Cycle 2 (Fig.3).
- Both cycles are denoted by erosional sandstone bodies at the base viz. P1 Pacoota in the case of Cycle 1, the Lower Stairway Sandstone in the case of Cycle-2 and the Upper Stairway Sandstone in the case of Cycle-3 (Fig.2) . With the exception of the Stokes Silstone, cap shale sequences have viable source rock quality with potential in some instances to form a semi-regional seal. However, available data does suggest the HVS is a better source rock than the MSSM.
- Both cycles have potential for unconventional shale gas in the cap carbonaceous shale sequences. Other unconventional shale gas plays could occur in a variety of hybrid lithologies including tight siltstone, limestone, and vfg tight sandstone.
- Both cap shales are pyritic which would affect the shale resistivity response. The sonic response in both cap shales sees a decline in interval transit times reflecting relatively high organic carbon contents.
- The amount of carbonaceous shale in both cap shales is not prolific; in most wells the carbonaceous shale thicknesses in the MSSM are usually < 25 m in total thickness (Fig.3). However, it is known the HVS has expelled very large volumes of oil and gas while the potential of the MSSM cap shales is largely unknown.
- Both shales have wide regional extent and reside in the oil – gas thermogenic maturity windows over very large areas. Nearly all of the prospective areas reside in Central's tenements or application areas giving the company control of these systems over virtually the entire basin.

East Mereenie-4 is a good reference well (Figs 6 and 7) where the sonic log clearly denotes carbonaceous shales in the Cycle 2 MSSM shale. **A gas flow of 76 mcfd was recorded from the middle of this shale zone.** A thin silty sandstone below this zone (at about 1035 m) flowed gas to surface at 44 mcfd (Fig.7). The fluid content of the upper Stairway Sandstone remains uncertain, but given the Stokes Siltstone is regarded as top regional seal, then this stratigraphic interval would represent a tight gas zone. This is supported by gas flows from this zone in other parts of the Mereenie field. As an example, in East Mereenie-4 it is likely the entire interval from the base of the Stokes Siltstone seal (876 m KB) to the gas-oil contact (1365 m KB) is a tight gas column with a gross thickness of 489 m. The gross gas column noted in the WCR was only 170 m thick. It seems probable the tight gas / shale gas potential of the field may be largely underestimated.

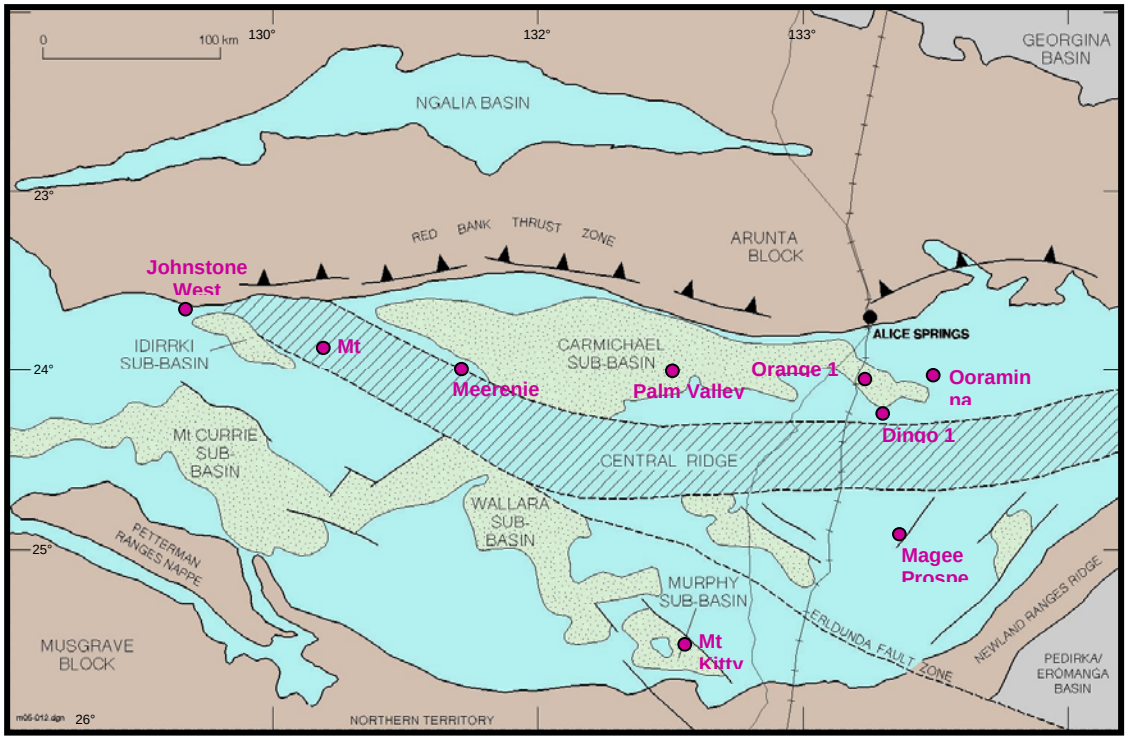
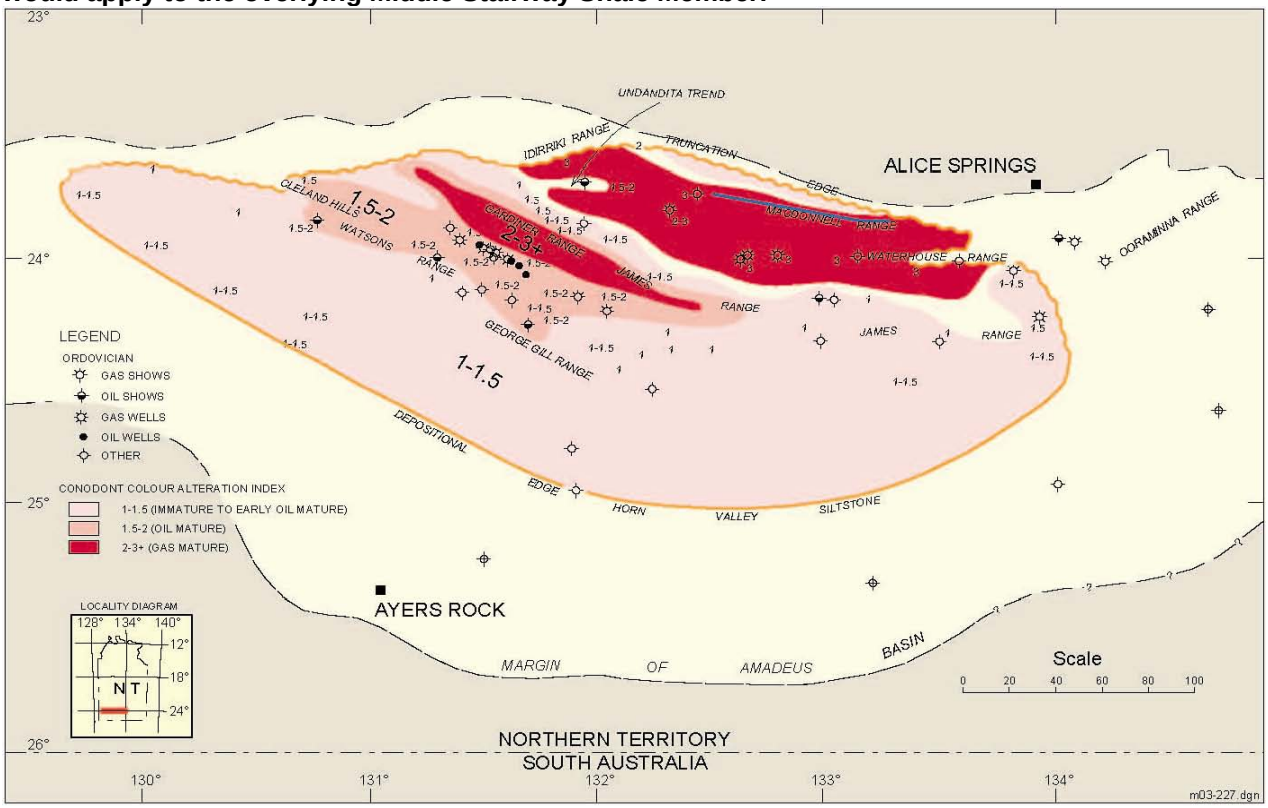


Figure 4 : Amadeus Basin Tectonic Elements

Figure 5 : Distribution of thermal maturity of the Horn Valley Siltstone; similar zones would apply to the overlying Middle Stairway Shale Member.



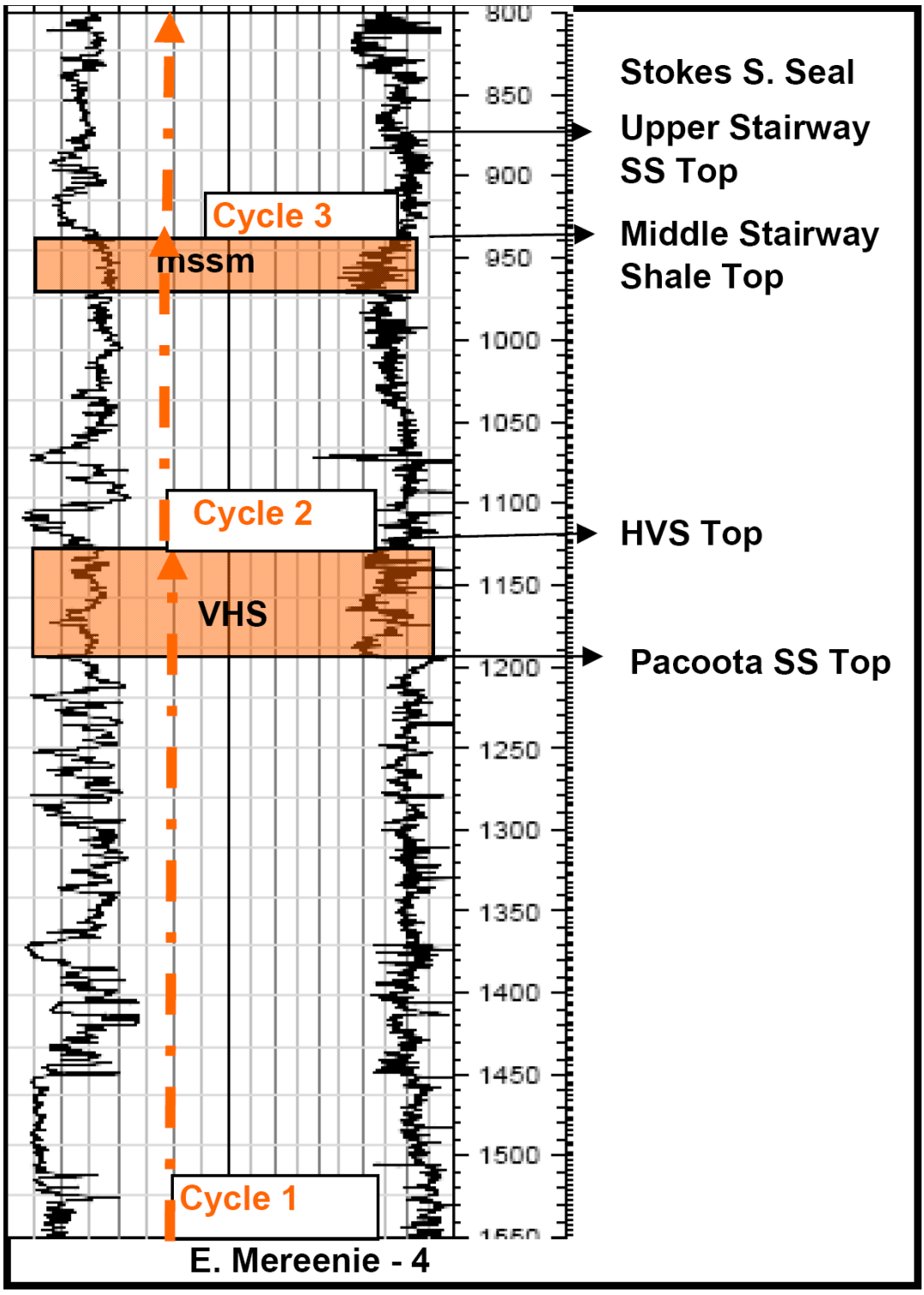


Fig.6 Cyclic Sedimentation and Basinal Shales in the Larapinta Group

A more detailed illustration of the MSSM shale occurs in Figure 6. The actual gross zone of carbonaceous shale as measured from the sonic log is 22 m. The lithology is mainly grey-dark grey siltstones and shales which are indurated and brittle. Occasional bioturbated sandstone interbeds were cored as were several indurated rudites. The latter are phosphatic, carbonaceous and dolomitic with black cobbles occurring in a siltstone matrix.

The shales are massive/fissile and sometimes contain reworked bivalves. The depositional environment was that of an epeiric sea with bottom waters being anoxic (dark grey carbonaceous shales) while some pale coloured clastics being deposited by turbidity currents sourced from the adjacent shelf.

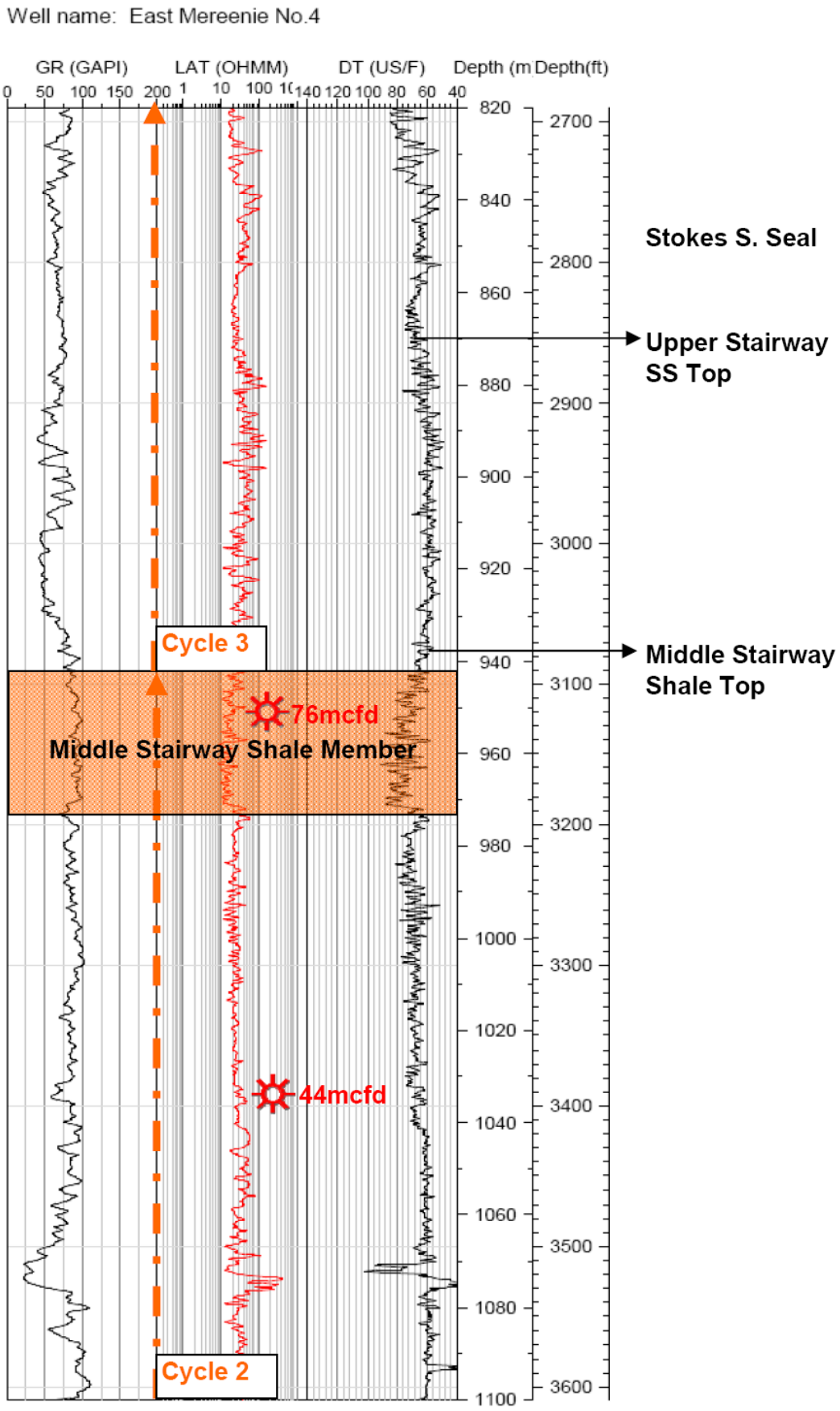


Figure 7 East Mereenie-4; Middle Stairway Shale Member

Cycle- 3

The topmost sedimentary cycle of the Larapinta Group comprises the Upper Stairway Sandstone Member (Figs 6 and 7) capped by the Stokes Siltstone. The former is a gas reservoir at Palm Valley and Mereenie fields with source in both instances being the MSSM.

The Stokes Siltstone is of Middle Llanvirnian age and defines a succession of fine clastics reaching a thickness of 650 m in the north-central part of the basin, thinning southward and westward. The depositional environment had become more saline by this time and intertidal, supratidal and hypersaline conditions prevailed (Kennard and Nicoll 1986). The dominant lithologies are shale and siltstone with occasional evaporites. The lack of organic matter indicates a restricted, rather than open marine environment, suggesting that the eastern Larapintine seaway closed at this time (Walley et al 1991).

In summary, the shale cap of Cycle-3 ie the Stokes Siltstone, is a regional seal but comprises a multicoloured shale /siltstone sequence deposited in an oxic marine setting thus resulting in a complete lack of source potential.

Geochemistry of the Larapinta Group

a) Horn Valley Siltstone (HVS)
The geochemistry of the HVS is well documented in Gorter (1984), Eliphinstone and Gorter (1991) and Summons and Powell (1991). Detailed analysis of fully cored sections in both Tempe Vale-1 and Tent Hill-1 indicate the majority of the shale section has a TOC of less than 1%. Indeed Summons and Powell indicate TOC's are generally in the range 0.4 – 1.0 % with occasional thin beds up to 4 – 6%. Thin bituminous shale zones in Temp Vale-1 recorded TOC's of up to 9% but these seem unusual. It appears that prolific oil and gas generation has occurred from this source rock where the majority of shale beds contain less than 1% TOC. Similarly the Pertatataka Formation, which is believed to have sourced the Dingo, Pioneer and Orange gas accumulations records consistently low TOC'S, 90% of values being less than TOC = 0.5%.

b) Middle Stairway Shale Member(MSMM)
This shaly unit has regional extent but the only significant sampling occurs in Tent Hill-1 where TOC's vary between 0.2% and 0.5%. The values are similar to the Pertatataka Fm but slightly lower than for the Horn Valley Siltstone. In summary it is believed the MSMM is generally not as organically rich as the HVS and is unlikely to be an oil source. However, its TOC's are in line with another ubiquitous gas source rock, the Pertatataka Fm and as such this shale's potential for widespread gas generation is high. In addition the shales are arenaceous in part which would improve their susceptibility to fracture stimulation.

CONCLUSIONS

The Larapinta Group can be subdivided into three regional, upward fining, transgressive sedimentary cycles capped by basinal marine shales with variable source rock potential and sealing capacity. The HVS capping Cycle-1 is well documented as an excellent oil/gas source rock and also has potential to provide local seal. The Middle Stairway Shale Member caps Cycle-2 and is a viable gas source rock and may provide base seal to the Upper Stairway Sandstone gas reservoir. The Stokes Siltstone caps Cycle-3 and provides regional seal but it is not considered a viable source rock. The basinal marine facies in each cycle appears to become progressively more oxic from Cycle 1 (HVS) to Cycle 2 (MSSM), and finally to Cycle 3 where the Stokes Siltstone completely lacks anoxic carbonaceous shale.

Shale gas potential can improve with depth as at higher pressures organic kerogen gradually loses its ability to hold methane which is displaced into shale porosity. Increase shale induration at depth also improves susceptibility to fracture stimulation. In most ways the shale gas story in Central Australia is just beginning.