A Devonian Rimmed Carbonate Platform Complex and Barrier Reef Complex Underlies the Pedirka Basin in the Simpson Desert

Executive Summary

- **New seismic data has outlined a giant Devonian barrier reef buildup up to 1.7 km thick formed on the margin of the Hale River Block where reef facies underlie the Pedirka Basin. This is the first example of this and associated features east of the Canning Basin and their presence gives creedence to earlier interpretations of a rimmed carbonate platform facies developed over the Arltunga Arch about 20 km to the south (Erec Prospect and Simpson East Prospect).**

- **Barrier reef development was controlled by interplay between gradual continued subsidence on a major tensional fault, the Pellinor Fault and eustatic sea level events which facilitated in a general sense, "keep up aggradational sedimentation" via barrier reef development. This style of aggradational sedimentation was also pervasive during development of thick back reef and fore reef facies which are over 1.2 km thick. Channelised fore reef / slope sdiments dip away from the barrier reef core at a high angle and thin basinward into pelagics and fine clastics of the distal basin.**

- **All the classic facies associations seen in the hydrocarbon bearing Devonian – Carboniferous sequences of North America (eg Leduc field) and the North Caspian Region (eg Tengiz field) are seen in some form or other in the Pellinor Barrier Reef Complex (Pellinor Lead) and the Arltunga Carbonate Platform Complex (Erec Prospect) developed to the south. Potential reservoirs in these two linked sedimentary complexes include, for the barrier reef complex: fringe reef / back reef / barrier reef / channelized fore reef slope / and toe of slope apron clastics. In the case of the carbonate platform to the south potential reservoirs occur in: the inner platform / carbonate mound facies/ platform rim/ fore reef slope / and toe of slope apron clastics. All of these facies have reservoired hydrocarbons in different basins around the world and examples are cited.**

- **The carbonate facies architectures in both studied complexes are controlled by salient basement faults which were largely tensional during the Devonian – Carboniferous with very large displacements of up to 2 km (eg Pellinor Fault). Drape and compaction effects both over the main tectonic elements and massive biohermal reefal developments controlled structures at Permian and Mesozoic levels. Consequently some of the mapped prospects have multi-target potential in both Palaeozoic and Mesozoic sequences.**

- **Hydrocarbon gas chimneys and associated HRDZ's are associated with major fault zones controlling basinal facies down dip from Devonian platform/reefal complexes. The charge is most likely coming from Devonian source rocks which were probably generative during the Cretaceous. This is encouraging from a charge perspective and it is well known from other drilled Devonian carbonate basins that associated facies can provide excellent oil/gas source potential (eg back-reef and fore-reef facies).**

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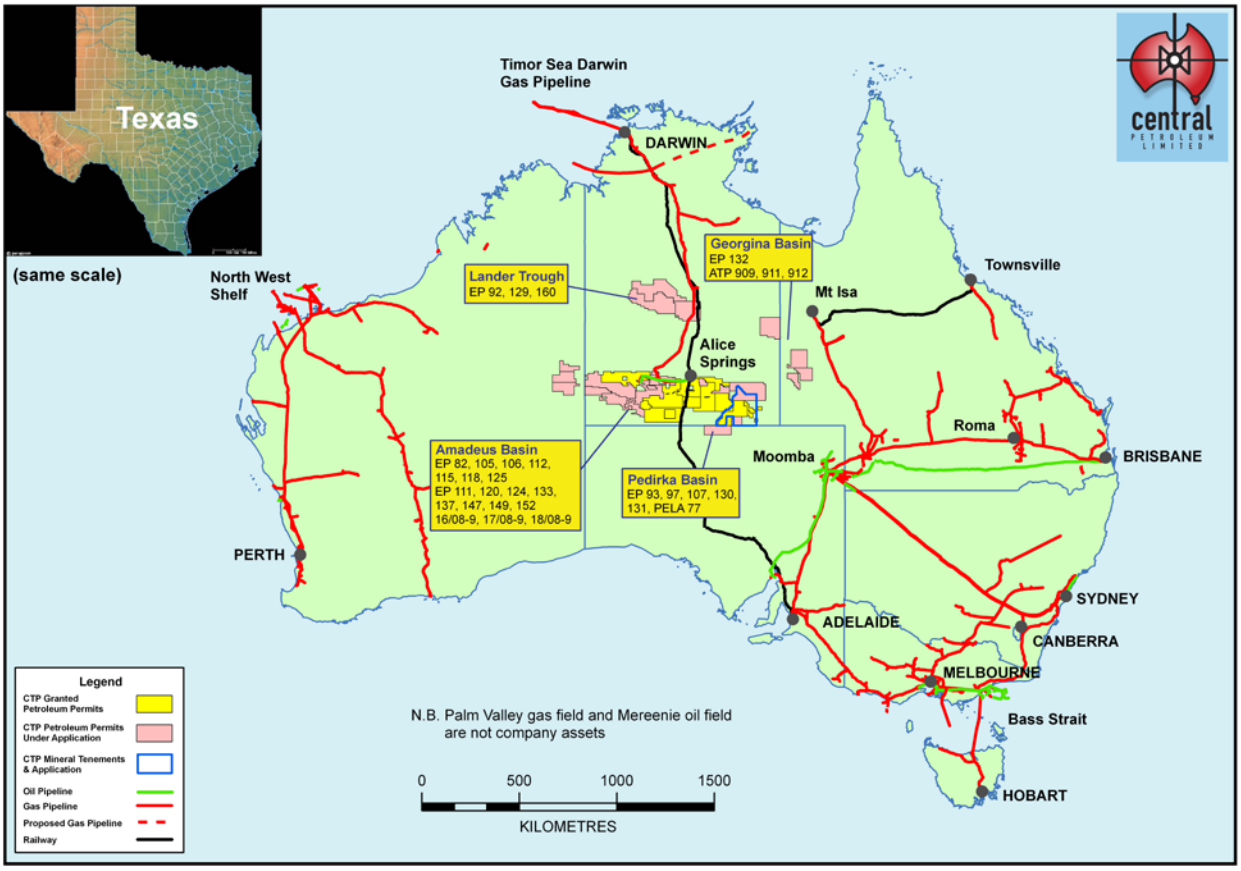
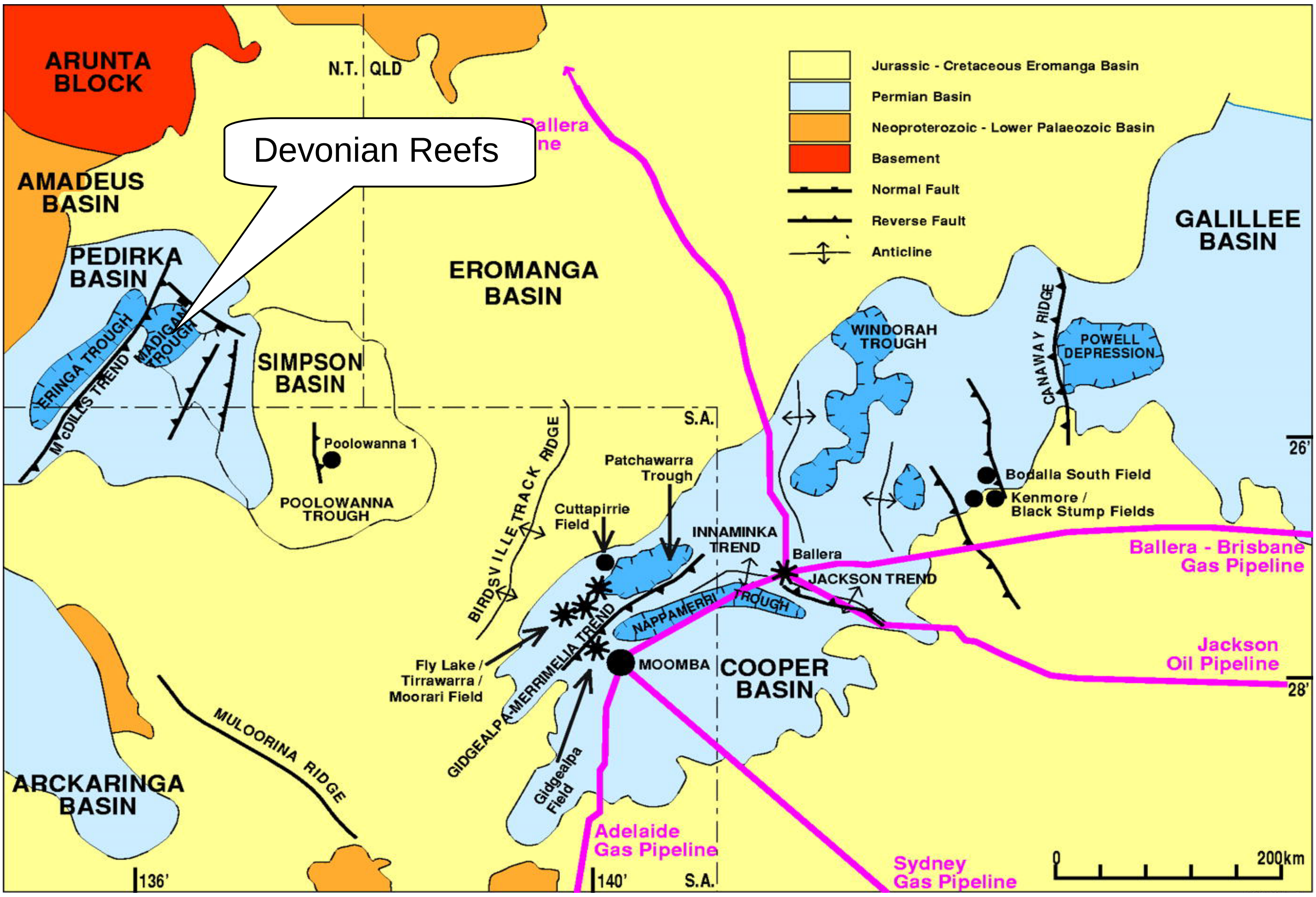


Figure 1 – Regional Location Diagram

Figure 2 - Semi – regional location diagram.



Introduction

Devonian – Carboniferous age rimmed carbonate platform and associated facies were first recognised in the Simpson Desert area by Central Petroleum (Ambrose, 2008) when diagnostic seismic signatures were investigated over the Simpson/Erec prospects located in the NE portion of the Pedirka Basin. These were later referred to in Ambrose and Heugh (2010) as was evidence for hydrocarbon seepage from this sequence in Ambrose (2009). Various elements of this platform sequence, including inner platform, carbonate mound, rim, slope, turbidite and basin facies were recognised. This was the first time a Devonian rimmed platform complex had been recognised east of the Canning/ Bonaparte Basins.

Later, in 2010, in order to investigate the southern faulted margin of the Hale River Block, CTP farmed in to a portion of EP 97 (Pellinor Farmin Block) and subsequently acquired seismic over this salient basement margin. Several of the seismic lines, acquired at a high angle to the SE trending fault system, clearly delineated a system of steep normal faults with down to basin displacements of up to 2 km. Their influence on development of a Devonian barrier reef complex developed in the hanging wall has been fundamental and a suite of hydrocarbon plays are now recognised in this unique geological terrane. Although there have been no drill hole penetrations, modern seismic provides clear evidence of a giant barrier reef and associated facies formed on the southern downthrown margin of the Hale River Block, adjacent to the Pellinor Fault Trend. Recognition of this suite of facies provides strong support for earlier interpretations of Devonian carbonate platform – rim reef complex associated with the Erec Prospect which overlies the Arltunga Basement Arch. There are important analogies with Devonian barrier reefs developed along the faulted margins of the Kimberley Block in the

Canning and Bonaparte Basins in Western Australia. However the massive vertical aggradation of clearly defined barrier reef, back reef and fore reef facies attests to a unique geological terrane in the Simpson Desert.

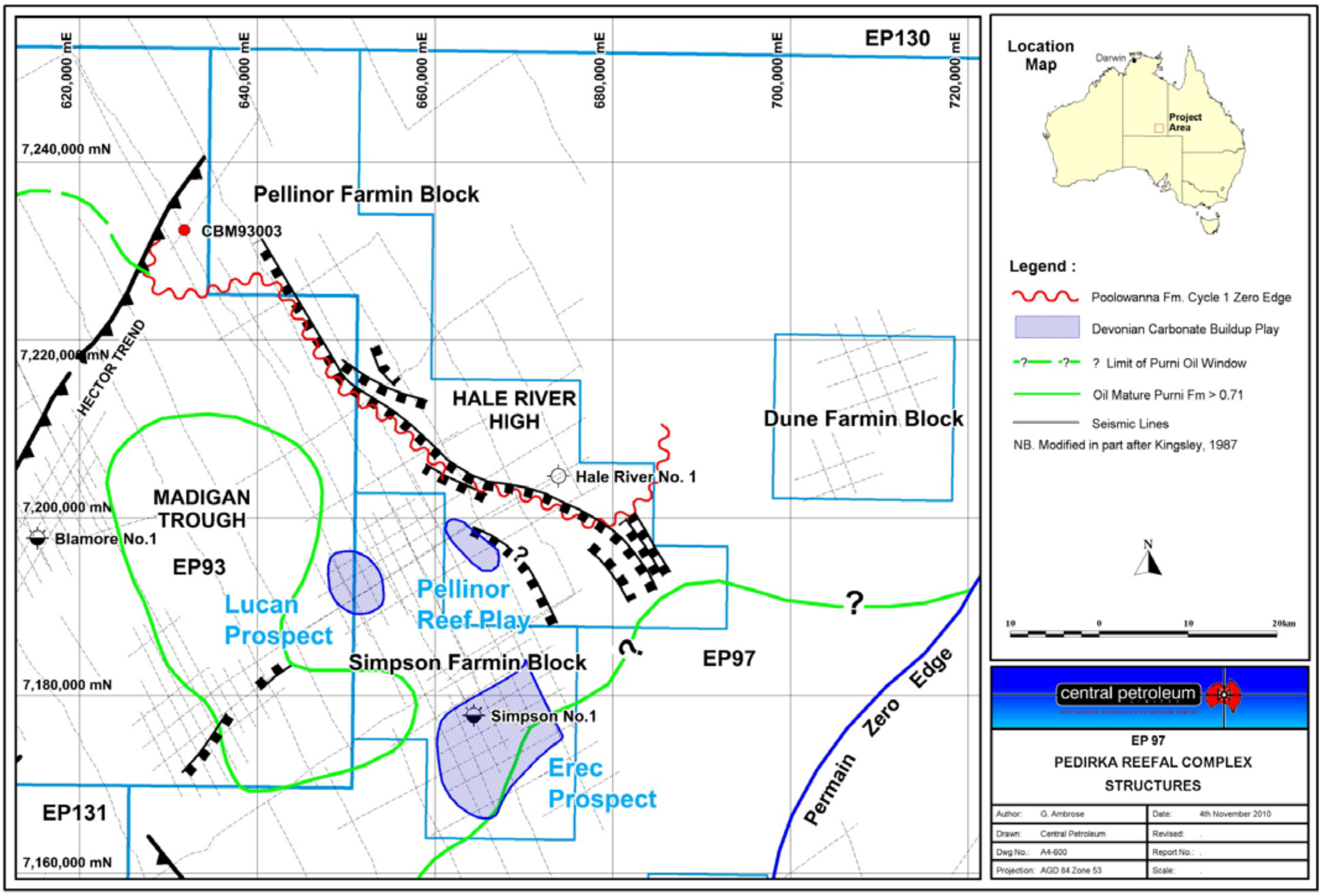


Figure 3 – Location of Erec and Pellinor Carbonate Plays

Regional Geology

The regional geology of the Simpson Desert area is described in Ambrose and Heugh (2010). To the north the Hale River Block is a pivotal tectonic element which deflected stress regimes through time; it is a major basement feature of similar age and origin to the Arunta Block to the north. The southern faulted margin (Pellinor Fault Trend) marks the effective basin edge for Palaeozoic sedimentation ranging from the Devonian – Carboniferous through to the Permian and Triassic section although sporadic thin sedimentary outliers are recorded (eg in Hale River-1). Jurassic- Cretaceous sediments of the Eromanga Basin are draped over the block which was probably originally bound by major normal fault systems on its western (Hector Fault Trend) and southern margins (Pellinor Fault Trend). Both these fault trends were reactivated during Miocene tectonism with the former becoming a major reverse fault while the latter remained tensional. Carbonate platform facies were deposited on the Arltunga Basement High which controls the Simpson Nose 20 km southeast of Pellinor Reef .

Devonian carbonate facies architecture in both areas is controlled by deep basement faults which were also fundamental to Permian depositional patterns (eg the deep seated Madigan Fault controlled the eastern edge of the Madigan Trough). Devonian carbonate bodies form major buttresses over which Permian and Mesozoic sequences are draped with major

Miocene reactivation on bounding faults; these are probably far more widespread than currently known and comprehensive exploration of this previously unknown sequence is at an early stage. A preliminary discussion of the various carbonate facies and their hydrocarbon potential occurs below.

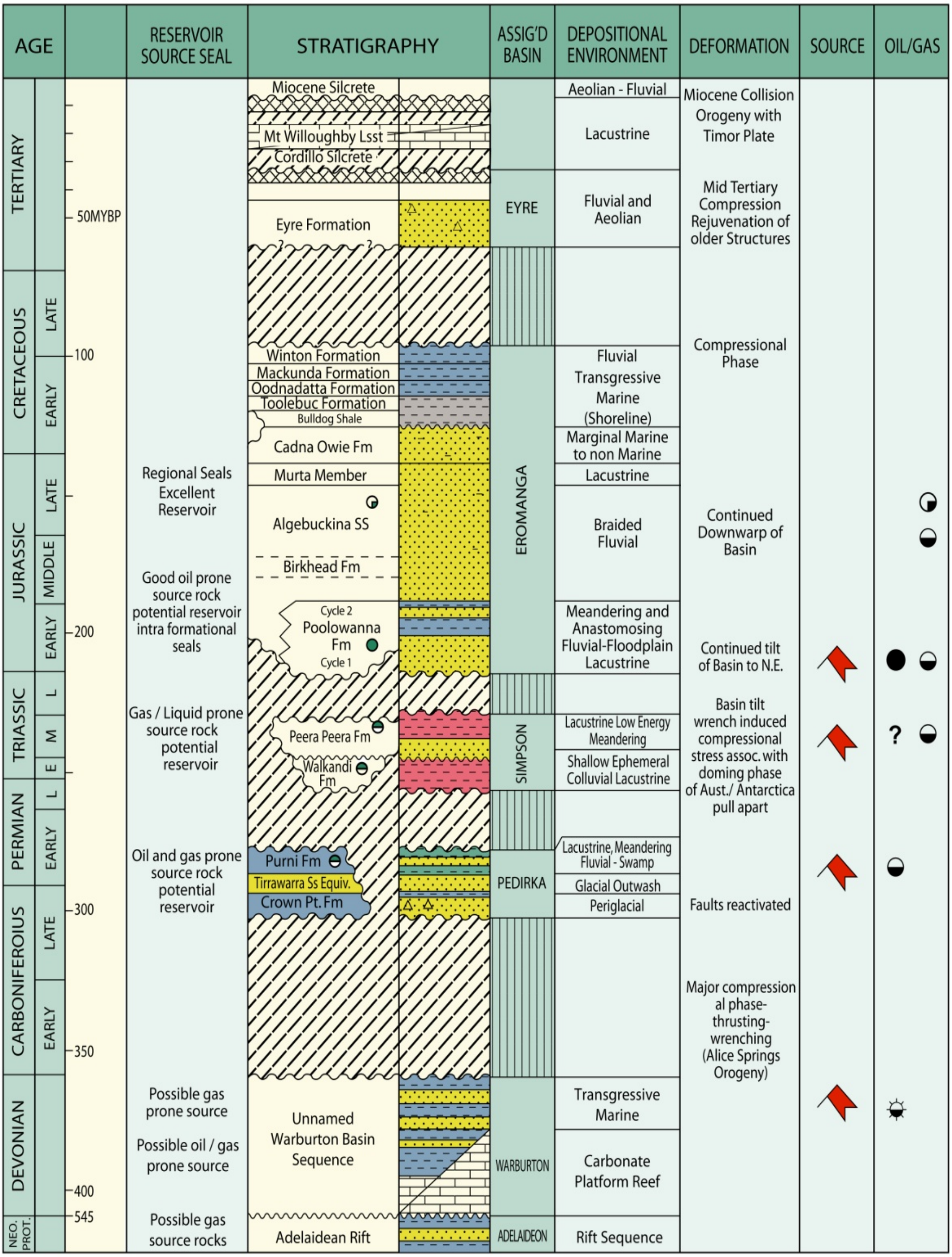


Figure 4 Stratigraphic Table

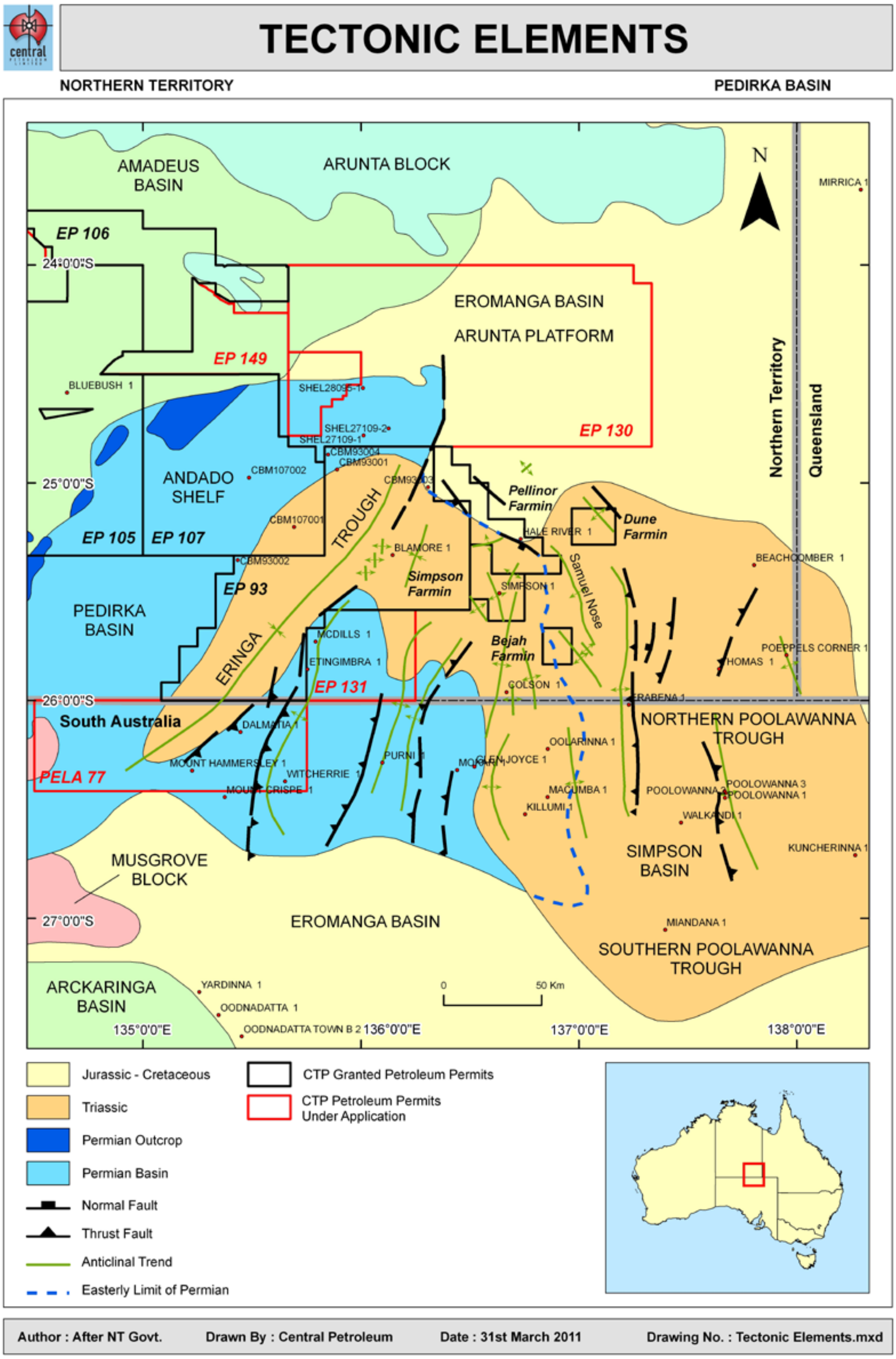


Figure 5 : Regional Tectonic Elements and Petroleum Tenements

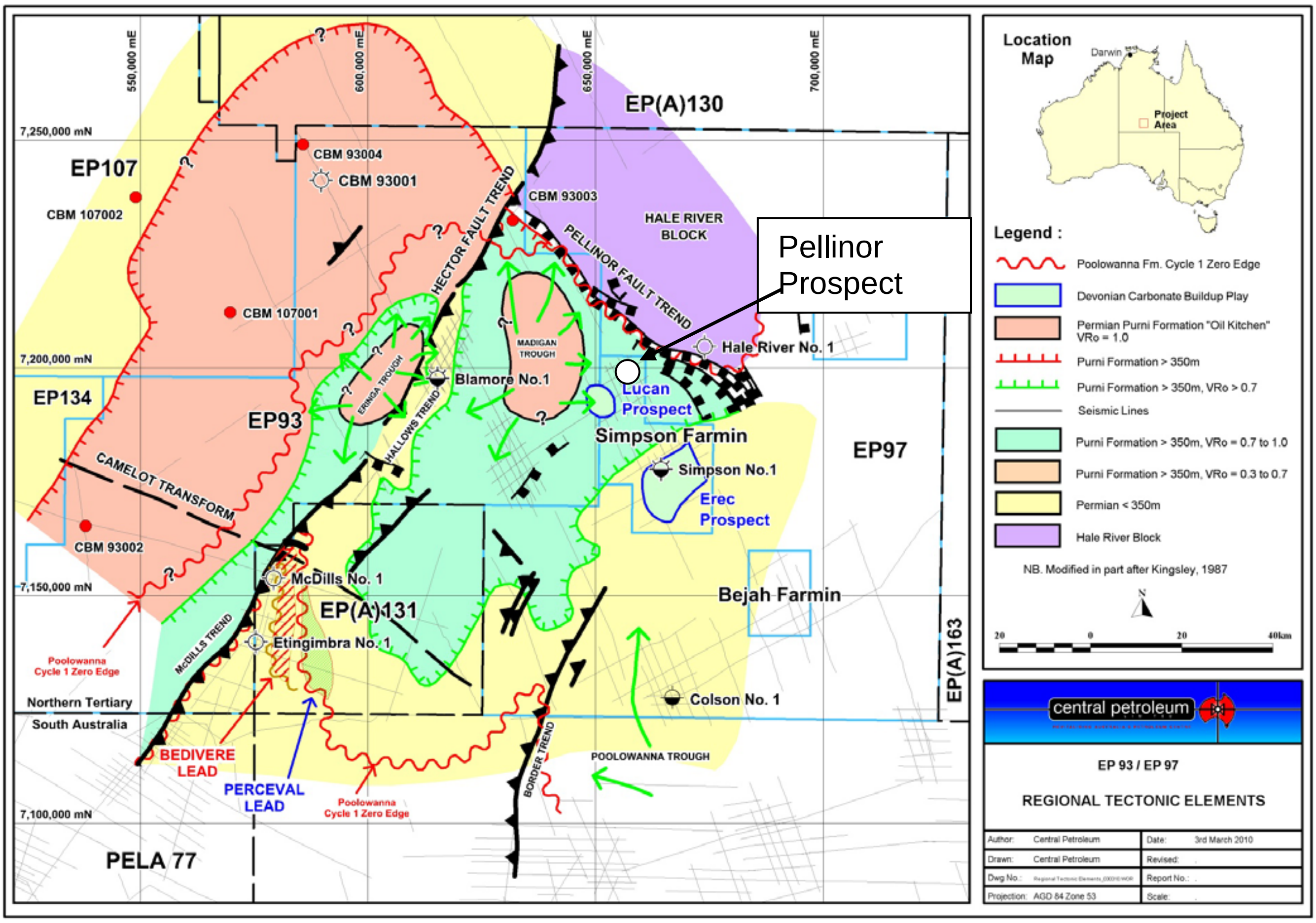


Figure 6: Local Tectonic Elements

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1. Pellinor Barrier Reef Complex (PBRC)

Recent seismic lines, located at a high angle to the Pellinor Fault Trend, clearly depict a massive normal fault which controlled, in the hanging wall, deposition of a Devonian barrier reef up to 1.7 km thick with similar thicknesses of back reef facies abutting the fault scarp. Fore reef facies dip away from the barrier reef and gradually thin down dip to distal slope and eventually to basin facies. The sedimentary architecture of the PBRC is described below and the petroleum potential of each component is interpreted from seismic signatures and comparisons with analogous carbonate complexes described elsewhere around the globe.

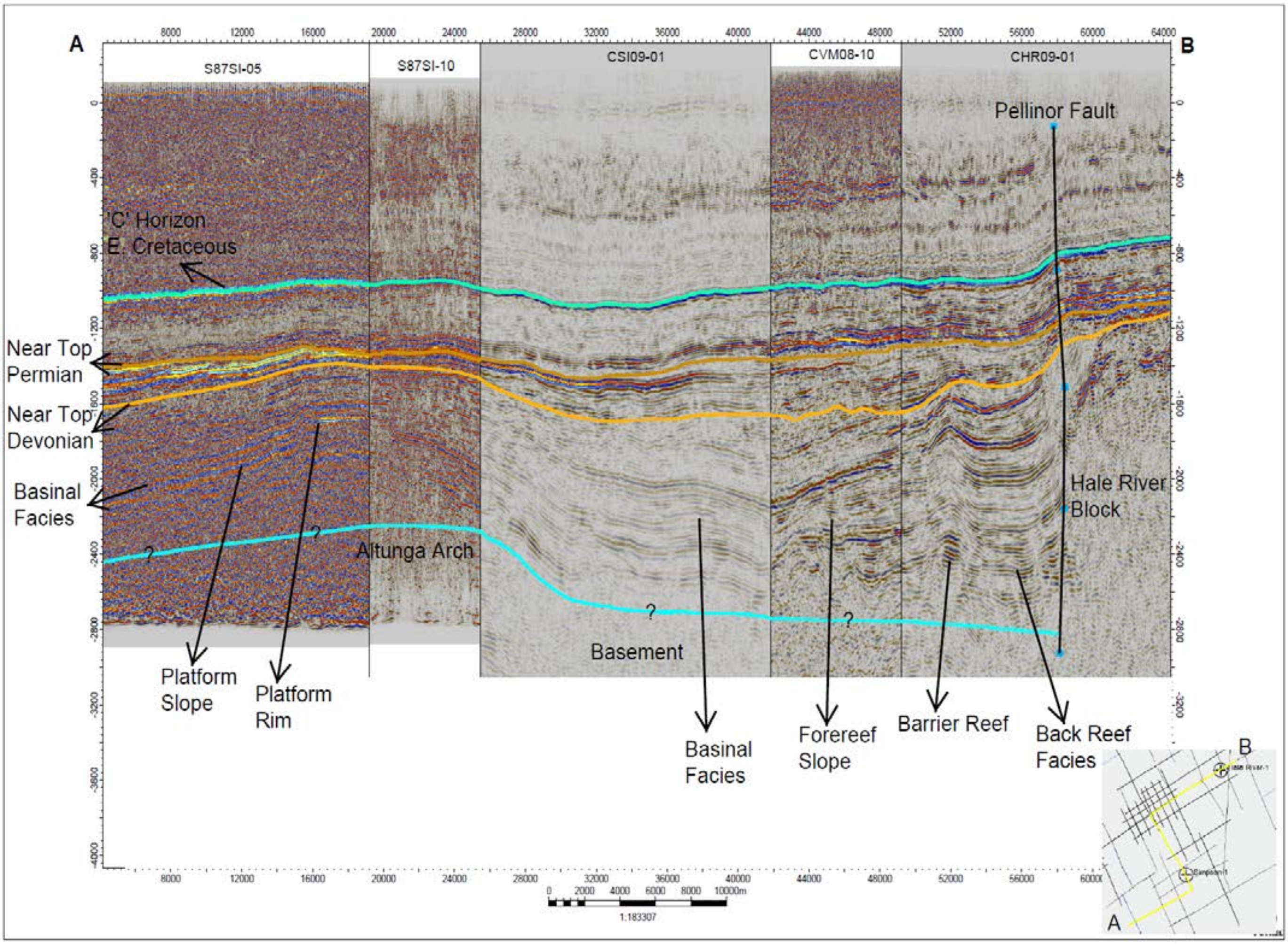


Figure 7 : Carbonates Buildups developed over the Arltunga Arch and at Pellinor Prospect.

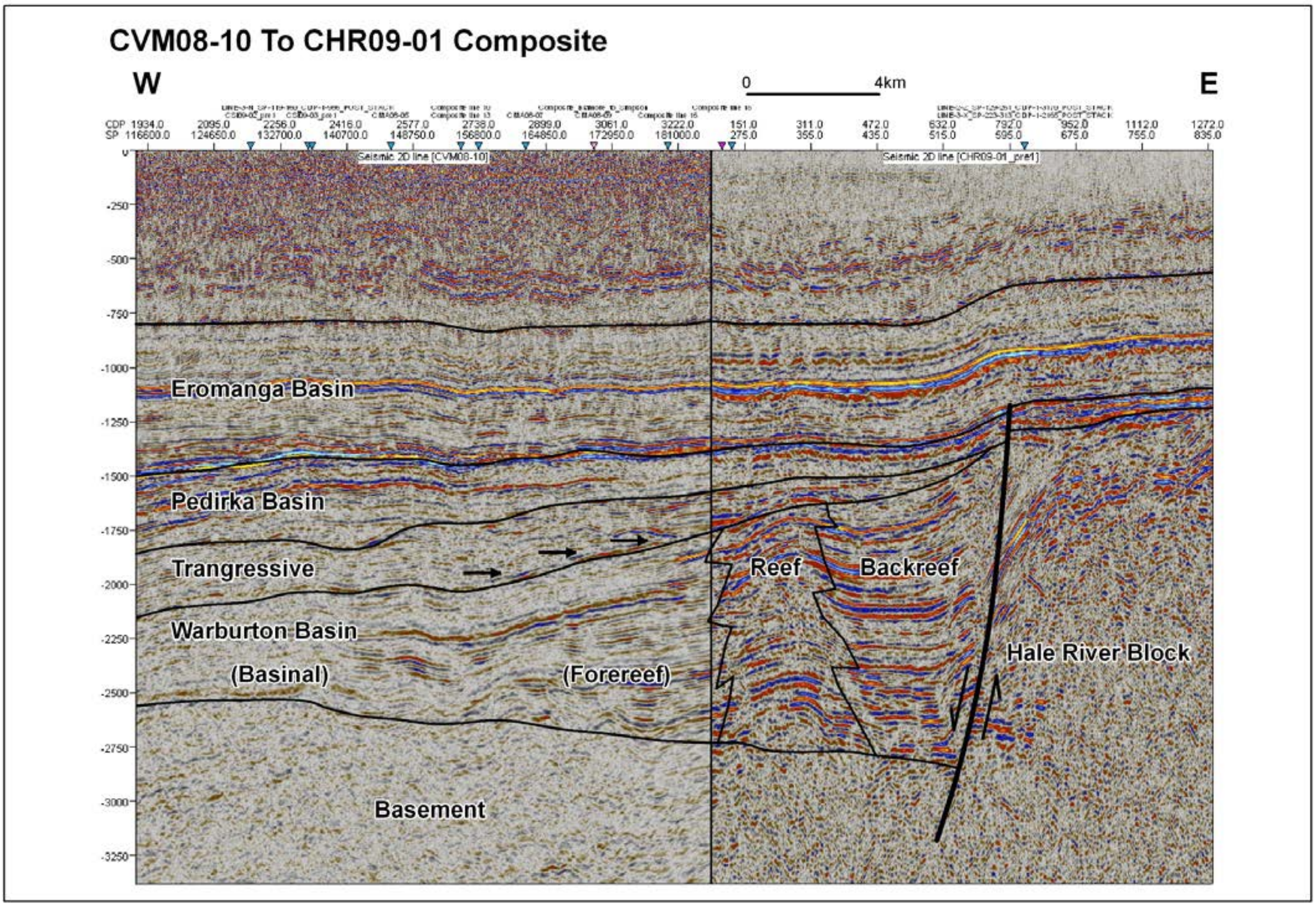
1.1 Barrier Reef Facies

By definition barrier reefs are narrow reef trends built parallel to a shoreline being separated from the hinterland by lagoonal back reef facies. The barrier reef can follow the coast for long distances often with short interruptions termed passes or channels (eg as seen on the Great Barrier Reef). The Pellinor Reef is 3-5 km wide and at least 10 km long although its exact dimensions have yet to be determined. A second ? back stepping fringing reef appears to be developed landward up against the main bounding fault and this may relate to a transgressive phase denoting the final drowning event.

The vertically aggrading barrier reef could be as thick as 1700 m and is clearly denoted by stacked, convex upward seismic reflectors. This style of barrier reef is very unusual largely because of its great vertical extent and the fact that it developed via a subtle interplay of sea level variations and continued subsidence on the Pellinor Fault. Certainly there would have been periods of emergence with associated weathering and karst development and seismic signatures give some indication of the complexity of this in the barrier reef facies. Diffuse seismic signatures within the reef core may indicate massive biohermal developments and intervene between intervals of strong amplitude reflectors. Some of these would be karsted surfaces while others could represent periods of transgression when various reef facies were interbedded with marine sandstones and shales. The sedimentary packages are up to 50 ms thick (~ 100 m thick) and maintain a strong convex upward attitude, probably largely as a result of drape and compaction over the narrow barrier reef core which underwent relatively early cementation.

The depositional regime responsible for this barrier reef – back reef complex is one of "keep up" sedimentation which occurs when the rate of sediment accumulation (reef aggradation) keeps up with basin subsidence, which itself results in the continual creation of accommodation space. In this case reef and back reef facies aggraded in shallow water. However, this is a generalisation in part, as eustasy would have complicated this model resulting in a complex history of emergence and karstification. The structural apex of the reef core appears to be rising to the southeast and additional seismic will determine if there is a structural/stratigraphic culmination in this direction.

Figure 8: Pellinor Barrier Reef Complex on the margin of the Hale River High



The " keep up" barrier reef facies is typical of reefs that tracked sea level but did not exceed it. Bourque (1992) indicates the geometry of ancient reefs is controlled by the nature of sea level fluctuations and the ability of reef-building organisms to track these. However, major subsidence in the hanging wall of the Pellinor Fault, which is equivalent to a rise in seal level, was a dominant driver for reef growth but eustatic sea - level variations would also have been superimposed on this overriding trend of basin subsidence.

The unconformity at the top of the PBRC is often denoted by a scalloped unconformity surface denoting a drumlin topography developed on the Early Permian - Carboniferous glacial terrane; the glacial sequence clearly onlaps this surface with evidence of some erosion of Devonian sediments over the crest of the main reef core. Detailed seismic facies/structural mapping awaits processing of 2010 lines but preliminary observations are outlined below:

- Figure 7 : This figure depicts a composite of regional seismic lines transecting the Erec Platform (Arltunga Arch) and the Pelinor Reef prospects and the intervening basinal section. The Erec play above the Arltunga Arch targets potential platform, rim reef/shoal and fore-reef slope targets. The Pellinor Reef comprises potential fore-reef, barrier reef, back reef and fringing reef targets.

- Figure 8 shows a thick clearly defined convex upward, barrier reef core flanked by distinct fore-reef and back-reef facies. Erosive scallopping at the base Early Permian unconformity surface is noted near the crest of the reef core. The reef core shows seismic evidence of emergence and karstification and there is a hint of vertical hydrocarbon migration. To the southeast carbonate platform facies with attendant rim reef development occurred over the Arltunga Arch.

- Figure 9 also shows seismic evidence of emergence in the reef core and this section probably transects a relatively shallow portion of the reef complex. The upper half of the barrier bar shows a twin reef culmination with intervening sag resulting from drape and compaction. The geological evolution of this feature is due to differential compaction over the two margin reef culminations (Figure 8) which probably underwent early diagenesis.

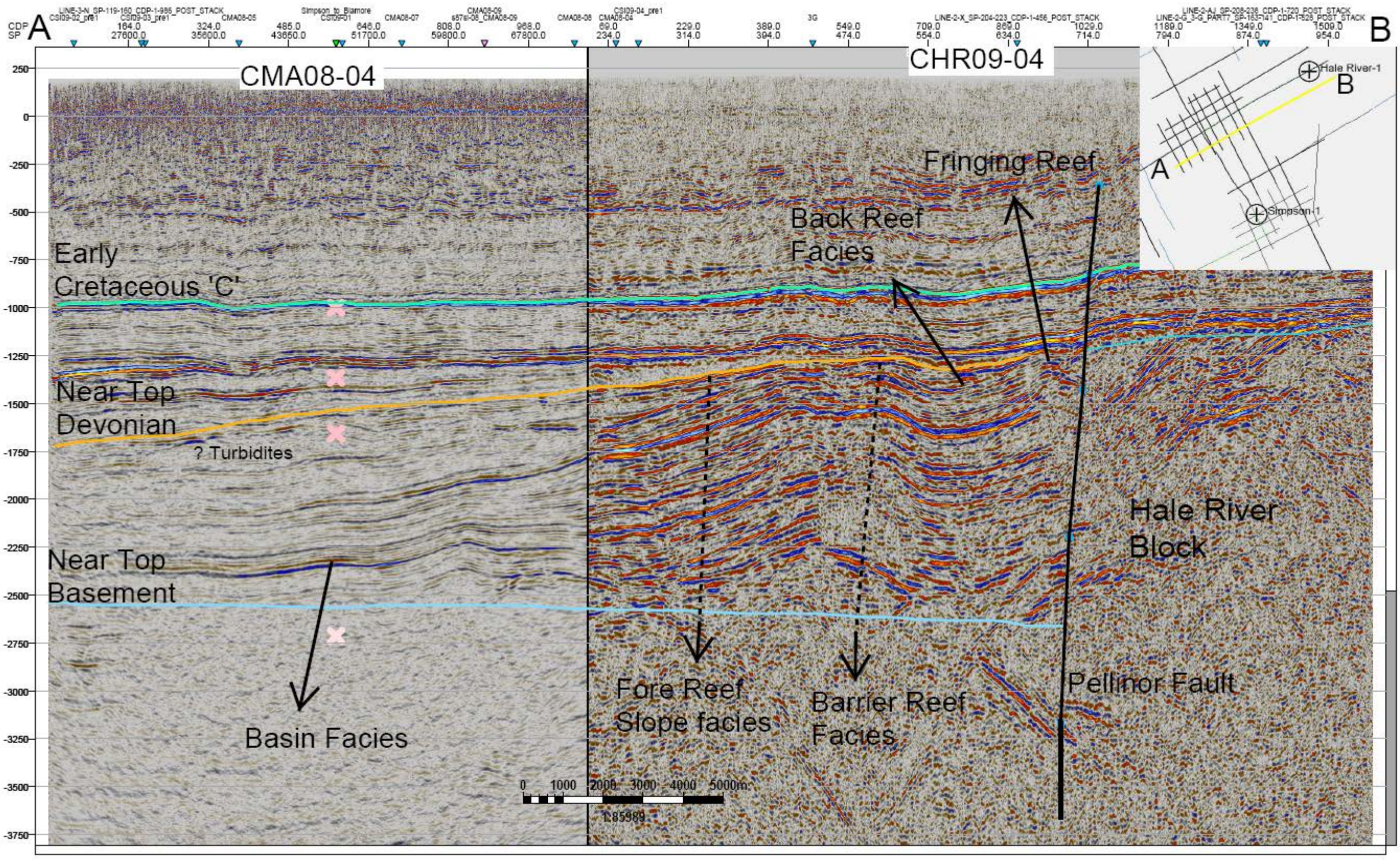


Figure 9: Pellinor Barrier Reef Complex

Barrier Reef Core : This facies was formed at water depths consistent with those necessary to allow active reef building by organisms such as stromatoporoids, corals and cyanobacteria for many millions of years. There is strong evidence of emergence and karstification in addition to evidence of layered sediments distinct from massive bioherms/biostromes/

boundstones which would have dominated the sequence. Early cementation was probably responsible for the twin culmination seen in the upper half of the barrier reef and a model for its development occurs below.

The barrier reef is itself a key petroleum target. However, subsequent to maturation of source rocks developed in the fore reef/basin facies, updip migration to the reef core provides a compelling exploration model. It is likely source rocks would also have been developed in the back-reef facies. Seismic evidence suggests the contacts between back-reef, barrier-reef and fore-reef/margin slope facies are generally gradational and interfingering thus facilitating hydrocarbon charge.

Thus at the top and base of the Devonian sequence there is a lateral facies transition from fringing reef→ back reef → barrier reef →distinctive dipping fore reef/reef slope facies grading basinward into flat lying pelagics and turbidites of the basin proper.

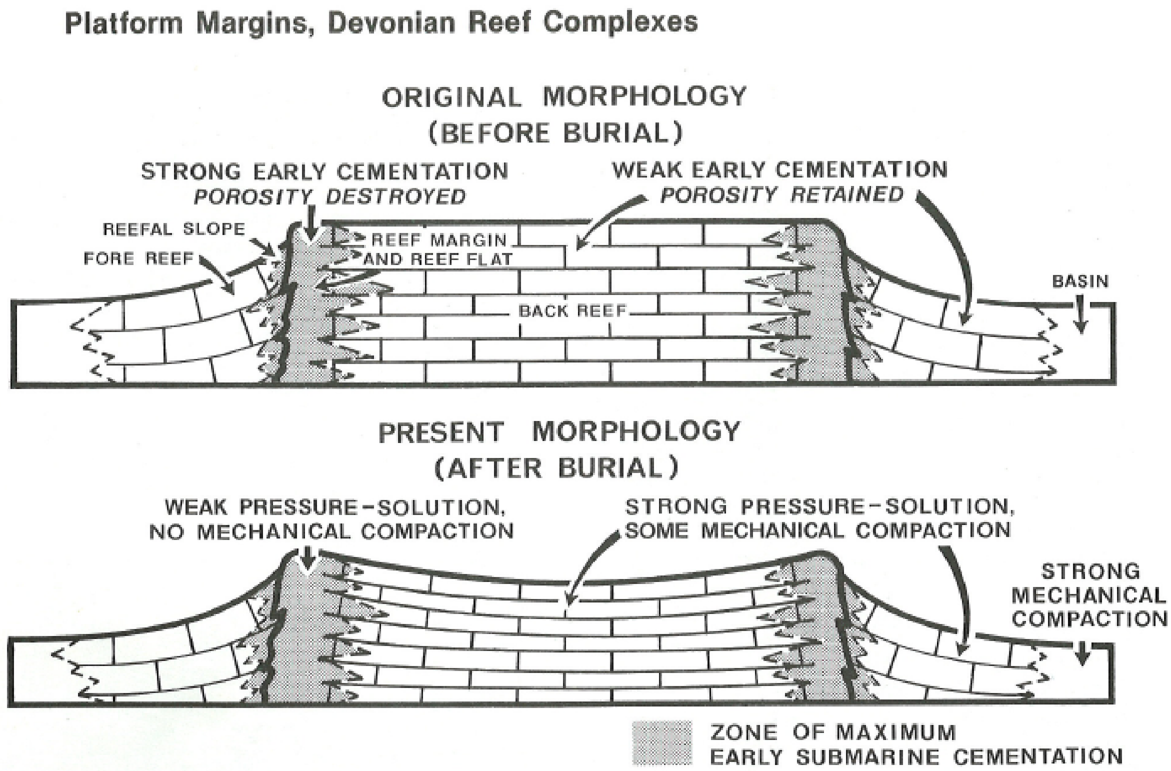


Figure 34: Diagrammatic cross sections illustrating morphological changes in the reef complexes resulting from mechanical and pressure-solution compaction.

Figure 10 – Model for a twin culmination Barrier Reef (after Playford, 1984).

1.2 **Fringing Reef Facies:** By definition a fringing reef forms along the shoreline of an island or some other continental mass and is not generally separated from such by a lagoonal facies. However in certain instances the reef may grow hundreds of metres from shore and contain extensive back reef areas with sea grass meadows and patch reefs. Barrier reefs tend to form much farther away from the shoreline and have at least some deeper water facies which are absent from fringing reefs. At the base and top of the Devonian sequence fringing reefs appear to have formed up against the Pellinor Fault. Through time the uppermost , wedge shaped fringing reef showed some minor seaward migration as did the main barrier reef facies, but aggradation remained largely vertical. The small convex upward fringing fault adjacent to the Pellinor Fault is seenon seismic line CHR09-01. This occurs near the top of the back reef facies and could be a back stepping reef associated with rising sea levels which eventually “ drowned” the complex.

Thus at the top and base of the Devonian sequence there is a lateral facies transition from fringing reef → back reef → barrier reef → distinctive dipping fore reef/reef slope facies grading basinward into flat lying pelagics and turbidites of the basin proper.

1.3 Back Reef Facies

This facies occurs on the landward side of the barrier reef and is commonly a lagoonal facies. It is the back reef facies where much of the mud formed on the reef comes out of suspension. Coarser material would also have been shed from the adjacent hanging wall (Hale River Block) into the lagoon where tidal influence would have been restricted and waters may have been intermittently hypersaline. Sandstone and conglomerate deposits could be expected adjacent to the Pellinor Fault. These comprise a significant oil play if source rocks are present in the back reef facies with capability of charging proximal clastics wedged against the fault plane and juxtaposed against basement lithologies. Apparent wrenching on the fault plane would have enhanced the possibility of fault gouge seal.

The back-reef commonly often shows prolific growth of sand and mud producing bottom fauna such as calcareous green algae. The Pellinor back reef facies is about the same thickness as the barrier reef showing similar vertical accretion controlled by subsidence on the Pellinor Fault. Seismic reflectors are well developed and are occasionally high amplitude, and show a concave downward configuration due to differential compaction and drag on the Pellinor Fault High amplitude reflectors within the back reef sequence are sometimes continuous over the barrier reef and pass into the fore reef section; these may indeed reflect major transgressive events, with resultant strata configuration modified by drape and compaction.

Back reef facies can include significant source rocks as exampled by the Salina Al back reef carbonate which is a brown, laminated dolostone deposited during recurrent back reef /lagoonal sedimentation during the Silurian in NW America.

1.3 Reef Front , Fore Reef and Basin Facies

These three facies are developed on the seaward side of the barrier reef; the associated strata generally thin and dip away from the reef core at angles of 30 degrees. The facies proximal to the barrier reef core is the reef front facies where pockets, streams and chutes of skeletal and calcareous algal sand could occur between areas of dense coral growth. Below this zone the fore reef facies generally would comprise gravel and sand composed of fragmented skeletal debris, blocks of reef limestone and skeletons of reef builders. This relatively steep (? channelized) slope grades downdip into toe-of-slope apron fans comprising debris flow deposits, density flow deposits and turbidites. A number of workers have shown that thick reservoir quality grainstones are often shed from platform margins during eustatic high stands. Structural-stratigraphic traps are defined by lateral pinchout of porous toe-of-slope apron deposits to tight pelagic deposits in the basin but there is also isolation from the porous carbonate margin.eg the Poza Rica field in Mexico (Janson et al, 2011).

1.4 International Examples of Carbonate Reef Hydrocarbon Reservoirs

The examples cited below come in part from the Middle East and North Africa which contain 70% of the worlds known oil reserves and about 50% of the world’s natural gas reserves. It is noteworthy that carbonate rocks make up only 20% of the sedimentary rock record yet account for 60% of the world’s proven hydrocarbon reservoirs. Most deposits occur in a variety of carbonate buildup facies and those relevant to the Warburton Devonian sequence are discussed below:

Fields in Barrier Reef Facies

a) The giant Kirkuk Field (17 Bbl recov.) in Iraq produces from reefal carbonates (Oligocene) flanked by fore reef/ back reef marls. Edgell (1997) notes production at Kirkuk field from a 610 m oil column located in mostly reef, fore reef and shoal reef limestones. The facies relate to a transgressive reef building shoreward over its earlier back reef lagoonal facies (Edgell, 1997). Note that known barrier reefs are limited to Middle Eocene limestone reservoirs of the western Kirkuk field. One reef wall reservoir is in Iraq in the Oligocene limestones of the Bai Hassan Oil field (1.8 Bbl Recov.oil). They are also known in the Bu Hasa Oil field of Abu Dhabi where 170m of rudist reef forms the core of this giant field.

b) In 1947 oil was discovered in Upper Devonian dolomitic coral reefs at Leduc Field, Alberta sparking an exploration boom which yielded many similar discoveries in the Great Western Basin (Waring and Layer,1954). Production comes from an Upper Devonian coral bioherm 228 m thick which includes a 71 m oil/gas column. Depth of production is about 1590 m and porosities average 6.8%.

c) The Mid-Late Devonian Kaybob Oil Field in Alberta is largely productive from the organic reef core which has the best reservoir quality. A discussion of this field occurs under the “backreef” facies which is also productive.

Fields in Fringing Reef Facies

a) The Ras Gharib oil field on the eastern edge of the Gulf Of Suez produces from a Miocene fringing reef reservoir (algal reef). An example of Devonian fringing reef oil production (reef abutts a landmass) comes from the Blina field in the Canning Basin in Western Australia (Moors et al, 1984).

b)Fringing reef carbonates are productive in the giant Kirkuk field (Eocene-Oligocene) in Iraq, and in other fields in southern Iran (Edgell, 1997).

c)Large fringing reef oil reservoirs occur in the Lower Cretaceous of Bu Hasa and Shah fields (Abu Dhabi), the Shaybah-Zarrara fields of eastern Saudi Arabia, as well as other fields in Oman, Qatar and Iran (Edgell, 1997).

Fields in Fore Reef Facies

a) Reef shoals are located in shallow seas seaward of the reef talus where shoal grainstones can develop. Important Cretaceous shoal grainstone oil reservoirs occur in the Bab and Zakum fields in the United Arab Emirates. In Iraq reef shoals are important oil reservoirs in the Qaiyarah oil field. Eocene nummulitic shoal limestones are excellent oil reservoirs in the Gialo Field in southern Libya.

b)Talus slope deposits consist of accumulated reef debris and broken shell fragments. They often have high porosity and permeability and thus account for more production in the Middle East and North Africa than reef carbonates eg in the Bu Hasa Oil Field of Abu Dhabi (Edgell,1997) and also in the giant Zakum field in Abu Dhabi.

c)In Libya Cretaceous fringing reefs flank granitic basement highs and their fore reef debris forms significant oil reservoirs in the Augila Oil Field (Edgell,1997).

d) The Poza Rica Field in Mexico produces oil from the Tamabra Formation (Albian) which comprises a thick accumulation of redeposited carbonate sediment in a fore reef facies (Janson et al, 2011). The field is a structural / stratigraphic trap defined by lateral pinchout of porous toe-of-slope apron deposits to tight pelagic deposits.

Fields in Back Reef Facies

a)The restricted back reef Permian carbonate shelf of southern Iran contains huge gas reserves in an number of structural traps at Kangan, Aghar, Nar, Varavi, Mand and Dalan fields as well as the giant Pars and North fields.

b) Oligocene back reef facies are major oil reservoirs in Iraq and are well known in the giant Kirkuk Oil Field.

c) Jurassic Reefal Complexes are productive in the west Ukrainian Carpathian foredeep from karstified reefs but also to some extent from back-reef facies.

d) The Permian upper San Andres Formation found in New Mexico was deposited on a restricted carbonate shelf and is a back reef deposit comprising dolowackestones, dolopackstones, and dolograinstones which comprise the main reservoir. In addition there are high frequency, upward shoaling carbonate cycles capped by low permeability peritidal (tidal flat) facies which compartmentalise the reservoir (Stoudt et al, 2001). These together with some karsted surfaces provide intraformational seal implying regional top seal may not be a prerequisite for oil entrapment. Seismic signatures suggest similar intraformational seals and reservoirs could have developed in the thick back reef sequence at Pellinor which probably also includes petroleum source rocks.

e) A mid-late Devonian limestone reef complex (Kaybob Oil Field) occurs in northern Alberta amongst numerous other reefal deposits (Beaverhill Lake Group reservoirs) which in this general area host greater than 6 Bbbl OOIP and more than 10 TCF OGIP (Skultheis,1976). Original oil at Kaybob Field was 300 mmbl OOIP with the thickest oil pay and best reservoir characteristics occurring in the massive reef core facies. The backreef facies has fair to good porosity and comprises 4 main facies: 1) a microidal pelletoid limestone dominated by *Amphipora.* 2) a pellet-microcrystalline limestone. 3) a fragmental limestone facies with good reservoir characteristics. 4) a pyritic green shale facies. The reef complex is much thinner then the Pellinor barrier reef with maximum core reef thickness of 78 m and dimensions 16 x 5 km. Average porosity/permeability are 7.4% and 24 md; the recovery factor is 42%. Off reef basinal shales provide the oil source and top seal.

f) In south Texas gas and oil is produced from the Cretaceous Edwards Limestone from reservoirs developed in both reef core and back reef facies of coquina – like fossiliferous limestone and dolomitised limestone (Beebe,1968). The reef mass is about 350 thick and is often tighter than the backreef facies with porosities / permeabilities up to 6 percent and 0.5 md respectively. In the backreef facies porosity/permeability range up to 16% and 6 darcies respectively. The top of the reef facies is erosional.

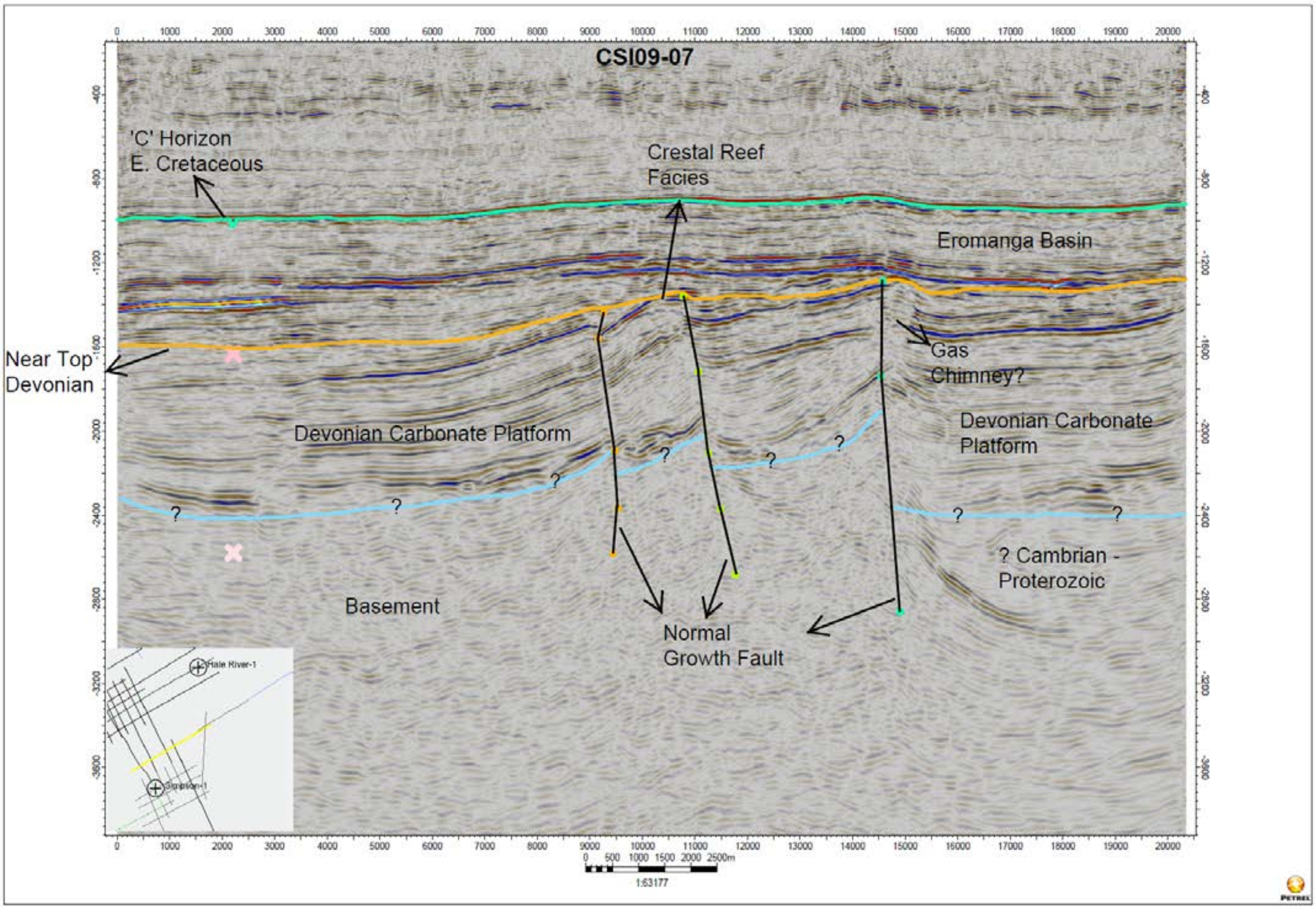


Figure 9 Tensional growth faulting in the Devonian platform sequence north of Erec Prospect.

1.5 Comparison with Canning Basin Reef Complexes

Devonian-Carbonate reef complexes in the Canning Basin occur as Famennian and Frasnian sequences separated by an important unconformity. Tensional faulting in the middle Devonian controlled basement features on and around which reef complexes formed. Movement continued through reef growth (eg Pillara Range complex) as is also well manifested at Pellinor Reef in the Simpson Desert. The faults in both areas seem to have a componenent of transcurrent movement. The facies in the older Frasnian reefs of the Canning Basin are summarised below and this is largely drawn from Playford et al (2009) Playford (1984), Lehmann (1984) and Benn (1984).

Frasnian Platform Facies (Pillara Sequence)- Canning Basin

1) Pillara Limestone Reef Margin- massive, thickly bedded, comprising massive reefal deposits built by microbes, stromatoporoids, and corals. The Pillara Limestone as a whole varies from 200-2000 m in thickness but the maximum thickness of the reef margin facies is uncertain. The thickest reef margin documented in the literature is about 1000 m within the east Pillara area (Benn,1984). The barrier reef at Pellinor is of the order of 1700m thick as is the back reef facies.

2) Pillara Limestone Reef Flat Beds Facies- comprises well bedded sediments formed by reef building stromatoporoids, fenestral stromatolites with zones of structureless microbial limestone.

3) Pillara Limestone Back-Reef Facies – comprises mainly medium bedded biostromes of stromatoporoid, coral and algal limestone with some oolitic carbonates.

4) Fore – Reef Facies – the Sadler Limestone - comprises mainly fore-reef clastics and reefal slope deposits including breccias and talus slope deposits.

5) Basinal Facies – The Gogo Formation comprises up to 700 m of pelagics (grey to black shales) with minor clastics; the former are known to have oil source rock potential.

Note: the relatively deeply buried Frasnian sequence is poorly imaged on seismic and is far more sparsely explored than the overlying Famennian section. In terms of the oil search in the Canning Basin, the Frasnian may well be more prospective than the latter in that dark grey to black organic facies occur in the Frasnian Pillara Limestone, but no such source rocks occur in the Famennian platform carbonates. The unconformity at the top of the Frasnian resulted in mild karstification and denotes a major mass extinction in the sedimentary record marked by the disappearance of many stromatoporoids, corals and bracciopods (Playford,1984). Cyanobacteria were the predominant reef building organisms in the Famennian.

Famennian Carbonate Platform Deposits (Nullara Sequence) – Canning Basin

1) Back-Reef Facies - The Nullara Limestone is a back-reef and bank unit which, together with the Windjana Limestone make up the Famennian platform facies. The Nullara is up to 470 m thick and comprises mainly fenestral calcarenite with columnar stromatolites and oolite, with subordinate sandstone and siltstone.
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2) Reef Core Facies – The Windjana Limestone is a massive reef limestone built mainly by microbes and sponges; this unit mainly belongs to the reef margin sub-facies. Micritic limestone, probably resulting from microbial activity, is the dominant lithology.

3) Marginal Slope and Basin – This facies comprises the Piker Hill Formation and consists of fossiliferous shale and multi-coloured calcarenites, wackestones, packstones and grainstones. Maximum thickness is about 350 m. The source potential of this section is uncertain.

A Famennian fringing reef is the producing reservoir at Blina Field but follow up exploration at this level has been unsuccessful up to the present time.

The oil search in the Canning Basin has been disappointing in the wake of the 1981 Blina oil discovery and subsequent small discoveries in the cover section. Playford et al. (2009) suggest the potential for significant new Famennian fringing reef targets is low given the existing coverage of seismic and drilling. Certainly erratic reservoir quality and veracity of hydrocarbon charge may be largely responsible. Significantly, the older Frasnian reef complexes are far less well explored because they are deeper and poorly defined on 2-D seismic lines. Also, as previously alluded to, the Frasnian reefs contain more organic matter than the younger sequence thus enhancing their prospectivity.

1.6 Factors Favouring Reefal Complexes in the Simpson Desert Area over those in the Canning Basin .

Some possible implications for Devonian reef prospectivity in the Simpson Desert area are;

- The back-reef facies at Pellinor with its high amplitude reflectors and strong evidence of periodic emergence suggest that this facies could contain organic rich evaporite sequences incorporating algal mat sediments comprising excellent source rocks. Local entrapment against the Hale River fault block is favoured by evidence of wrenching on the Pellinor Fault and the fact that back reef facies are juxtaposed against basement lithologies.
- Ancient, deep seated tensional faults control Devonian Carbonate Complexes and major drape closures which occur in the overlying section may have tapped these deeper source horizons.

- No detailed maturation modelling has been undertaken for the Devonian basinal section in the Madigan Trough and the back reef facies adjacent to the Hale River

Block, but potential source rocks are likely to have reached the oil window in Jurassic-early Cretaceous times. This relatively late migration (compared with the Canning Basin) and the absence of significant late tectonic disturbance over the Erec and Pellinor Fault Trends would favour retention of hydrocarbons. The Permo-Triassic section in the Canning Basin is generally much thicker than in the Madigan Trough dictating earlier expulsion with consequently a longer period of preservation required.

Conclusions – Pellinor Barrier Reef Complex

- **Seismic mapping at several different horizons within the Devonian/Carboniferous section is the next priority as is maturation modelling of source rock horizons.**

- **Numerous hydrocarbon plays are developed in a full facies mosaic which has been successfully explored elsewhere around the globe. Excellent analogies occur in the Devonian / Carboniferous of North America, Mexico and in Kazakhstan.**

- **The definition of these unique carbonate formations is a major breakthrough as it is the first time these facies have been recognised away from the Canning/Bonaparte Basins.**

- **Recognition of the carbonate barrier reef complexes and platform/rim complexes (described in the next section) announce a new era for exploration in the Simpson Desert area; the fact that these carbonate complexes are strong drivers for drape and compaction structures in the overlying Permian and Mesozoic section dictates many prospects will have multiple stacked targets.**

- **Basinal facies downdip of Pellinor lead are likely to have acted as source rocks given : 1) evidence of hydrocarbon migration up fault planes with associated HRDZ's 2) evidence from other basins of source potential in this facies 3) Depths of burial of 2.5 seconds – cf. detailed Permian source rock maturation modelling in the Madigan Trough indicates these are in the peak oil generation window (Vr0 = 1.0) at about 1.6 seconds(Ambrose et al, 2002).**

- **Source rock facies are also likely to have developed in back reef facies especially if evaporite sequences are present. These are buried to depths of 2.5 seconds. There is also possible source potential in the barrier reef facies** *sensu-stricto.*

- **The Pellinor Barrier Reef Complex is extraordinary in terms of its vertical relief (~ 1.7 km) and hence reservoir / seal scanarios cannot be easily correlated with international examples without at least some drill core data. However, possibilities for reservoir – seal couplets follow and modes of entrapment are: 1)**

Transgressive marine shales capping barrier reef reservoirs either internally or at the top of the sequence. 2) Transgressive marine shales/evaporites capping back reef reservoirs 3) Sealing of back reef/ fringing reef facies against the Pellinor Fault . Note that juxtaposition against basement together with a degree of transcurrent movement on the fault plane would both enhance seal integrity. 4) Shale seal isolating fore reef slope clastics from the barrier reef facies.

2. A Devonian Rimmed Carbonate Platform on the Arltunga Arch- Erec and Simpson East Prospects

Introduction

A Devonian rimmed carbonate platform occurs over a basement high named the Arltunga Arch 20 km south of the Hale River Block. It was initially described by Ambrose (2008) but a brief review occurs below as the play compliments the earlier described barrier reef complex formed along the Pellinor Fault Trend. The two areas form part of a larger facies mosaic with the Erec rimmed platform believed to be an approximate time correlative of the lower Pellinor barrier reef complex.The whole area requires a remap focussing on Devonian carbonates as seismic coverage is very poor and there are hints of these targets along the entire Hale River Trend and further north on the far reaches of the Hector Trend.

By definition a carbonate platform comprises a large edifice formed by the accumulation of carbonate sediment in an area of subsidence; the platform may be several kilometres thick and can extend over hundreds of square kilometres. An exceptionally thick carbonate platform section is denoted by the Devonian/Carboniferous Bolshoi carbonates of southern Kazakhstan which are 4500 m thick. In this area classic giant platform oil fields occur at Kashaghan and Tengiz.

The generic component facies of a carbonate platform in the Simpson Desert area are summarised below and this review draws heavily on studies by Ambrose (2008) and examples described in Walker and James (1992).

The main play elements for the carbonate platform formed over the Arltunga High (viz Erec Platform) are described below:

2.1 Carbonate Platform Facies : carbonate sediment forming the platform probably largely comprise skeletal material secreted by algae and/or other organisms. Generally lithofacies on rimmed platforms are muddy while those on open, unrimmed platforms are grainy and during exposure karsted surfaces may develop. The inner carbonate platform at Erec is up to 750 m thick but thins rapidly as it onlaps the underlying rotated fault block.

Seaward of the Erec Prospect, which marks the crestal point of the platform sequence, a platform margin rim developed probably comprising shoal deposits and possibly margin reefs. Any drop in sea level would have been pivotal in that shallowing may have triggered karsting on the platform and siliciclastic sediment influx into basinal areas, thereby providing two potential reservoir targets in addition to those formed in the platform rim. The platform section grew over time until it was eventually “drowned “ by a transgressive marine shale/clastics sequence.

The inner platform is best denoted on seismic line S87SI-07 where platform slope, rim, and inner platform facies are recognised. The inner platform displays carbonate mound development at the base of the section as the platform strata onlap ? pre Devonian basement; the structure developed as a rotated fault block controlled by the Erec Fault. Inner Platform strata onlap the crest of the fault block (ie the foot wall crest) while in the hanging wall there was sedimentary growth in the Platform sequence as the fault plane rotated.

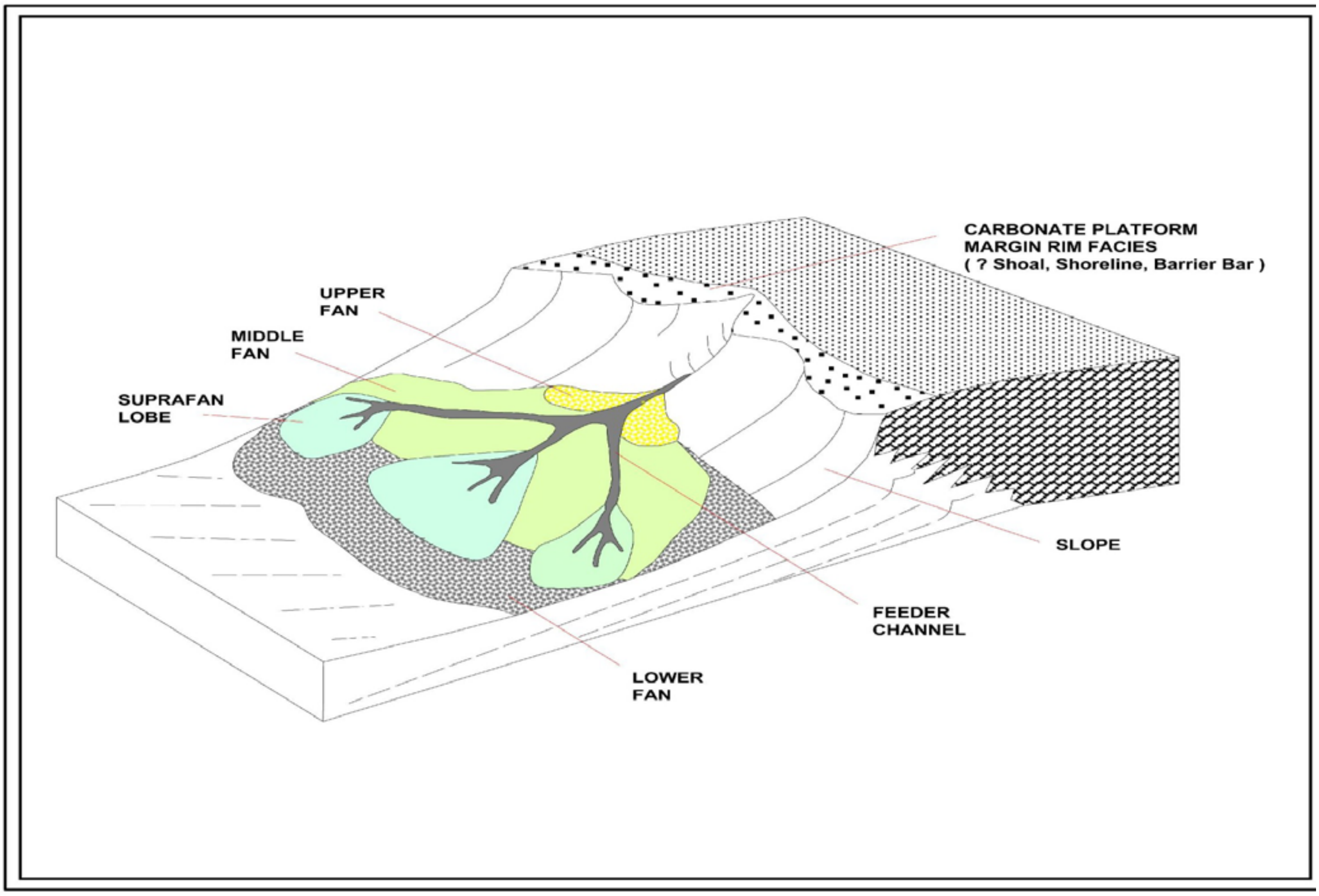
Examples of Petroleum Fields: Devonian - Carboniferous carbonate platform plays have considerable importance in producing basins in a global context. The Tengiz, Karachaganak, Astrakhan, and Kashagan super giant fields in the Caspian Sea host c. 46 Bbbls of Oil Equivalent in Place (OEIP). Other noteworthy examples are the “Wehlu” fields in the southern USA, the Lisburne Field in Alaska, the Golden Lane field in Mexico (Cretaceous), and the Nisku and Wabuman fields in the Western Canadian Basin.

2.2 Platform Rim Facies : Platform rim deposits form on the seaward-side of the inner platform at the top of the platform sequence. This facies is clearly discernable on seismic and probably built by organisms such as corals stromatolites, coralline sponges, rudist bivalves and various types of algae. Drape and compaction in the overlying Permian – Mesozoic section is further evidence that a relatively hard platform rim facies exists at depth.

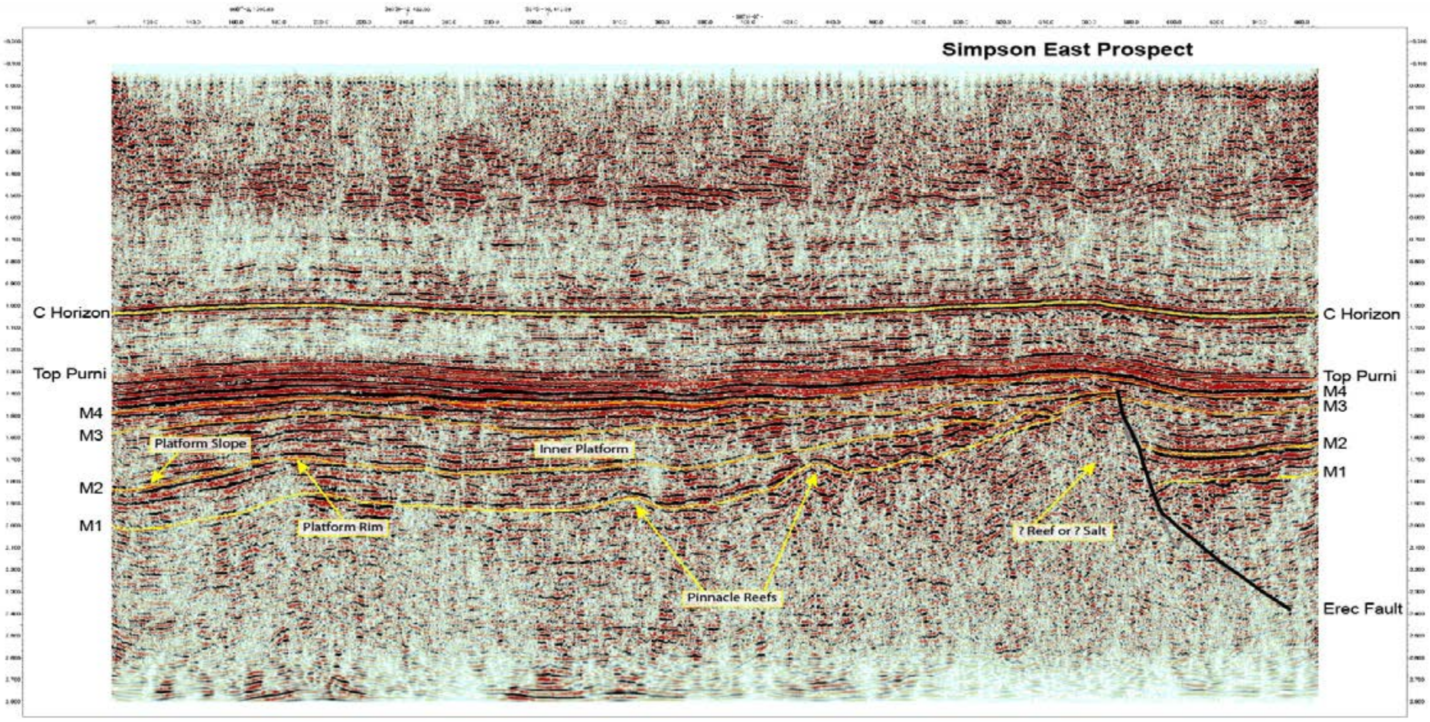
Some of the organisms forming the rim spontaneously disintergrate upon death to form sand size particles which could form sandy shoals. The rim reef may have rubble on the crest and an apron of sand on the landward side.

Example of Petroleum Fields: The Jeruk field, offshore from Java, is an example of a platform margin reef rim developed along the margin of an ancient platform. At Jeruk field, back reef facies were developed landward of the rim with fore reef facies developed seaward. The hydrocarbon column was at least 379 m in rim carbonates but reserves were less than 50 mmbl.

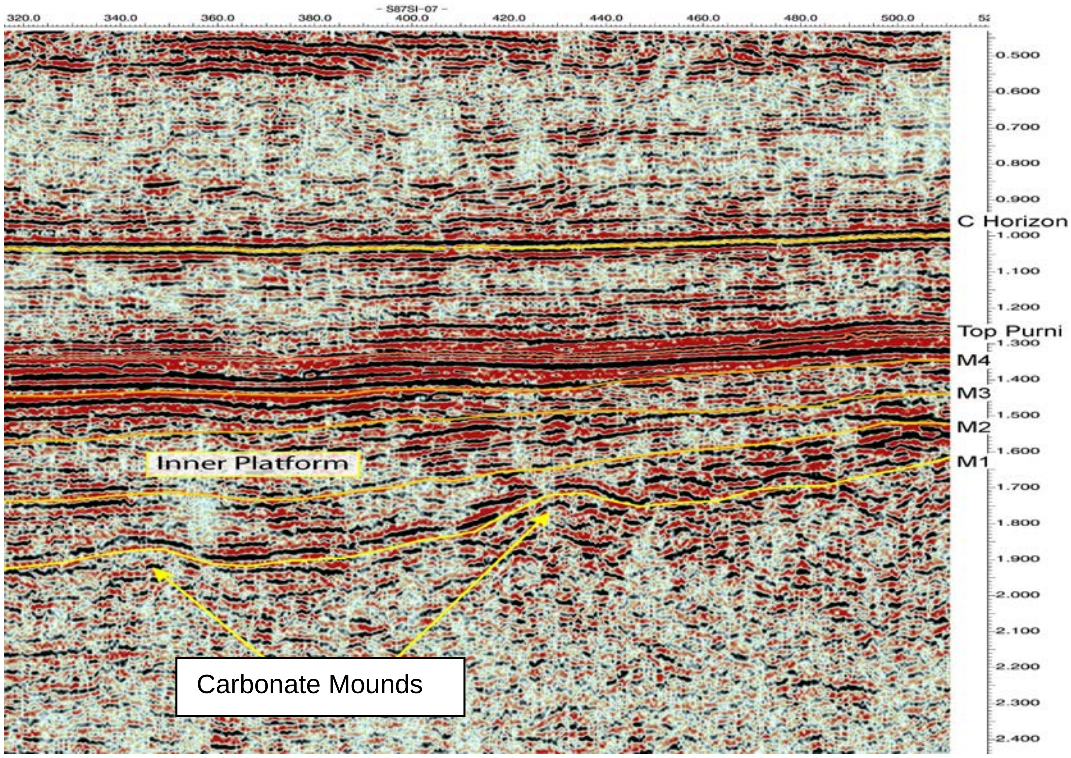
Figure 1: Schematic representation of Carbonate Platform Rim facies development.

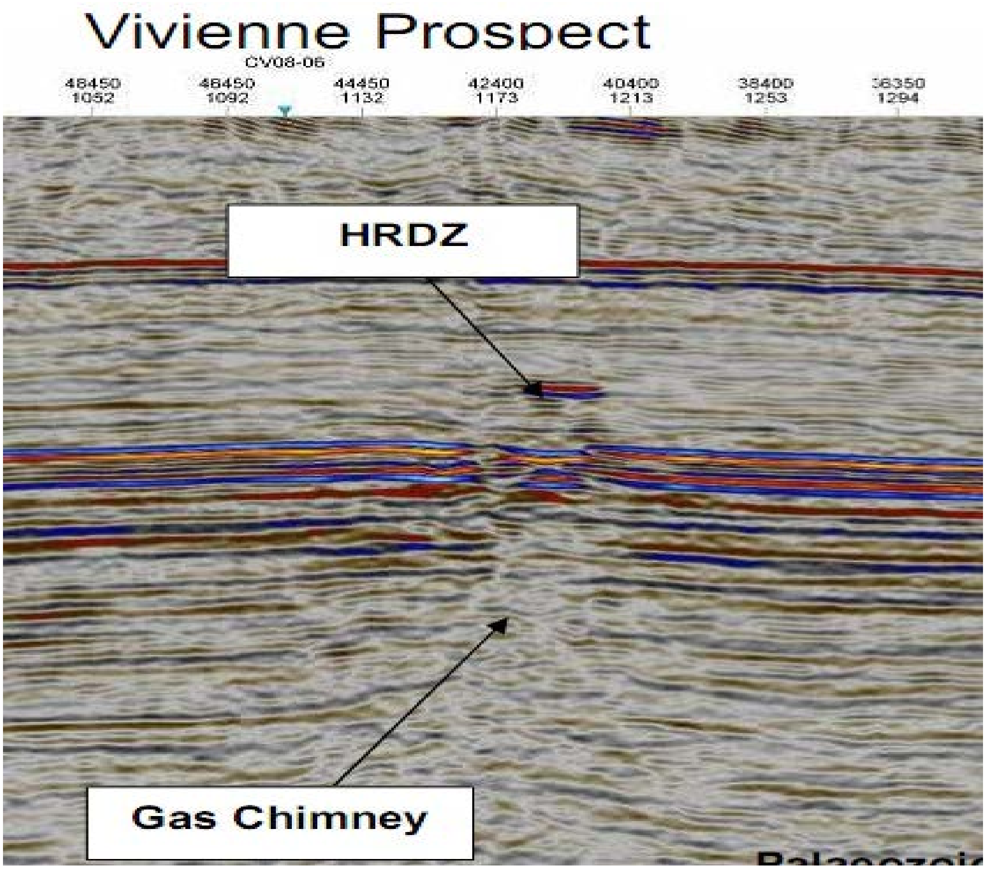


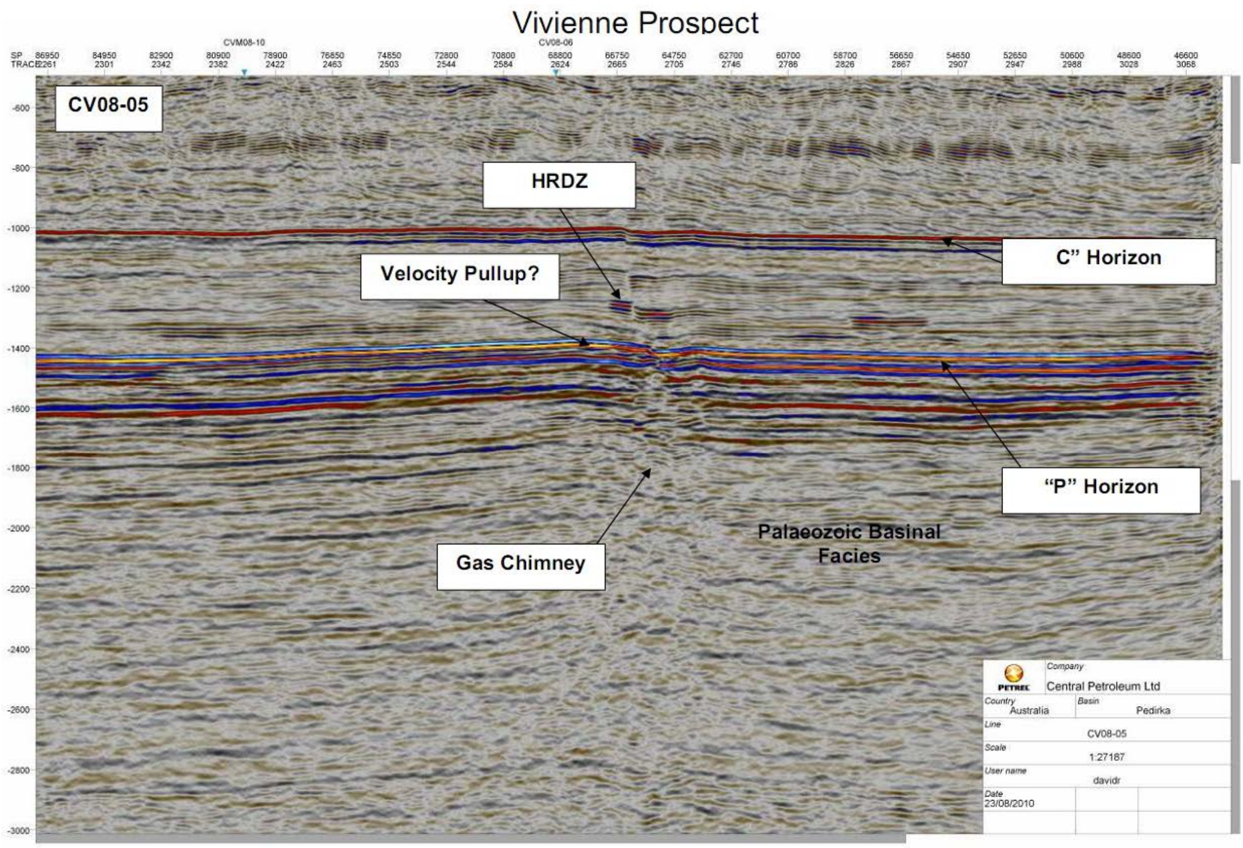
2.3 Platform Slope Facies : the slope largely comprises detritus shed from the reef rim and probably sourced coarse – grained sediment via gravity flows thus forming in some cases, thick prograding or forestepping wedges of slope sediment. At the rim lead downdip of the Erec Platform only very minor seaward migration of facies is displayed on seismic.



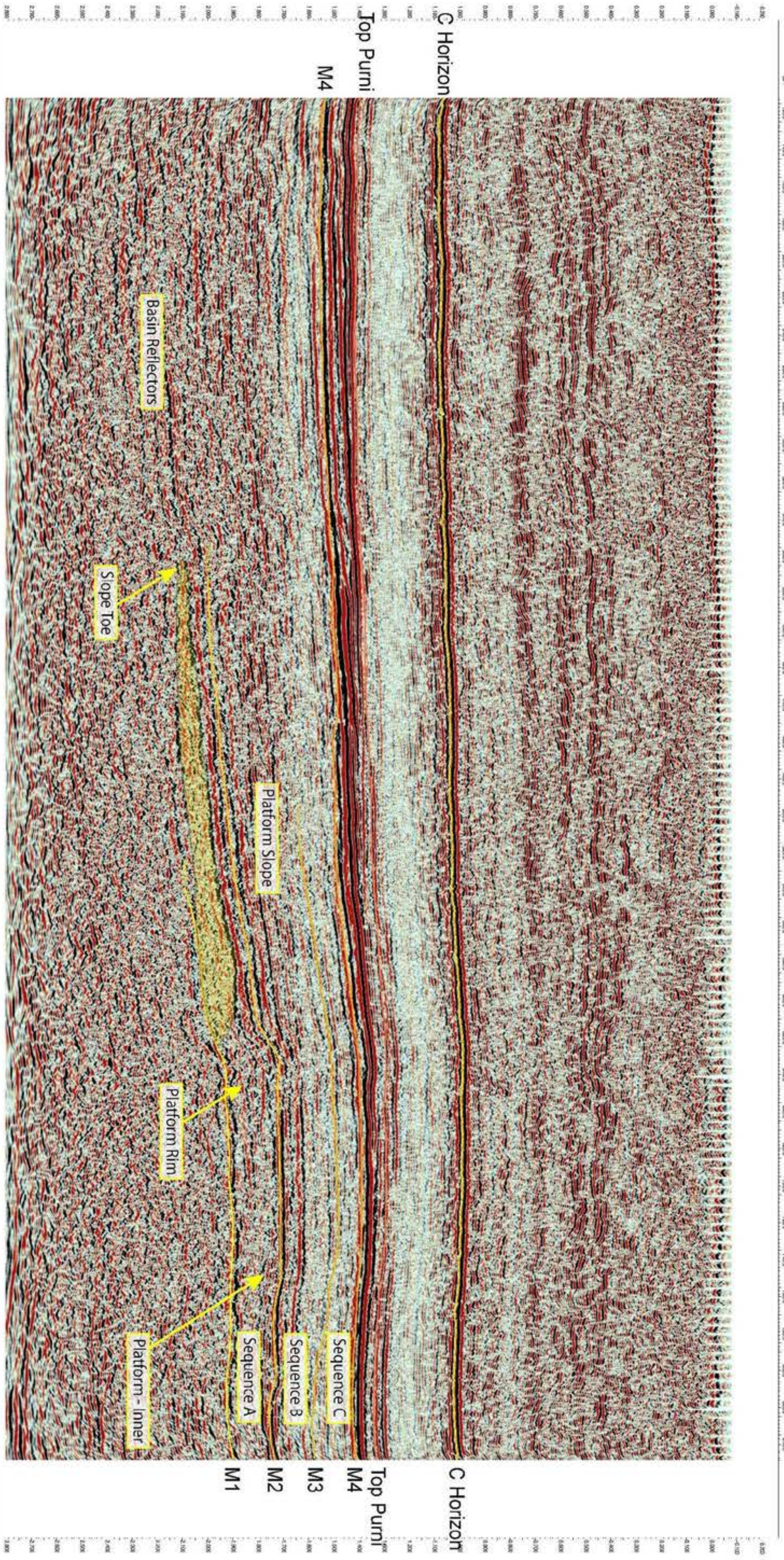
Figures 2 and 3 : Devonian carbonate platform with carbonate mounds developed at the base of the section.







Figures 4 and 5: Hydrocarbon Chimneys Originating in the Palaeozoic.



C Horizon
Top Purni
M4
Basin Reflectors
Slope Toe
Platform Slope
Platform Rim
Platform - Inner
Sequence A
Sequence B
Sequence C
M3
M2
M1

2.3 Platform Slope Facies : largely comprises detritus shed from the reef rim and probably sourced coarse – grained sediment via gravity flows thus forming in some cases, thick prograding or forestepping wedges of slope sediment. These are prime reservoirs in the Middle East where sediments in the slope facies frequently have better reservoir characteristics than reefal buildups. The sedimentary facies are likely to be far less coarse grained than the more steeply dipping slope facies associated with the barrier reef complex at Pellinor.

2.4 Carbonate Mound Facies: these are recognised at the base of the Devonian sequence where the inner platform onlaps pre-Devonian basement. In an overall sense ,most carbonate mounds develop either 1) downslope on gently dipping platform margins, 2) in deep basins, and 3) spread widely in tranquil reef lagoons (back reef facies) or on wide shelf areas. The shape of carbonate mounds varies from flat lenses to conical piles up to 100 m high or more. Most of the mounds recognised this area are less than 150 m high.

Vertical zonation of carbonate mounds, which are often dominated by mud, is energy dependent (Walker and James, 1992). A tripartite zonation is sometimes recognised in the rock record comprising: 1) A basal accumulation of bioclastic muddy sediments without baffling or binding ie mud mound stage, 2) a core of lime mud rich with platy algal bafflestone of relatively low energy ie skeletal mound stage, 3) a crestal bindstone of encrusting skeletal organisms sometimes capped by a sand shoal. Shallow mounds sometimes act as foundations for reefs. Most deep water mounds comprise carbonate facies developed below or near storm wave base.

Examples of Petroleum fields: Reservoirs in the Permian Basin (Northwest Shelf) in western USA are often limestones and dolostones comprising phylloid algal mounds (and associated carbonate sands) with a strong stratigraphic control on entrapment (Broadhead et al,2004). Total production is about 354 mmbo. The Tin Cup Oil Field in Utah produces from a 37 m Pennsylvanian algal mound (4000m x 700m). The mode of entrapment is stratigraphic and many similar plays occur in the Paradox Basin which extends through Colarado, Utah and New Mexico.

2.5 Basinal facies – Deepwater basinal facies were only significant repositories for carbonate sediment in post Jurassic time when pelagic calcareous microorganisms evolved. Devonian basinal sediments are likely to be terrigenous clastic or siliceous with some carbonate input from density flows tapping the platform margin. These basinal shales could include alginite enriched shales. To preserve these potential source rocks, partial or complete anoxia may have been induced by 1) stratification of the water column by pronounced temperature and /or salinity layering 2) a dramatic increase in nutrient supply to surface waters from increased runoff or upwelling of deep ocean waters. The basinal facies reach a maximum thickness of 800 m and the exact composition of this sequence can only be determined by exploration drilling.

Basinal shales are clearly defined on seismic and probably comprise pelagic and fine-grained turbidite deposits which may include viable source rocks ; evidence of hydrocarbon leakage up major faults lines with associated HRDZ's is encouraging. Fine-grained submarine fans probably occur through most of the lower section where very fine-grained clastics were deposited by density flows (fine grained tempestites and turbidites) with some associated pelagic sedimentation.

2.6 Transgressive Topset Beds – this sequence transgresses the platform sequence as it onlaps and eventually overlaps the platform slope and interior platform facies, perhaps effectively drowning the platform. This sequence is up to 800 m thick and onlaps the platform sequence. This facies would probably provide a viable seal and possible source to the underlying platform facies. It is significant that petrophysical studies define possible log pay (gas) in the Palaeozoic section in Colson-1 but the zone was not tested. Red brown silty

shales were intersected in the Simpson-1 well providing evidence of a degree of sealing capacity.
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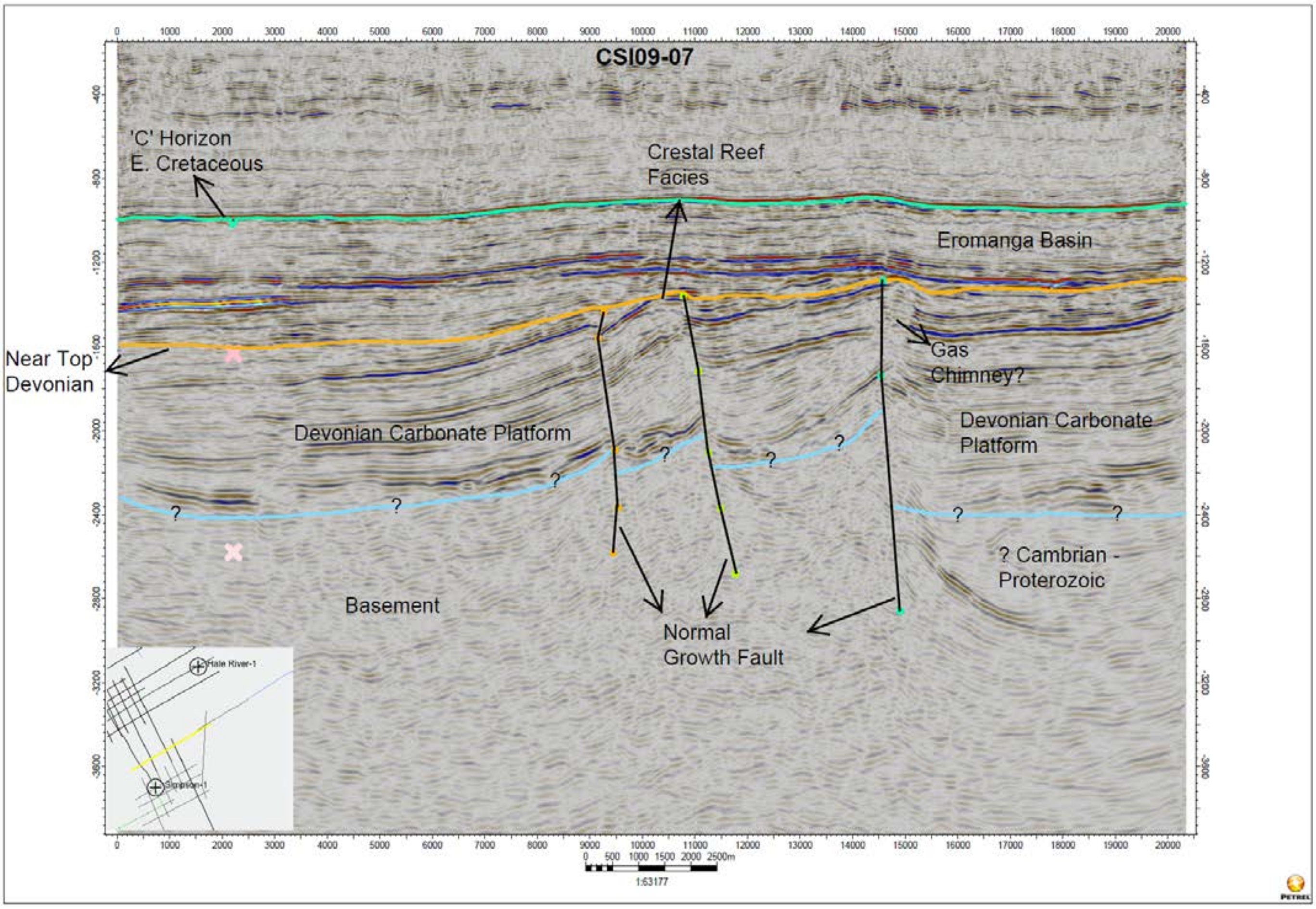

Figure 7 : Tensional faulting and block rotation immediately north of Erec Prospect

Future Program

The Devonian carbonate complexes described herein are described from limited seismic coverage without any drill hole control, except for minor intersections of the top most transgressive facies in Colson-1 and Simpson-1. Figure 7 is a case in point, in that it shows tensional structuring featuring rotated fault blocks just north of the Erec Prospect. If this line extended further updip there is a strong possibility reefal facies would be encountered. In addition there is a high probability that Cambrian / Ordovician sediments underly the platform package but little is known of these sediments save for one well intersection in McDills -1.

The future program will be directed at a complete remap of the Devonian section in both the Pellinor and Erec regions and also on the Blamore and Hector Trends. This will be undertaken at the top and base of the Devonian sequence, and also for at least two reflectors within the section. Subsequent to this mapping, a program of incremental seismic will be designed to bring leads to prospect status.

Conclusions – Rimmed Carbonate Platform Complex (Erec Prospect, Simpson East Prospect)

- **The rimmed platform complex seen over the Arltunga Arch (including the Erec Prospect) comprises a different set of carbonate facies compared with the Pellinor Barrier Reef Complex seen to the north, although they are linked into a continuous facies mosaic. The platforms are controlled by major tensional faults with the platform wedging out onto a tilted-rotated fault block (s).**

- **The main facies recognised seaward of crestal reefs developed on the fault block (s) are as follows : Thin crestal reef facies → inner platform carbonates thickening seaward with carbonate mounds developed on the sea floor → platform rim shoal/reef facies → fore reef/ platform slope facies → apron fan deposits → basinal distal fan and pelagic deposits.**

- **Hydrocarbon targets occur in the above facies and world wide examples of commercial deposits are cited. Highest grade targets occur in the crestal reef facies, the platform rim shoal/reef facies , and within the inner platform itself including carbonate mounds; these various targets occur in the depth range 2300-3500 m.**

- **There are numerous plays in this general area but the two key prospects are Simpson East (crestal reef target plus major closures at Jurassic levels) and Erec Prospect (inner platform** *sensu stricto)* . **The volume of the latter is the largest with UOIIP (filled to spill) at 1.4 Bbbl. While volumes would be smaller in the platform rim facies (requires remapping) deliverability would be relatively enhanced in this higher energy facies.**

- **Basinal facies are likely to have acted as source rocks given : 1) evidence of hydrocarbon migration up fault planes 2) evidence from other basins of source potential in this facies 3) Depths of burial of 2.5 seconds indicate thermal maturity – cf. detailed Permian source rock maturation modelling indicates this source is in the peak oil generation window (Vr0 = 1.0) at about 1.6 seconds.**

- **Source rock facies are also likely to have developed in the inner platform facies especially if evaporites sequences are present. These are buried to depths of 2.5 seconds indicating sufficient thermal maturity to develop hydrocarbons.**

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