

Outcrop models and seismic reflection images of the Devonian Reefs of the Canning Basin, Western Australia - Evolution and Inter-action

PP at Windjana Gorge

History, it has been said, is something that didn't happen written by someone who wasn't there. This panorama taken at Windjana Gorge in 1978, is to witness that I was there for some of the time, probably longer than I like to remember.

Reef outcrop location map (Playford).

The Devonian reef outcrops along the northern Canning Basin margin have become world famous, largely because of work by Phil Playford and his colleagues. In the subsurface this complex has been one of main petroleum exploration objectives in the basin for over 50 years.

My interest is in the depositional models based on those outcrops, in the evolution of those models, and in their influence on the geophysical imaging and imagining of the reef play in the subsurface.

Basin location map.

Over 50 wells have been drilled for Devonian 'reef' objectives in the Canning Basin. Almost all of them have been based on seismic interpretations influenced by those models.

This talk focuses on the Lennard Shelf but, even so, this history is necessarily brief and simplified. Many of my slides use original drawings and sections and I want to acknowledge the many individuals and companies who helped locate old documents. Especially the West Australian Department of Industry and Resources, and Chevron, who now own West Australian Petroleum, the pioneer of the Devonian reef play. .

Guppy model

The Devonian reef complex was first mapped in the late 40s/early 50s by geologists from the Australian Bureau of Mineral Resources. Guppy et al (1958) described an upper reef system uncomfortably overlying a widespread, tilted and eroded Givetian platform system, somewhat as illustrated by this cartoon. The interpreted erosional contact between those two systems can be seen in these old photos. It was to be the most controversial element of reef models for decades.

Smith, Playford and Williams model

In 1956, several young geologists from Western Australian Petroleum, Phil Playford among them, made the first detailed map of the Oscar Range area. They recognized two reef cycles, separated by a major drowning event and saw that back-reef, reef and fore-reef facies were contemporaneous.

Oscar Range and Meda

In 1958, Wapet drilled Meda 1, the first well to target the reef. Located on anomalous dips, on poor quality single fold data, Meda proved an auspicious beginning, encountering reef and fore-reef facies. Gas flowed from the reef itself and oil was recovered from overlying Carboniferous sandstones. This cross section of the interpreted Meda reef and the proposed Meda-2 clearly shows the influence of that Oscar Range model.

First drawing of the 'classic face'

In 1958, Phil Playford and another legendary Australian geologist, Murray Johnstone, made the first detailed geological examination of Windjana Gorge. Their report included this first drawing of what would become known as 'the classic face'.

Cross-section and map

Playford described Winjana Gorge as the 'best section through a typical reef complex' and stressed its importance to any understanding of the reef in the subsurface. Barrier reef, back-reef and fore-reef facies were mapped, as was 'algal reef' thought to represent the last phase of reef growth. The age of the reef complex was believed to be Famennian and Frasnian.

Langoora/Hawkstone Peak drilling

The decade after Meda was a frustrating time for Wapet. Seismic reflection and refraction data could not distinguish reef from basement, and several key wells drilled bald basement knolls or, as at Hawkstone Peak shown here, encountered only a thin reef section. Then, when seismic improved, and the Meda mound could be seen more clearly, the new seismic did not confirm the reef leads projected along trend..

St George's Range-1

During this time, other companies were drilling for Devonian objectives in the Fitzroy Trough, based, I suggest, on Guppy's concept of widespread platform complexes. This is the pre-drill prognosis from Conoco's St George Range-1. Like all other wells in the Fitzroy Trough, it never reached the Devonian complex, encountering instead thousands of metres of Permo-Carboniferous.

Playford and Lowry (1966)

In 1966 Playford and Lowry published the results of several years work by the Survey and the BMR. This slide shows their cross-section of the Oscar Range complex and their general model for the reef. The reef growth was seen as continuous, with a lower transgressive phase, with near vertical margins, and an upper regressive phase.

By this time, however, the drilling results had convinced Wapet that the reef growth was not continuous; that there was a major tectonic event at or near the end of the Frasnian.

Blackstone-1

The introduction of multifold seismic coverage in the mid 60s improved data quality considerably but mapping continued to rely on isopaching to map drape over the reefs. Then, at Blackstone, SE of Meda, new 6-fold data yielded high amplitude events which Wapet interpreted as a Frasnian atoll complex. It was considered the first seismic identification of the reef itself. However, drilling showed the Upper Devn section was missing by erosion and interpretations based on the older seismic were closer to the mark.

Wapet new model

Wapet felt their subsurface results were inconsistent with the outcrop models –they were even discussing Meda in terms of Units A, B and C – and they initiated their own extensive mapping programme. It convinced them that there was a major angular unconformity between the faulted and eroded Pillara platforms and the younger onlapping sediments, as you see illustrated here.

Mimosa-1

New seismic in 1972 seemed to support this new model of Pillara platform complexes overlain by basinal Famennian sediments. This slide shows Wapet's pre-drill interpretation of the interpreted Pillara platform complex at Mimosa-1. There was no platform, however; the Frasnian section was entirely basinal. Their other two wells also failed to encounter the predicted section and Wapet relinquished all Canning Basin blocks.

The Playford model (1976-80)

With such endings, however, come new beginnings, and a new round of exploration was about to start.

The WA Survey and BMR conducted major mapping programmes in the 1970s. This diagram, first seen in his 1976 IGC Canning Guidebook, publicized internationally by his AAPG Distinguished Lecture tour in 78/79 and formally published in AAPG in 1980 was the new Playford model, as it was soon known. A Givetian-Frasnian Pillara transgressive reef cycle, with vertical backstepping margins, was overlain by the regressive Famennian Nullara reef cycle.

From an historical perspective, there are two key points. Firstly, the unconformity between the Pillara platform and the onlapping clastics and carbonates was unequivocally defined as deposition, not erosional: it was the reef scarp, against which contemporaneous and younger sediments onlapped. Secondly, controversially from an industry perspective, the reef was still seen as continuous from Frasnian to Famennian.

Slide 79-11

This was a watershed time for the Devonian reef play, as a large and diverse group of companies commenced exploration. International giants such as Esso. Large Australia companies such as BHP. Many American and Canadian independents and small Australian companies. The Playford model gave them a new way of looking at the Canning seismic, as this 1979 scribble section of mine shows.

Photos and platforms

Playford's many publications also included excellent aerial photographs of the reef complex, such as these in the Bugle Gap area and they too influenced the geophysical imagination.

Blobs: Libya/Algeria/Canada/old Wapet lines

Conversely, some new explorers were acting independent of the Canning outcrop models. They had come to the basin from Canada and elsewhere and they brought their own reef models with them. Conrad Maher, for instance, Canoxy's new WA Manager popularized this image of the D reef from his AAPG paper. Sections such that on the upper right, from AAPG Memoir XXX, showed that relatively small, inelegant moundforms on old seismic data could be giant oil fields.

... and the old Wapet seismic revealed a plethora of such mounds and shapes. Blob maps became the order of the day, guiding the first new surveys in the late 1970s – and even more blobs were found.

Wells drilled on Devonian indicators

In some cases, the seismic reef-like shapes were the basis for picking the Devonian. and wells were drilled to test reef plays solely on the basis of the seismic anomaly. This proved less than successful!

Fitzroy River-1 targetted a shallow Devonian reefs in the Fitzroy Trough. A Meda-like seismic flexure was interpreted as the top Devonian and moundforms at separate levels were interpreted as Frasnian pinnacle reefs. There was no reef, only thick Permo-Carboniferous.

The Auld-1 well, upper right, was drilled on an elegant atoll-like anomaly in the South Canning Basin. It encountered a glacial erosional mound of Permian age.

Boronia-1 was interpreted as a reef because of the seismic bland zone and steep dip interpreted as the reef slope, supported by coral debris in the otherwise basinal Frasnian section in Mimosa-1 only a few kilometers away. It was entirely basinal sediments!

Blina

Not all reef anomalies from old Wapet seismic were unsuccessful. What began as WAPET's Blackstone Strat Trap and then their Erskine Prospect – a tilted Famennian reef margin - was ultimately drilled by Home Oil as Blina-1. The well flowed 905 bbl/day from the reef body and a 36 bbl/day from the overlying Yellow Drum dolomites.

Blina maps.

Some saw Blina as proof of the potential of the Devonian reef play. Others were less enthusiastic. The problem was, though first touted as 100 MMbbls recoverable, Blina quickly 'shrank' to about 1 MMbbl, as these common scale maps show. That was not the reef play most were chasing. Home and subsequent operators drilled many other reef tests in the Blina area – Yarrada-1, for instance, but encountered no other significant oil accumulation.

Meda Anomaly remodeled

That said, the Playford model was the main influence on seismic interpretations through this period. By the early 1980s seismic data quality was considerably improved and more detailed interpretations were possible. This slide shows Charlie Kerans re-interpretation of Meda in the context of the Playford model, and Mike Middleton's modelling.

Playford model interpreted on seismic – examples.

The geoseismic concept of many reef plays was drawn almost directly from the outcrop model. The example on the left shows pre-drill interpreted Frasnian and Famennian reef systems at Grevillea-1. The upper sequence proved to be entirely basinal facies; the lower sequence was a very tight platform sequence devoid of porosity or shows. At right is a 1984 interpretation by Whitestone's Bud Stilley of a stratigraphic trap along the faulted edge of the Oscar reef complex.

Kambara and the F/F Unc

For all that synergy between geophysical image and outcrop model, there remained one major point of disagreement. Drilling in the early 1980s reinforced the industry conviction that significant tectonism occurred in the Late Frasnian.

Esso's Kambara-1 is a good illustration. Esso interpreted a pinnacle reef growing on the Pillara platform is shown here. Drilling showed that it was not a reef but an erosional knoll of Pillara platform limestone. The Frasnian platform had been uplifted and eroded prior to subsidence and deposition of Famennian basinal clastics.

Esso models

Based on this and other wells, Esso concluded that reef-like anomalies on the seismic could be generated in many different ways. What looked like a beautiful reef on seismic could as easily be a structural or erosional construct. The continuous reef Givetian to Famennian reef concept just did not work in the subsurface.

Logan model

Ironically, this disagreement lent token credence to a radically different model that had also emerged in the 1970s. In the Logan and Semeniuk model, there were no reefs. The entire outcrop was seen as a structural metamorphic complex. The angular contacts between platform and onlapping sequence were seen as shear zones. This model was controversial from the start and dismissed by most. Explorers never adopted the Logan model, but many were sympathetic to its emphasis on the role of faulting and tectonism.

In 1982, the Frasnian-Famennian tectonic event was recognized in outcrop by Playford and has been a fundamental element of the model ever since.

Padilpa

For all that, the Canning reef play has proved a frustrating experience for explorers. No matter how systematically the seismic and geological models were integrated, the results were a disappointment. Esso's Puratte well here was testing a pinnacle reef on a Pillara terrace, in front of a back-stepping faulted margin. The well encountered a Famennian clastic fan. Santos later went onto the higher platform and drilled the broad Padilpa moundform. It was basement!

Gap Creek

Even when the geophysicist predicted a reef anomaly on scant evidence, and then saw new seismic define an excellent reef-like anomaly ... it didn't work. The anomaly turned out to be a tilted faulted platform, with interference creating the pinnacle shape.

Justago

The prevalence of the Pillara platform rather than reef margin or pinnacle reefs was one of the persistent disappointments of the last round of exploration. Here, at Justago the reef interpretation is shown on 1982 and 1984 seismic before and after the well. The pinnacle reef target might be there but the size would be uncommercial.

Limestone Billy Hills

Part of my own experience was just as frustrating. In 1984 BHP's Mike Hall and colleagues published a detailed model of the atoll complex at Limestone Billy Hills. In outcrop, the reef had vuggy porosity and was oozing oil in several places.

Fossil Downs Embayment

We'd seen the BHPP seismic adjacent to the outcrop, and the reef didn't look particularly elegant. A recon line we shot showed a new sub-basin and our detailed grid yielded high quality data and excellent reefs images.

Margaret-1

Margaret-1 was drilled on an interpreted pinnacle reef on top of the Pillara platform, shown here on Kufpec's pre-drill section. This was it, we thought. But the well did not encounter reef facies and the thin porous zone in the platform sequence had only a trace of gas.

Needle Eye Rocks-1

A second well, Needle Eye Rocks-1, also targeted a pinnacle reef on top of the Frasnian platform. No reef body was encountered and there were only minor shows and porosity. This failure marked the end of the reef play, except for a few wells in the Blina area.

Low stand fans in GA model

Exploration attention shifted briefly to the possibility of fan plays in front of the main faults, coincidental with this model by BMR geologists showing basin floor and slope fans as low stand deposits.

Whittam Model: Sequence Strat

Subsequent models post-date the reef exploration effort. Geoscience Australia, working with BHPBP geologists, developed a detailed sequence stratigraphic model for the reef complex.

Playford 2002

In 2002, Playford issued a much upgraded modelling featuring multi-cyclic backstepping and atoll development, and much greater detail in the tectono-stratigraphic classification of the reef development. This will be a guiding model, I'm sure, in the next round of exploration.

Blina back-reef and Meda

That new round is commencing now, notably with Australian company Arc Energy.

That exploration effort will have modern seismic data, such as this acoustic impedance section over the Blina back-reef strat play. It is a far cry from hand picked sections across Meda 50 years.

This history teaches us that successfully defining reefs in the subsurface requires good regional geology, good seismic data, and close integration of outcrop and seismic models.

The ultimate lesson is that/// even when the geophysicists get it dead right, the Canning presents the explorer with serious challenges regarding porosity and sourcing. Successful exploration will need models to address these geological risks, co-incidentally with the seismic mapping of the reef prospects.