Faster play-based exploration, Petrel Sub-basin, Australia

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**SUMMARY**

The Paleozoic extensional Petrel Sub-basin within the Bonaparte Basin, Australia is relatively underexplored. Historical two-dimensional seismic data and 59 exploration wells provide a substantial residual subsurface uncertainty. Woodside’s WA-522-P exploration permit comprises 7806 km² on the western flanks of the Petrel Sub-basin in shallow-water (<150 m) that hosts proven oil (Turtle and Barnett fields). Furthermore, the Torrens-1 well located within this permit encountered Paleozoic oil shows (KUFPEC, 1994).

Polarcus, on behalf of Woodside, acquired the 2846 km² Zenaide three-dimensional seismic survey between February and April 2018. The aim of the survey was to better resolve the Paleozoic exploration potential within the north-eastern area of WA-522-P. Final pre-stack depth migrated data received in December 2018 followed preliminary (fast-track) seismic data received in July. This modern seismic data contributes to the polarisation of key subsurface uncertainties.

We report the application of an Agile approach to exploration delivering regional interpretation, gross depositional environment mapping, charge modelling and biostratigraphic analysis in support of play-based exploration attribution of risk and uncertainty prior to receipt of seismic data. Integration of play and prospect analyses will support faster portfolio maturation.

**Key words:** Petrel Sub-basin, play-based exploration, Bonaparte Basin, exploration portfolio, Agile working

**INTRODUCTION**

The Petrel Sub-basin is a northwest-trending depocentre within the Bonaparte Basin (Figure 1). It remains a relatively underexplored extensional sub-basin. The sub-basin hosts a poorly constrained crystalline Proterozoic basement overlain by ~0.8 to 21 km of Paleozoic, ~0.2 to 4.5 km Mesozoic and 0.3 km of Cenozoic strata (Figure 2). The western and eastern basin margins converge to the south and Devonian to Permian strata subcrop onshore, intersected by wells such as Waggon Creek-1A (1996), Ningbing-1 (1982) and Keep River-1 (1969). Northwest-striking basin-bounding faults with ~200 to 400 m maximum throw define the transition from an approximately 3 km thick inboard Permian to present-day sedimentary succession onlapping a basement high (Berkeley Platform) to an outboard 24 km thick sequence of Devonian to present-day strata.

The Petrel Sub-basin hosts a proven petroleum system as demonstrated by both oil (e.g. Turtle and Barnett fields) and gas discoveries (e.g. Tern and Petrel fields; McConachie et al., 1996; Barnett et al., 2004). Seven play intervals exist between the lower Carboniferous and upper Permian (Figure 3). Key plays within WA-522-P identified from literature (Mory, 1991; Barnett et al., 2004) historical proprietary work and well failure analysis of the Petrel Sub-basin comprise:

1. Pennsylvanian Kuriyippi Formation (C50);
2. Lower Permian Keyling Formation (P20); and
3. Mid- to upper-Permian Hyland Bay Sub-group (P50).

![Figure 1. Map illustrating the location of exploration permit WA-522-P and the Zenaide Multi-client 3D seismic survey. Proven fields are shown on the map (green: oil discoveries, red: gas discoveries).](image-url)

Woodside currently operates WA-522-P at 100% equity (Figure 2) and NOPTA awarded the permit on 4 April 2016. Polarcus acquired the 2846 km² Zenaide Multi-client 3D (Zenaide) seismic survey in 2018 and Down Under Geosolutions (DUG) processed these data to pre-stack depth migration in fulfillment of the Primary Work Program. These data reduce the sub-surface uncertainty attributed to pre-existing sparse historical 2D seismic data imaging of the permit.
The northwest-striking basin-bounding fault system bisects the permit located on the western flank of the Petrel Sub-basin. Torrens-1 (KUFPEC, 1994) remains the only well drilled within the permit (Figure 1).

**Figure 3. Stratigraphy of upper Paleozoic strata within the Petrel Sub-basin following Gradstein et al. (2012).**

This study reports the rapid generation of a prospect and lead portfolio by implementing Agile project management methodology (Philip, 2019). As defined by Philip (2019) a ‘Rapid Sprint Study’ was constructed which combines analysis and collaboration into a facilitated workshop. The preliminary end deliverables are predefined prior to the workshop. The play-based exploration occurred as three successive workshops with the objectives:

1. Create gross depositional environment (GDE) maps;
2. Produce common risk segments (CRS) maps; and
3. Produce a stratigraphic and structural interpretation of the Zenaide fast-track seismic survey.

**METHODOLOGY**

Workshops 1 and 2 were each conducted on one day, in a single room, one week apart. Workshop 3 occurred over one week with participants working at their workstations.

The objective of the three workshop sessions was to produce assured products to support the creation of a prospect portfolio ahead of final Zenaide seismic data:

1. Workshop 1 produced seven GDE maps for the area of interest over the Petrel Sub-basin;
2. Workshop 2 produced reservoir presence and effectiveness, trap presence and charge CRS maps for the same area of interest covered in Workshop 1; and
3. Workshop 3 produced stratigraphic and structural interpretations and a preliminary PaleoScan™ model (semi-automated horizon interpretation of 500 horizons) of the Zenaide fast-track volume.

Subject matter advisers within Woodside contributed to workshops 1 and 2. Early engagement with these focal points influenced the final product and reduced corrections. Workshop 3 utilised expertise from the wider organisation.

Before each workshop the participants were given an outline of the objectives and goals. Workshop participants utilised live seismic sessions, well correlations, published literature and expert knowledge to produce outputs.

**RESULTS**

Workshop 1 and 2 produced seven GDE and CRS maps for the upper Paleozoic plays within the Petrel Sub-basin in two days. Consistency with interpretation between the two workshops was assured by collaborating with the same ten personnel. This also decreased the upfront explanation time in the second workshop, allowing more time to focus on business-critical objectives. Workshop 3 produced full seismic event interpretation, a structural model and a PaleoScan™ model in four days.

**Gross Depositional Elements**

The GDEs reconstruct the most regressive environment within each play. GDE maps comprised broad facies belts due to sparse well and seismic control. The Petrel Sub-basin records a series of mid-Carboniferous to upper Permian marine transgressions and regressions (e.g. Mory, 1991). Glaciogenesis (e.g. Mory and Haines, 2013) and complex tectonism (e.g. O’Brien et al., 1996; Goncharov, 2004) control the rate of sedimentation, relative to accommodation space creation and eustatic sea-level rise, precluded deep-marine deposition.

**Sub-surface Uncertainty and Risk**

Play-based exploration highlighted reservoir effectiveness as a key risk. Ascalalon-1A (Mobil, 1995) penetrated effective Permian (within the Hyland Bay Sub-group, P50) reservoirs at 4.5 km burial depth. However, rapid subsidence coupled with high sedimentation rates resulted in 15 km of Carboniferous and Permian strata within the sub-basin depocentre; confining the effective Paleozoic reservoir depth range to the basin margins.

Key Paleozoic source rock bearing play intervals identified within the basin comprise C10 (Langfield Group), C30 (Tanmurra Formation), P20 (Keyling Formation) and P50 (Hyland Bay Subgroup). Present-day burial results in over-mature (Vr >3.0) source rocks towards the depocentre and under-mature (Vr <0.8) source rocks at the sub-basin margin. Fifty-kilometre buffers account for plausible lateral migration pathways (e.g. Cornea oil, Browse Basin; Ingram et al., 2000) with greater uncertainty.
Seals of regional extent comprising P10 (Treachery Formation), P40 (Fossil Head Formation) and TR10 (Mount Goodwin Formation) overlie key reservoir intervals. GDE mapping supports lower delta and shallow-marine environments that present low- to moderate-risk for reservoir and seal presence.

**Seismic Interpretation and Model Building**

Spread over three days and with seven people involved, Workshop 3 utilised the expertise within the Exmouth and Bonaparte exploration team. Key seismic events were interpreted on the Zenaide data and stratigraphically calibrated by Torrens-1 well data. Integration of these interpretations with extant regional 2D interpretation provided contiguous, calibrated and depth converted structure maps used for charge modelling.

The upper section of the C50 (Kuriyippi Formation) onlaps onto the Berkley Platform occasionally draping basement highs. Drainage features and channel geometries can be observed along the heavily faulted basement on the Zenaide 3D data set within the identified C50 package. A lower delta plain environment was interpreted for the C50 within WA-522-P. The package thickens towards the east of the block and into the paleo-depocentre of the basin (Figure 2) where the offshore transition occurs.

Similar onlapping geometries have been identified in the P10 (Treachery Formation) and P20 (Keyling Formation). The P10 predominately consists of discontinuous seismic facies (on block), which become better defined and sub-horizontal towards the depocenter of the basin. The P10 has been predominately interpreted to have been deposited in a prodeltaic to siliciclastic offshore depositional environment. In contrast the overlying P20 consists of sub-horizontal laterally continuous seismic reflectors, that occasionally brighten and show sinuous morphology when tracked. An upper to lower deltaic depositional environment has been interpreted for the P20.

The P40 (Fossil Head Formation) does not onlap onto the basement and maintains a constant thickness across the block. Wells across the basin that have intersected the P40 have a lower net-to-gross ratio. The P40 has been interpreted as an offshore depositional environment.

Regional limestone markers within the P50 (Pearce and Doonbong formations) are clearly observed and in the absence of multiple well penetrations, provided a clear marker horizon across the lease. The most regressive surface within the P50 has been interpreted as a lower delta plain depositional environment. The P50 and overlying TR10 (Triassic Mount Goodwin Formation) are truncated by the Early Jurassic J10 unconformity (Figure 2).

Structural interpretation of Zenaide data identified northeast- and northwest-striking faults (Figure 4). The superordinate basin-bounding faults strike northwest and have maximum throws of 200 m. The confluence and bifurcation of these fault systems generates fault-bound structural closures.

Seismic and structural interpretation supported the generation of a succession of geologically calibrated amplitude models using PaleoScan™. The model illustrated depositional features and amplitude anomalies. These features both confirmed and iteratively modified the GDE maps developed during the play-based exploration Workshop 1.

The accelerated approach delivered seven GDE maps, seven CRS maps, a seismic interpretation, a structural model and a PaleoScan™ model of the Zenaide seismic survey fast-track data in a total of five days. It is acknowledged that an accelerated approach to a task may result in slight oversights, however when providing a foundation platform where further work will be conducted, anything that has gone unnoticed will be picked up later. Comparison between the Agile project management and traditional workflows has demonstrated that it is cost effective (Philip, 2019), offered early insights, obtained a focus for future work and provided a platform for further portfolio maturation.

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**REFERENCES**

2014, Bonaparte Basin, Biozonation and Striatigraphy, chart 33, Geoscience Australia.


Kufpec Australia Pty Ltd, 1994, Torrens-1 Well Completion Report.


Mobil Exploration and producing Australia Pty Ltd, 1995, Ascalon-1 IA well completion report.


Figure 2. Seismic stratigraphic interpretation of Line 100_003 AGSO 100 Petrel 2D MSS (2014).