Geologic and geophysical challenges that were overcome with the use of technology — Caswell subbasin, Browse Basin

Jenny Greenhalgh[1] and Rick Irving[1]

Abstract

The Browse Basin is part of the larger Westralia Superbasin, which underpins much of the Australian North West Shelf region. The 2013 acquisition of 9224 km^2 of multiclient 3D GeoStreamer dual-sensor deep-tow seismic over the Caswell subbasin gives new insight into this hydrocarbon province, where the 2014 discovery of Lasseter-1 in the basin has resulted in renewed exploration interest. Numerous imaging challenges within the Browse Basin have added to the complexity of the area. Therefore, acquiring and processing data of sufficient quality to allow sufficient resolution of reservoir distribution around target structures and clarity to image subtle stratigraphic traps is critical. Improved imaging of the data allows identification of potential new play fairways, such as the Aurora subbasin, which was bypassed previously because of imaging challenges.

Introduction

The Caswell subbasin is a major depocenter within the Browse Basin, situated entirely offshore in the northern region of the Australian North West Shelf. The discovery in 2014 of Lasseter-1 (operated by Santos) in the basin has resulted in renewed exploration interest. The 2013 acquisition of 9224 km^2 of multiclient 3D GeoStreamer dual-sensor deep-tow seismic over the Caswell subbasin has given new insight into this hydrocarbon province. The acqusition allows not only for detailed inversion work in the primary reservoir fairway but also for greater low-frequency signal preservation of the deeper sediments and structures that previously have not been possible to image. The benefits of using dual-sensor acquisition data in the developing Caswell subbasin and the adjacent areas of the Browse Basin will be discussed, with an examination in terms of potential oil and gas prospectivity.

The imaging challenges within the Browse Basin are numerous. Surface-related multiples contaminate the section at several intervals (with multiple bounces), and generation of interbed multiples within the more recent sediments appears to produce multiple energy with similar appearance to primary data. A velocity inversion at the base of the Jamieson Formation adds complexity to the demultiple approach as velocity discrimination between primary and multiple energy is diminished, resulting in more reliance on model-based multiple-attenuation techniques. There is also evidence of orthorhombic anisotropy within the Jamieson Formation, which causes apparent velocity differences, depending on the acquisition direction of the survey.

This article will discuss new discoveries such as Lasseter-1, a demonstration of the uplift and benefits of the newly acquired data versus legacy data sets, and a comparison of depth versus time imaging. In addition, the improved imaging of the Triassic interval in this area will be demonstrated; with the oil discovery of Phoenix South 1 in the offshore Canning Basin (Roebuck Basin) to the southwest, it is being viewed as a major potential new play fairway previously bypassed because of imaging challenges.

Location

The Browse Basin is part of the larger Westralia Superbasin, which underpins much of the Australian North West Shelf region (Figure 1). The basin is bounded to the southeast by the Australian craton, to the northeast by the Bonaparte Basin (Vulcan subbasin), and to the southwest by the Roebuck Basin (offshore Canning Basin). To the west and northwest is the deepwater Scott Plateau, which lies outboard of the major Browse Basin depocenters.

Within the Browse Basin, there are several constituent structural elements. The largest depocenters are the Caswell and Barcoo subbasins, of which the Caswell is the deepest, containing more than 15 km of sedimentary succession. The Caswell subbasin is separated from the Barcoo subbasin to the southwest by the Buffon-Scott Reef Anticlinal Trend, which is a major north-to-northeast-trending feature. The anticlinal trend structure also separates the Caswell subbasin from the Seringapatem subbasin to the northwest. The southeastern part of the Browse Basin is shallow basement, known as the Yampi Shelf in the central and northern parts of the basin and the Leveque Shelf

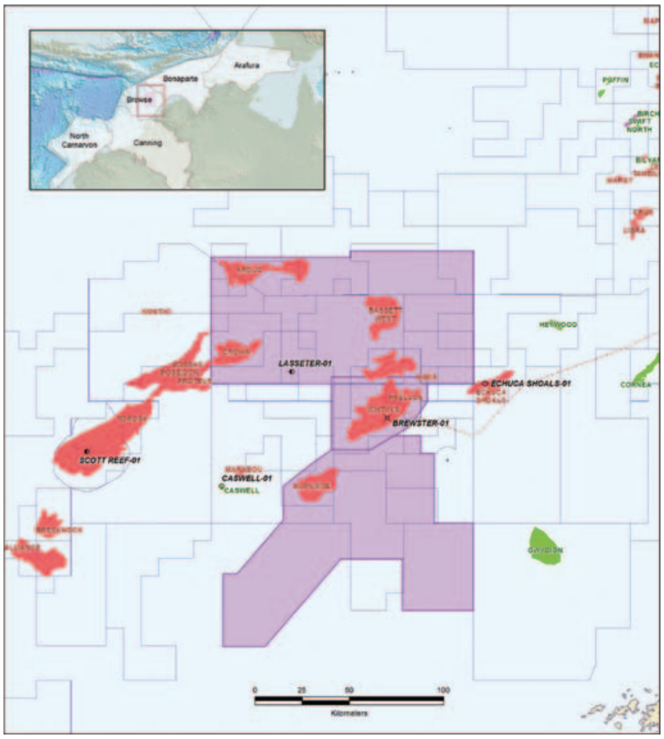

Figure 1. Browse Basin location map.

[1]PGS Australia Pty. Ltd.

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in the south; the basement dips to the northwest. There is an overall northeast-southwest structural trend that dominates the entire basin.

Exploration history

The first discovery of gas in the Browse Basin came in 1971 with the drilling of Scott Reef-1 (Figure 1), which encountered gas in a thick succession of fluviodeltaic sediments of the Lower-Middle Jurassic Plover Formation. Several associated prospects were drilled later along the Buffon-Scott Reef-Brecknock Anticlinal Trend, encountering significant amounts of gas and condensate. Discoveries continued to be made during the 1980s, including Brewster-1A ST1, Caswell-2 ST2, and Echuca Shoals-1. Each well encountered gas in Lower Cretaceous (Berriasian) sandstone reservoirs, with the Caswell-2 ST2 and Echuca Shoals-1 also encountering gas in Late Jurassic sediments. More recent discoveries in the Caswell subbasin, including the Crown and giant Ichthys gas fields, highlight the potential in this area.

The first discovery of oil in the Browse Basin was in 1978, when the Caswell-2 well encountered the first oil in the Caswell subbasin in Upper Cretaceous sandstones. In 1995, further oil discoveries were made in Cretaceous sandstones at the Gwydion-1 well on the Yampi Shelf. This discovery and further related tests proved that there had been oil charge and migration through the area.

The most recent discovery in the Browse Basin is the Lasseter-1, drilled in 2014, a significant gas-condensate discovery in Block WA-274-P. The well encountered a gross gas-condensate-bearing interval of 405 m, with 78 m of net pay over the Jurassic Lower Vulcan and Plover intervals. The Lower Vulcan reservoir system, which is developed between the major Ichthys and Poseidon structural trends, holds great promise because it suggests much more remaining potential away from the previously recognized fairways.

Tectonic evolution

The Browse Basin and its component structures were formed as extensional half-grabens in an intracratonic rift setting. This first phase of extensional block faulting began in the Early Carboniferous and continued until the Early Permian, leading to the formation of the main Caswell and Barcoo subbasin depocenters. The structures and alignments formed during this early period of basin development have controlled both subsequent reactivation events and the locus of sedimentation. The depositional environment during this extensional event was initially fluviodeltaic, whereas the succeeding Early Permian sediments were marine-dominated limestones and shales.

Extensional block faulting was followed by thermal subsidence (sag phase) throughout the Late Permian to Middle Triassic. The sediments that were deposited during the remainder of the Permian were sandstones grading into shales and limestones. The Triassic sediments were dominated by a regional Early Triassic marine transgression, leading to the deposition of fluvial and marginal- to shallow-marine sandstones, limestones, and shales. Between 8 and 10 km of synrift and early postrift sediments are thought to have been deposited.

The underlying Paleozoic faults were reactivated during the Late Triassic to Early Jurassic as a regional contractional event affected the region (Fitzroy Movement). This resulted in the inversion of the half-graben structures formed during the earlier extensional phase and the formation of large anticlines and synclines. The major Buffon-Scott Reef- Brecknock Anticlinal Trend also was formed at this time.

A second extensional phase occurred through the Early to Middle Jurassic, causing the collapse of the anticlinal structures formed by the preceding inversion event. The formation of the Heywood Graben also occurred at about this time. Sedimentation was dominated by sandstones, mudstones, and coals of deltaic and coastal-plain origin (Plover Formation), and the succession contains both source and reservoir rocks. The Browse Basin then underwent widespread erosion and peneplanation during the Middle Jurassic because of continental breakup and the initiation of seafloor spreading in the Argo Abyssal Plain.

From the Late Jurassic and throughout the Cretaceous and much of the Cenozoic, the Browse Basin became a passive margin, controlled by thermal subsidence and eustatic changes. Marine conditions were established, with a major transgressive cycle beginning in the Early Cretaceous and continuing to the Late Cretaceous. Marine sediments containing sandstones and shales that are potential source-rock intervals and regional seals onlapped and draped the older structures. The transgressive cycle reached its height in the Turonian and then a major regressive cycle followed, during which the shelf edge migrated to the northwest. Major erosion occurred on the shallow Yampi Shelf area, and turbidites were deposited within the Caswell subbasin. The deposition of carbonate sediments increased, although fluvial-deltaic to nearshore sediments still were deposited on the basin margins.

A second period of inversion began in the Miocene as the northwestern margin of the Australian Plate collided with the Eurasian Plate. This oblique-angle collision led to the reactivation of older faults within the Browse Basin area. Carbonate deposition became dominant across the area.

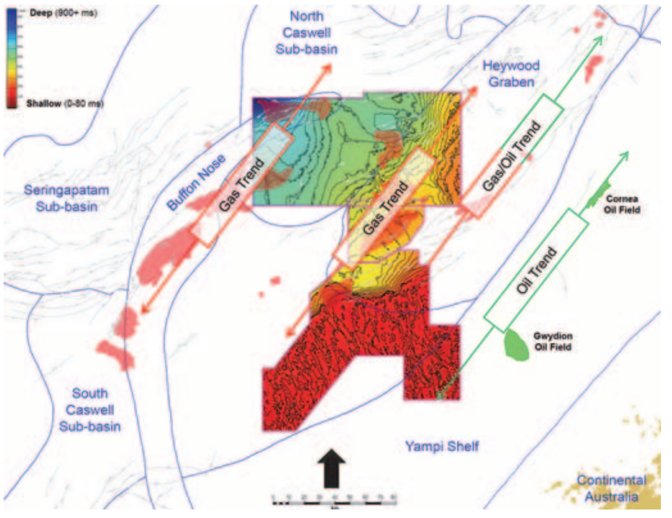

Figure 2. Petroleum distribution in the Browse Basin.

Petroleum systems

Within the Browse Basin area, multiple petroleum systems have been identified, suggesting that there are at least three major petroleum systems (Figure 2). The Jamieson Formation is a regional seal across the basin, and all major source-reservoir units are beneath this.

Source

A series of potential source-rock intervals has been identified at multiple stratigraphic levels, ranging from Permian to Cretaceous. The majority of hydrocarbons in the Browse Basin, if not all, are sourced from the Lower to Middle Jurassic Plover Formation, the Upper Jurassic Vulcan Formation, and the Lower Cretaceous Echuca Shoals and Jamieson formations.

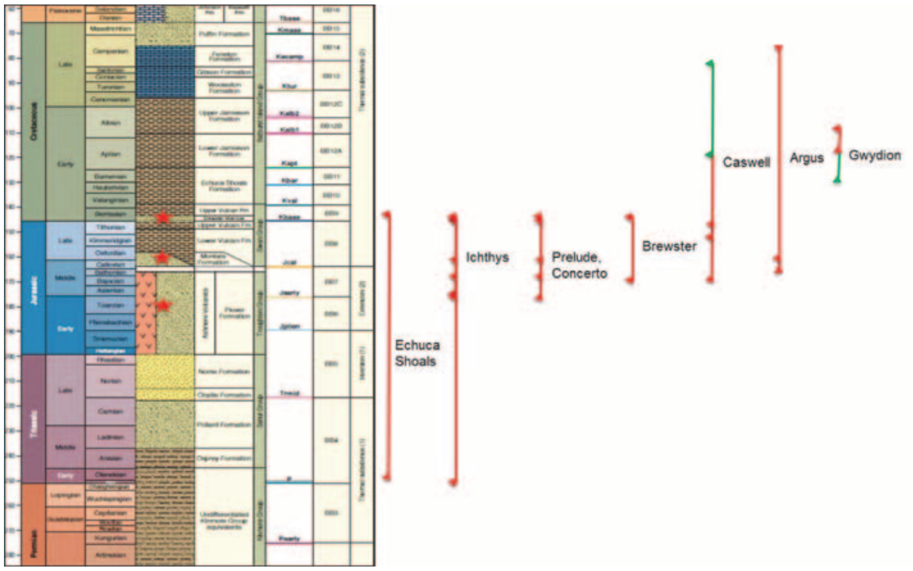

Figure 3. Chronostratigraphic distribution of Browse Basin producing reservoirs.

The fluviodeltaic Plover Formation hydrocarbon potential comes from thin beds of coals and prodelta shales. The sediments are distributed across the Browse Basin, reaching their maximum thickness in the Barcoo subbasin, and are predominantly gas prone. The marine Vulcan Formation also is distributed widely across the Browse Basin, although it is usually a thin unit, only thickening locally in the Heywood Graben area and parts of the shelf. The restricted conditions in the Heywood Graben suggest that this area might have the best-developed source-rock potential for oil generation. The marine Echuca Shoals and Jamieson formations are distributed mainly across the Caswell and Barcoo subbasins and contain both marine and terrestrially derived plant material.

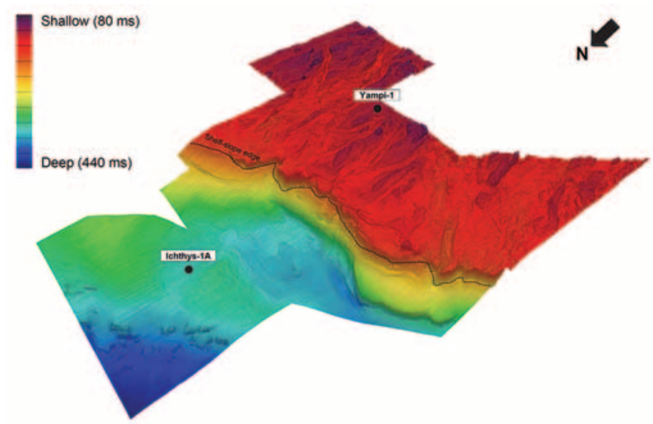

Figure 4. Seafloor two-way traveltime (TWT) on Browse Basin margins.

Reservoir

Exploration has focused on the Caswell subbasin, being the largest and deepest depocenter in the Browse Basin. The major reservoir targets lie underneath the main regional seal of the Echuca Shoals and Jamieson formations (Figure 3).

The most laterally extensive reservoir unit is the Plover Formation. The reservoir sandstones were deposited in a delta plain setting, initially fluvial dominated but becoming more tidally influenced upsection. The distribution of this unit is controlled strongly by the anticlinal structural trends formed during the Fitzroy Movement. Plover Formation sandstones are the producing reservoir in the Torosa, Brecknock, and Calliance fields of the Buffon-Scott Reef-Brecknock Anticlinal Trend and are among the producing reservoirs in the Ichthys, Prelude, and Concerto fields. The Brewster Member of the upper Vulcan Formation is also a widespread reservoir unit and was deposited as turbidity currents in a deepwater marine setting. It also contains mudstone and hence frequently exhibits poorer reservoir properties and is among the producing reservoirs in the Ichthys, Prelude, and Concerto fields. The Middle-Upper Jurassic Montara Formation exhibits good reservoir properties but has a restricted distribution within the Browse Basin. This unit is also one of the producing reservoirs in the Ichthys, Prelude, and Concerto fields.

There are further reservoir targets across the Browse Basin. In areas with reduced overburden, the Triassic Nome Formation fluviatile sandstones are a recognized target and successfully produce gas in Crux field in the Heywood Graben area. Triassic targets are not targeted elsewhere in the basin because of the inability of conventional seismic data to image them successfully.

Prospectivity

Focus on the large structures targeted in gas exploration has meant that the search for subtle stratigraphic traps is overlooked. There is proof of generation and migration of oil in the Browse Basin (discussed above), and high-quality data sets can be used to identify the presence of turbidite sandstones on the basin margins that could have been charged. The depositional model proposed by Benson et al. (2004) focuses on the identification of ponded turbidity currents and accumulation of sands within topographic lows. The present-day geometry

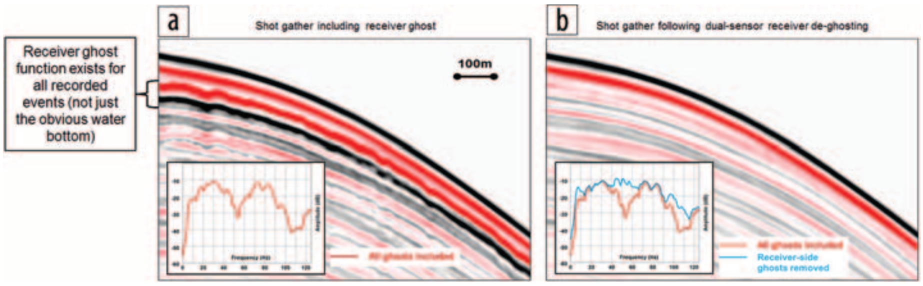

Figure 5. Seismic data (a) with and (b) without receiver ghost.

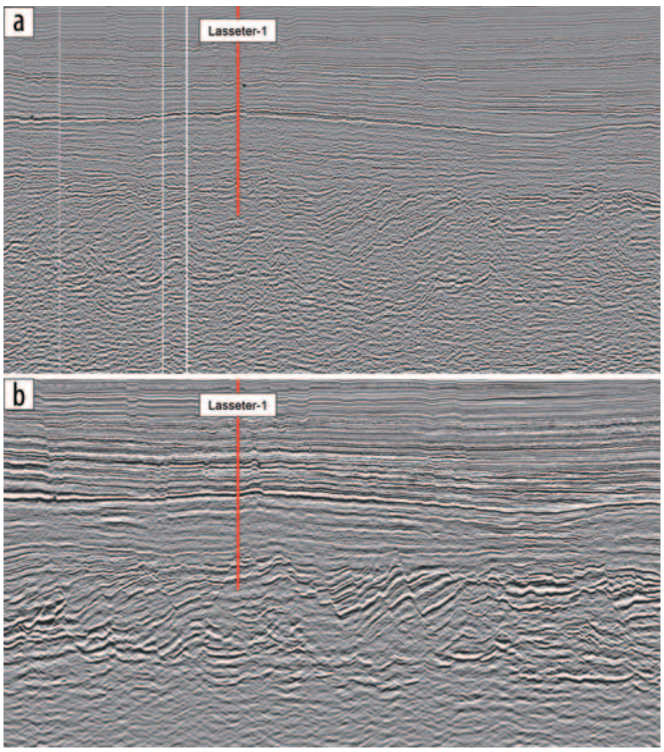

Figure 6. Comparison of (a) legacy seismic versus (b) broadband seismic at Lasseter-1 well.

of the Browse Basin margins (Figure 4) demonstrates a suitable area for the formation and accumulation of these stratigraphically trapped sandstones.

Reactivation of faults because of ongoing inversion in the Browse Basin also provides a potential for migration of hydrocarbons into stratigraphically shallower targets, especially on the shelf and slope area, where the thickness of the Jamieson Formation regional seal does not exceed the throw of the faults.

The discovery of the Phoenix South-1 oil well in the offshore Canning Basin has highlighted the importance of the Permo-Triassic interval that previously has not been subject to systematic interpretation because of imaging challenges. This can change now, with a more in-depth focus possible.

Imaging challenges

The major challenge that faces interpretation geologists and geophysicists in the Browse Basin has been that of acquiring data of sufficient quality to resolve the detail of reservoir distribution around target structures, a lack of penetration into the Triassic, and sufficient clarity to image subtle stratigraphic traps.

In all seismic acquisition, a ghost function is recorded that is overlaid on the raw primary data. The ghost function comes from energy that travels up past the sensors and then is reflected off the sea surface and recorded again by the sensors as it travels back down toward the earth. This is most obvious at the water bottom but is present at all times on the section and effectively adds additional false-seismic events that hinder interpretation.

The use of dual-sensor acquisition and specialized imaging flows allows improved definition of reservoir horizons with greater clarity by removing these ghost functions. This is achieved by using the different recording properties of the hydrophones, which record pressure, and the geophones, which record vertical particle velocity. In the case of the hydrophones, the polarity of the recorded wavelets is reversed after reflecting off the water bottom, but for the geophones, the polarity remains unchanged. This difference allows for the separation of the receiver ghost from the primary upgoing data, resulting in a much cleaner seismic section (Figure 5).

Much of the exploration effort in the Browse Basin is focused on the gas play, identifying sandstones of the Plover Formation, Montara Formation, and Vulcan Formation and their distribution around anticlinal structures that form the major traps. The improved resolution at depth, which is available using the new acquisition technology and imaging techniques, also reveals structures at depth not currently observable on legacy conventional data. This comparison can be seen in Figure 6, where part (a) shows legacy data and part (b) is new broadband acquisition. Both images are in the time domain for easier comparison.

In addition to deghosting and broadband processing, the enhanced imaging has been accomplished with modern demultiple techniques using a combination of data-driven and model-based demultiple procedures. True-azimuth 3D surface-related multiple elimination (SRME) uses a multidimensional interpolation procedure to form colocated source-and-receiver trace pairs at every subsurface reflection point. The trace pairs then are convolved to generate a 3D shot-domain multiple model, which is stored for multiple removal at a later stage.

The shallow-water demultiple technique uses a model of the seabed and convolves this with the data in the T-p domain to obtain a model of source-side and receiver-side multiple energy. The 3D SRME and the shallow-water demultiple techniques produce complementary multiple models, which then are subtracted from the data using a multimodel adaptive subtraction (Figure 7).

True broadband also allows relative inversion of the data set, which uses the ultralow-frequency components of the seismic data. We gain the ability to distinguish between the populations of sand and shale and hydrocarbon-bearing sandstones (Figure 8). We can use the new acquisition technology to benefit the entire exploration-and-production cycle, enabling exploration

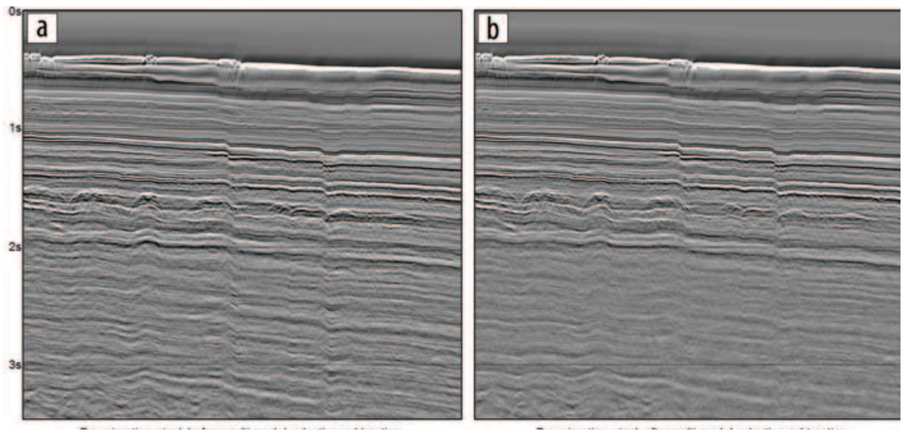

Figure 7. Stack (a) before and (b) after multimodel adaptive subtraction.

from a regional extent to the prospect level and with greater clarity regarding shallow-drilling hazards such as faulting and carbonate mounds.

The focus of explorationists on the large structures targeted in gas exploration has meant that search for the subtle stratigraphic trap is overlooked. There is proof of generation and migration of oil in the Browse Basin (discussed above), and high-quality data sets can be used to facilitate a more robust interpretation of the sequence-stratigraphic framework. This is critical to identify and map the lowstand development of turbidite sandstones on the basin margins in the Aurora subbasin area, which could have been charged during oil migration.

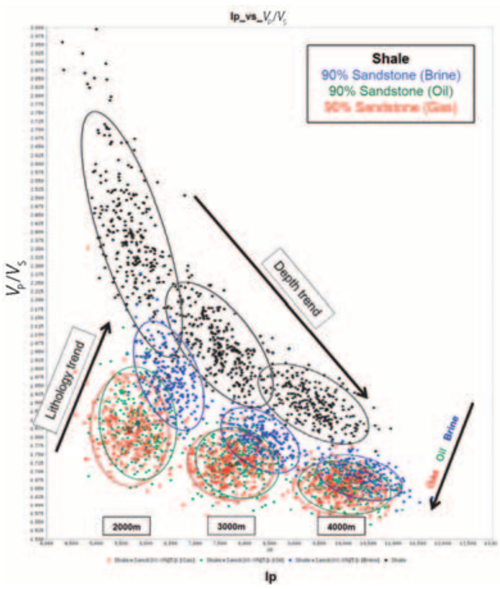

Figure 8. Summary of inversion study on Caswell MC3D data set.

Conclusions

With the new acquisition of broadband data in the Browse Basin, we see better resolution of structures and reservoir distribution in the main gas-prone fairway. We also have better data integrity, which improves imaging of the previously unresolved Triassic sequence and allows interpreters to use the improved low-frequency content of the data for QI work at the reservoir level. This offers geologic confidence in quantitative amplitude analysis and prospect derisking. Interpreters can have increased confidence in the interpretation of the structural and stratigraphic framework, which gives a better understanding of the potential for a findable oil leg in the margins of the Browse Basin. TLE

Corresponding author: jennifer.greenhalgh@pgs.com

Reference

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