Broad bandwidths reveal double the expected sediment depth in the Northern Carnarvon Basin

By
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INTRODUCTION

The North West Shelf of Australia is one of the most prospective hydrocarbon areas in the world, containing significant oil and gas discoveries. However, despite exploration success with the discovery of huge gas fields and considerable oil accumulations, the Dampier and Barrow sub-basins still contain large undrilled areas with significant potential. These two sub-basins lie inboard of the Rankin Trend within the Northern Carnarvon Basin and host both oil and gas accumulations with petroleum systems of Late Triassic, Middle–Late Jurassic and Early Cretaceous age, located within close proximity to existing infrastructure. CGG's new Davros multi-client 3D survey is located within this sub-basin and the current acquisition covers an area of 6,405 km², although permits are in place to extend this to approximately 11,000 km², see figure 1.

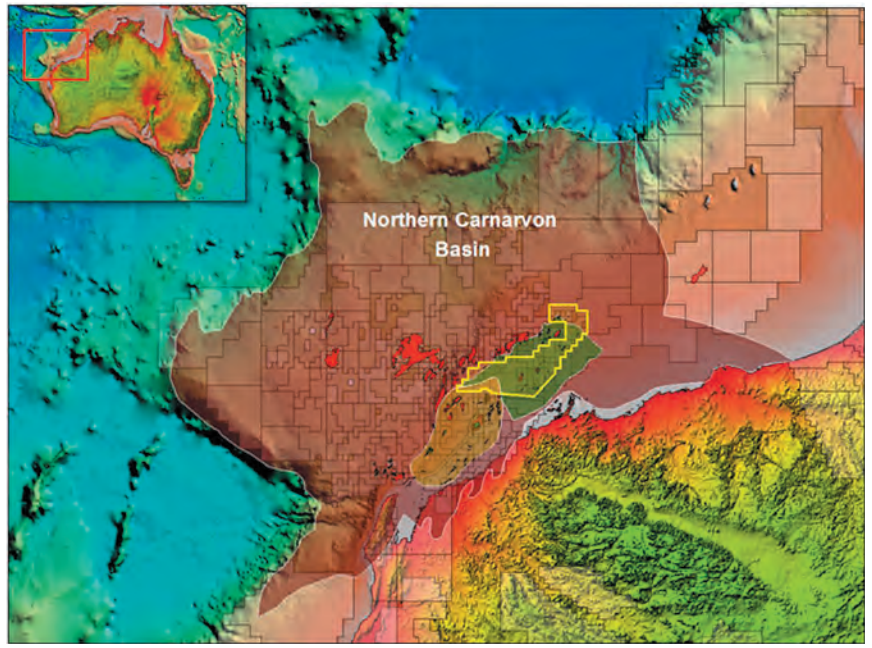


Figure 1: *Map of the Davros 3D survey.*

BACKGROUND GEOLOGY AND SEISMIC IMAGING CHALLENGES

The Dampier sub-basin is known to host over 10 km of late Paleozoic to Cenozoic sediments with a high recent success rate for drilling. Plays exist at multiple stratigraphic levels, including oil-prone Jurassic and gas-prone Triassic successions, see figure 2. One of the key impediments to further exploration in the area has been the lack of high-quality 3D seismic data. The main seismic imaging challenge is the effect of the high-velocity Tertiary carbonate overburden. The transition from carbonate to underlying clastic successions produces a velocity inversion which makes multiple discrimination and removal problematic. The characteristic impedance variation within the carbonates also produces interbed multiples, further degrading the data at the target reservoir levels. In addition, the shallow water bottom generates its own set of multiples, so that both long- and short-period multiples from a number of different sources contaminate the data and require effective management to improve the imaging of the underlying geology.

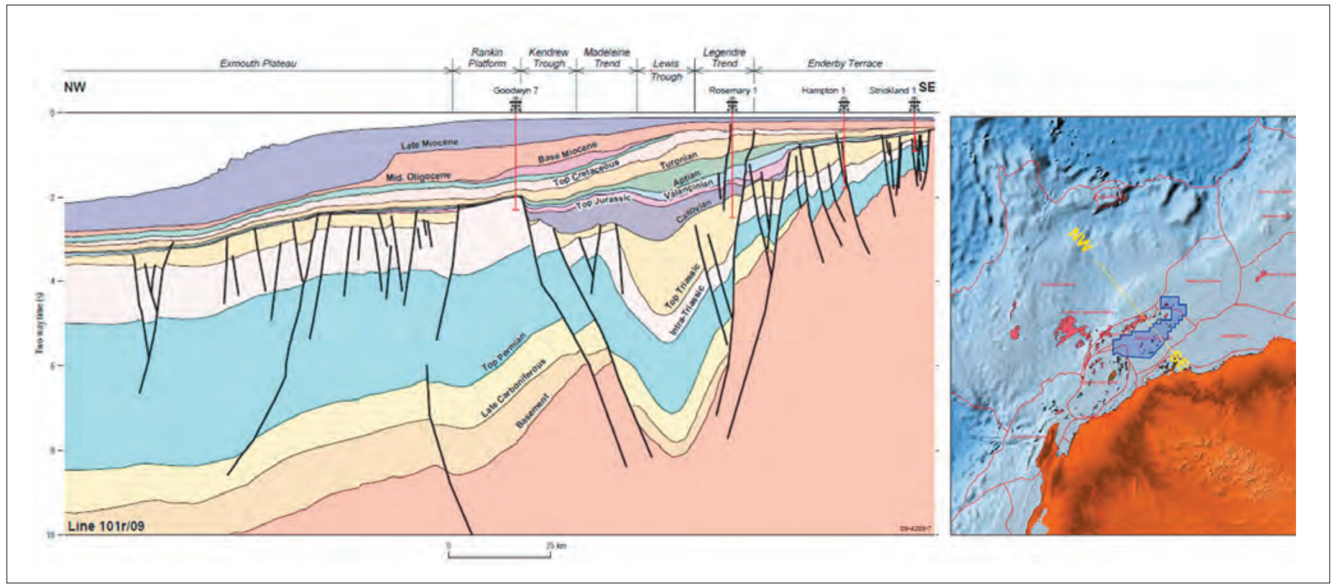


Figure 2: *Geology cross section (from Geoscience Australia, 2010).*

The thin shallow carbonate layers cause both scattering attenuation and anisotropy as there is a strong contrast in elastic properties between the layers. This can significantly affect the seismic image quality by attenuating the high-frequency component and greatly reducing vertical resolution with depth, as well as affecting the amplitudes of the target horizons. The amplitude attenuation inferred from seismic primaries is believed to derive from two sources, intrinsic attenuation (wave energy decay due to inelastic absorption) and scattering (wave energy decay due to loss of coherence). Analysis of numerous wells in the area (Pevzner et al., 2015) showed that intrinsic attenuation is the dominant factor in many areas, while large scattering attenuation was reported in others. This attenuation has a substantial effect on surface-seismic data quality, resulting in a fourfold loss of energy and an approximate 10-Hz dominant frequency shift towards the low frequencies. This makes the recording of good-quality low frequencies with a high signal-to-noise ratio imperative for imaging the deep sediments.

SURVEY DESIGN

The Davros survey has been designed to take advantage of recent advances and innovations in seismic acquisition and processing solutions to overcome these issues and enhance the imaging of reservoir units in the prospective Triassic to Lower Cretaceous section, in order to help identify and understand new play types. The survey covers all stages of hydrocarbon exploitation from exploration to production, including prospective new exploration areas, appraisal areas and producing fields which may be nearing the end of their life, but which may have significant potential to tie in new discoveries from near-field exploration. There are large undrilled areas within the survey and therefore the imaging improvements delivered will be critical for detailed prospect analysis and, when completed, should provide the clearest images in the industry of this potentially highly prospective area. The survey will form a key part of a comprehensive geoscience approach, which will also include interpretation and attribute volumes, and will contribute towards a Triassic-focused geological study of the North West Shelf being undertaken by CGG. The survey was acquired using the BroadSeis™ and BroadSource™ broadband solution which combines acquisition technology with advanced deghosting, demultiple and depth processing to deliver the broadest bandwidths for detailed prospect analysis. Broad bandwidths are required to provide low frequencies to image beneath the high-velocity carbonates at the same time as high frequencies for detailed imaging of the near-surface data.

BROADBAND DATA

BroadSeis variable-depth streamer acquisition is a solution for broadband marine seismic, which uses a proprietary curved cable shape and a novel deghosting technique to remove the receiver ghost and extend the usable primary bandwidth to six octaves (Soubaras, 2010). This solution benefits from towing streamers at depths of up to 50 meters, which, combined with the use of Sercel Sentinel® solid streamers, ensures the raw data has an exceptionally good signal-to-noise ratio, especially at low frequencies (Dowle, 2006). However, in the Davros survey area the water depth was too shallow in most areas to tow the streamers this deep and so for the majority of the survey they were towed at 30m, still deep enough to provide good-quality low-frequency data. The curved streamer profile enables robust removal of the receiver ghost across the full bandwidth of the recorded primary

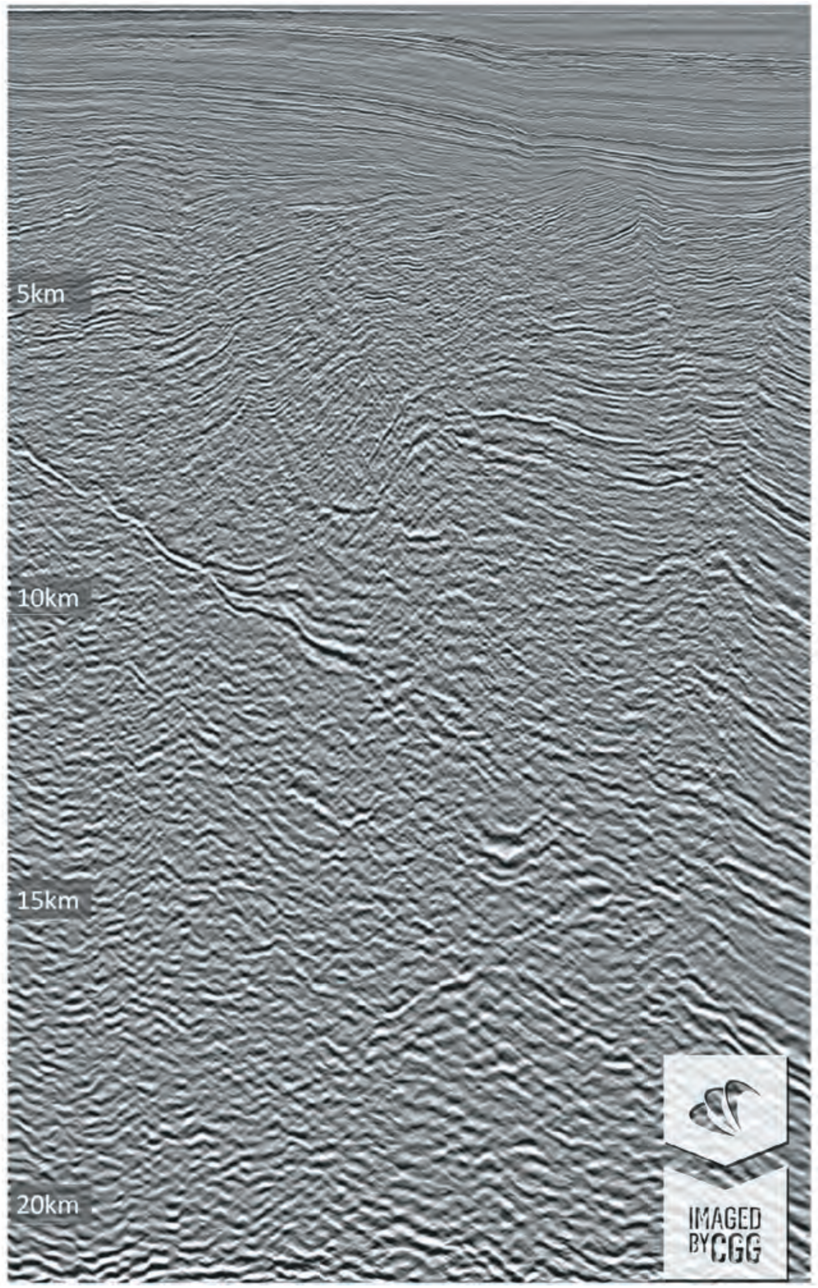


Figure 3: *New broadband fast-track data (images courtesy of CGG Multi-Client & New Ventures).*

energy using hydrophone sensors alone, to deliver broad bandwidth wavelets without sidelobes for enhanced seismic interpretation and improved inversion results.

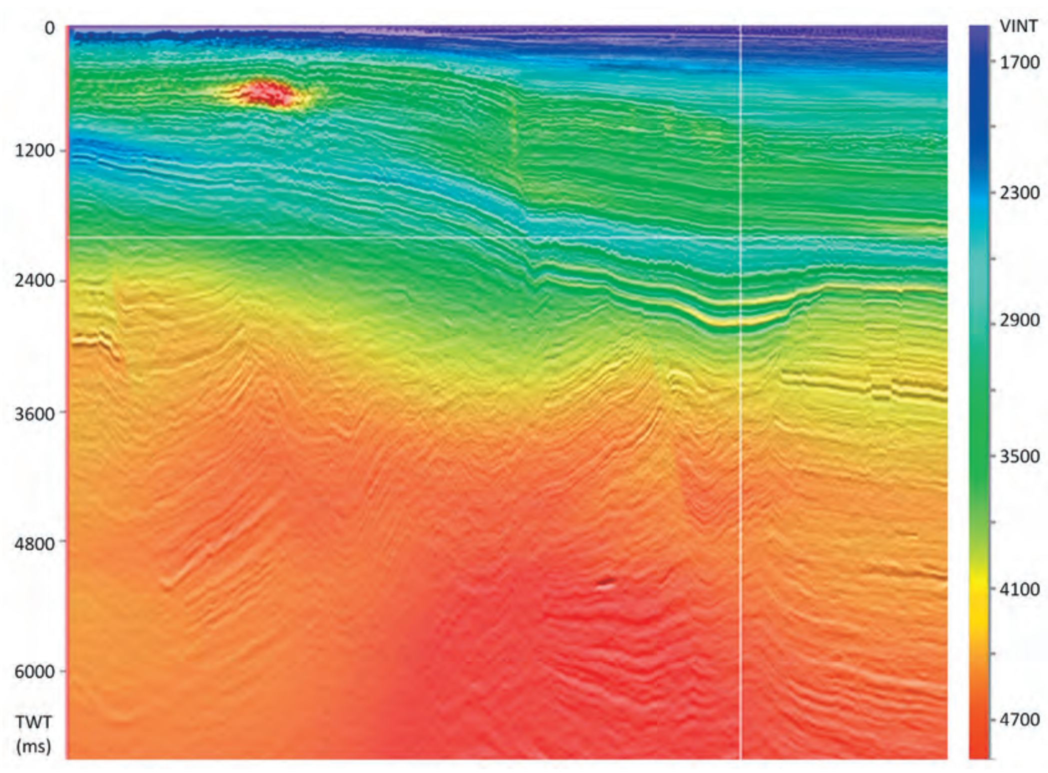
BroadSource complements BroadSeis by extending the frequency range to the sampling interval Nyquist, without compromising the low frequencies, by eliminating the source ghost notch (Siliqi et al., 2013). This is filled by combining acquisition using a synchronized multi-level source with specially developed processing algorithms, to deliver the broadest bandwidth available from towed-streamer seismic. BroadSource uses air guns at different levels to defocus the source ghost, so that it can be removed by designature. The firing of the guns is synchronized so that the deeper gun fires as the downgoing energy from the shallower gun reaches it, creating a consolidated, focused, downgoing wavefront. The upgoing energy is unsynchronized and therefore delivers unfocused ghost wavefronts, enabling attenuation of the ghosts by designature. The designature process requires the use of an accurate far-field signature, which is derived in the field by inversion of recorded near-field hydrophone measurements, as part of our Full Source Characterization (Ni et al., 2014). This direct measurement approach delivers a more accurate estimation of the bubble effect, and the ultra-low frequencies fundamental for broadband acquisition, than the use of a signature derived from pressure field modelling.

The key benefits of broadband data are that reflectors become sharper and more coherent by extending the high-frequency component, and sidelobes around the central peak are reduced by extending the low-frequency component. This enhances interpretation since the higher frequencies provide more detail, such as thin stratigraphic features and subtle rock structures, and the low frequencies give an envelope to the seismic signal that shapes the larger-scale impedance variations or, in geological terms, the major lithology variations (Duval, 2012). This increases confidence in correlating seismic interpretation across faults and other major structural features and allows layers to be easily differentiated. In addition, the low frequencies contribute to better penetration and imaging of deep targets and reveal large-scale facies variations, as well as providing better stability for seismic inversion.

SURVEY ACQUISITION

The Davros survey was conducted by the Viking Vision, using twelve streamers of 8,100 meters (7,500 meters active) in a variable-depth configuration in combination with the synchronized, multi-level broadband source. Acquisition was complicated by numerous installations in the area, necessitating cooperation with various operators and stakeholders to ensure safe and successful operations. This included staying clear of platform and FPSO exclusion zones, collaborating with diving support vessels and synchronizing timing of vessel passes with tanker offloads and the installation of the Wheatstone platform. During the acquisition of Phase 1, some strong currents were encountered but the Sercel Nautilus® streamer steering system was more than adequate to control the cables in these conditions.

Figure 4: *Velocity model derived by refraction tomography, showing a localised high-velocity anomaly amongst the suspected hydrocarbon-related digenetic zones..*



SUBSURFACE IMAGING

The Davros survey area is noted for its high level of water layer-generated multiples and interbed multiples generated within the carbonate layers. To address these, the processing includes many combinations of sophisticated demultiple techniques. These are targeted at different aspects of the multiple generation system to derive an accurate model of the multiple wavefield, which can then be subtracted from the data while preserving the primaries. Special care has to be taken to preserve the recorded broad bandwidth during this process, in particular the low frequencies. This cascading of demultiple techniques is common practice in areas where multiples are particularly challenging.
Various techniques were combined to create a model of the multiples. Shallow water demultiple (SWD) was used to build a model of the water layer multiples using convolution (Yang, 2013). Model-based water layer demultiple (MWD) (Wang et al., 2011), which uses a model of the water bottom and the wave equation to predict multiples, was used to create a more accurate model for near offsets and outer cables. Surface-related multiple elimination (SRME) (Verschuur, 2006) models all surface-related multiples by convolution, without the need for any information on the subsurface.
In addition to direct water bottom multiples and water layer peg legs, direct multiples from deeper horizons are also addressed, although this technique is not so effective for shallow water bottom multiples, near offsets and outer cables. Least-squares and curvelet-domain adaptive subtraction techniques were used (Wu and Hung, 2013), combining the three models in a joint subtraction for optimal multiple removal whilst protecting the primary events. In addition to this, water bottom targeted tau-p deconvolution was applied as well as a second pass of residual SRME. Radon-domain demultiple, based on differential normal moveout of primaries and multiples, was also applied both pre- and post-migration.

The outcome of these many passes of demultiple, combined with the broad bandwidths recorded, was the imaging of over 20 km of sediment, twice the depth that had been imaged previously, see figure 3. The clear imaging of these deep events was enhanced by sophisticated high-resolution velocity model building. Refraction tomography was employed as it helps to produce more accurate and detailed depth velocity models below a shallow sea floor (Birdus et al., 2013). Refraction tomography complements reflection tomography with the reflections guaranteeing the stability of the solution and avoiding uncertainties associated with refractions and diving waves in complex media. In this instance, the refraction tomography produced a high-resolution velocity model, identifying localised high-velocity anomalies amongst the suspected hydrocarbon-related digenetic zones, as shown in figure 4. Accurate modelling of these shallow anomalies is important for accurate imaging of the deeper structures, since raypath deviation is cumulative and so a modest inaccuracy in the near-surface model can significantly deteriorate the seismic image at depth.

CONCLUSIONS

The final seismic dataset for Phase I was completed in May and will be available for Phase II in November; acquisition of further phases is still under discussion. The survey will be interpreted and a small area will be the focus of a reservoir characterization and inversion study.

Initial imaging results are deeper and clearer than have been seen in this area before, with enhanced imaging of the Triassic to Lower Cretaceous reservoir units, as shown in figure 5. In addition to demonstrating that there is at least 20 km of sediment in this area, clear faulting and structure of the deep layers can be seen, demonstrating the exceptional penetration power of broadband low-frequency seismic data. Close cooperation between our geology and subsurface imaging experts promotes understanding of the challenges involved in the survey, why they exist and the methods of overcoming them, and leads to the delivery of a high-quality, geologically coherent dataset, which it is anticipated will revolutionize the understanding of this area. ◗

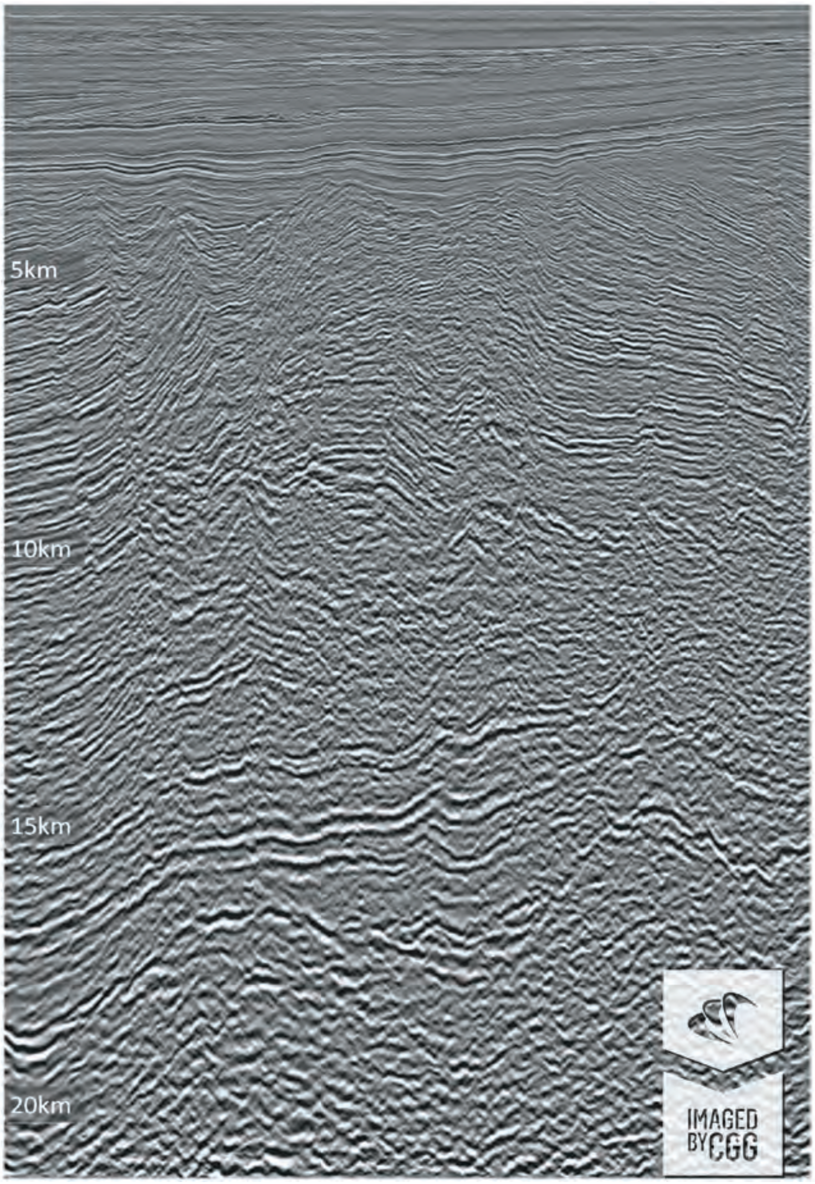


Figure 5: *Example of the exceptional deep imaging achieved by even the fast-track data from the Davros survey (image courtesy of CGG Multi-Client & New Ventures).*

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