Benefits of two-boat 4D acquisition, an Australian case study

Tom Ridsdill-Smith, Woodside Energy, Perth, Australia
Des Flynn and Stuart Darling, Concept Systems

In February 2007, Woodside acquired a two-boat, push reverse 4D monitor survey over the Enfield oil field offshore Western Australia (Figure 1). Two-boat push reverse acquisition maximizes 4D repeatability and minimizes 4D infill in a survey area known for strong, unpredictable currents. Significant survey planning and focused 4D field expertise resulted in excellent source and receiver positional repeatability with a mean |Dsrc|+|Drec| of 27 m at the target offset of 1900 m. Survey infill is only 7% compared to a predicted infill of 30% to achieve the same 4D coverage with conventional one-boat acquisition. Shortcomings of the two-boat push reverse technique include a large minimum near-offset of around 500 m and a receiver motion 4D error when matching to the conventional one-boat baseline survey. An nrms of 15% was obtained for the final processed data. Due to the success of the 2007 Enfield survey, Woodside is planning a second two-boat monitor survey on Enfield and a two-boat 4D baseline survey on the neighboring Vincent Field in 2008. In this article, we discuss the results of the 2007 Enfield monitor survey and our thoughts on possible future improvements for two-boat acquisition.

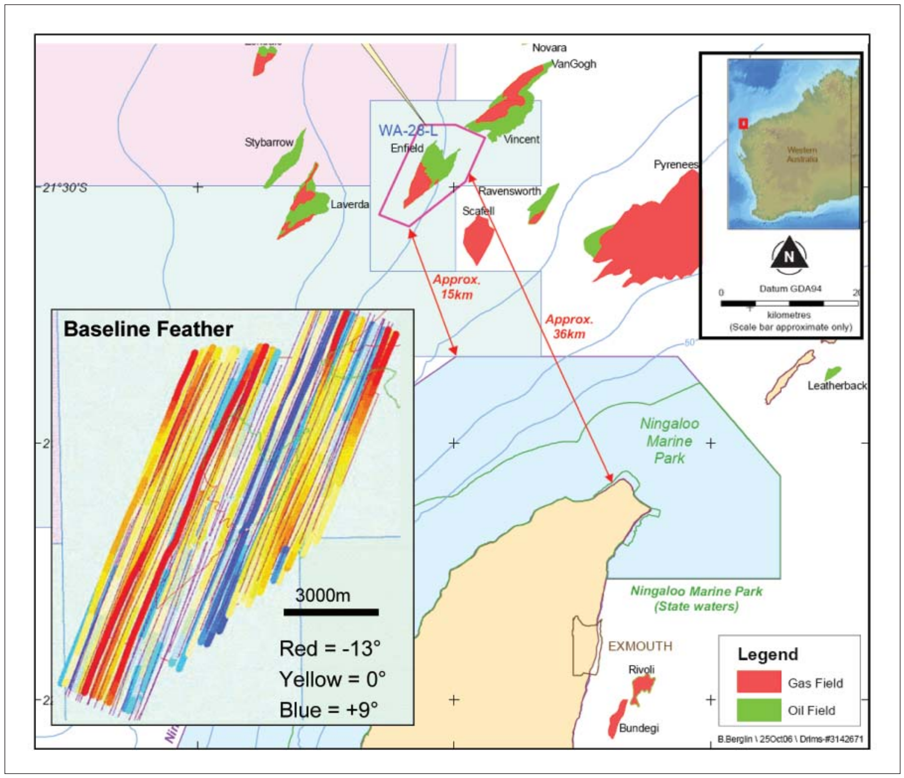

Figure 1. *Location of the Enfield 4D monitor survey. Inset shows the feather encountered on the baseline survey in 2004.*

Survey design and acquisition

The Enfield Field, in the North West Shelf of Australia, commenced oil production in July 2006. Woodside acquired a 4D monitor survey, Australia's first dedicated 4D survey, just seven months after production began.

Woodside acquired the baseline seismic data in 2004 using a one-boat, dual source, 6 × 100-m streamer configuration. Water depth in the area is around 500 m and seismic data quality in the area is excellent with a usable bandwidth of 15–80 Hz at the target level of 2 s twt.

We encountered large and rapidly varying streamer feather during the baseline survey, resulting in around 50% infill (Figure 1).

The key elements of the 2007 monitor design are: high 4D repeatability, maximum offset of 2300 m, and minimal infill due to limited (10 days) vessel availability.

To meet these requirements, Woodside opted to use a two-boat acquisition configuration with separate source and streamer vessels. Two-boat 4D acquisition is routinely used to maximize coverage around obstructions, but it is relatively rare to acquire complete surveys in this configuration.

In the Enfield monitor survey, the source boat followed the original baseline track; it also matched the baseline shot-point interval (18.75 m, flip-flop) and gun separation (50 m). The streamer vessel was steered to match the baseline receiver positions at a target offset of 1900 m which represents the center of the far-offset group where the expected 4D signal amplitude is strongest.

Crossline drift (or feather) of streamers and sources occurs due to both currents and changes in the vessel track and needs to be accounted for dynamically during two-boat 4D acquisition. The effect is particularly significant for the streamers due to their length. Analysis of historical data from current meters and previous seismic surveys shows that the currents are largely unpredictable in this area. As a result, the streamer vessel track cannot be accurately planned in advance and needs to be adjusted during each line as the currents change. To minimize the effects of vessel-induced crossline drift in the sources, baseline source tracks were smoothed prior to the survey to create the monitor preplot.

To manage the operational complexity of steering the source and streamer vessels to dynamic tracks, three Concept Systems Limited (CSL) acquisition specialists provided in-field expertise and assistance to the seismic crew throughout the survey.

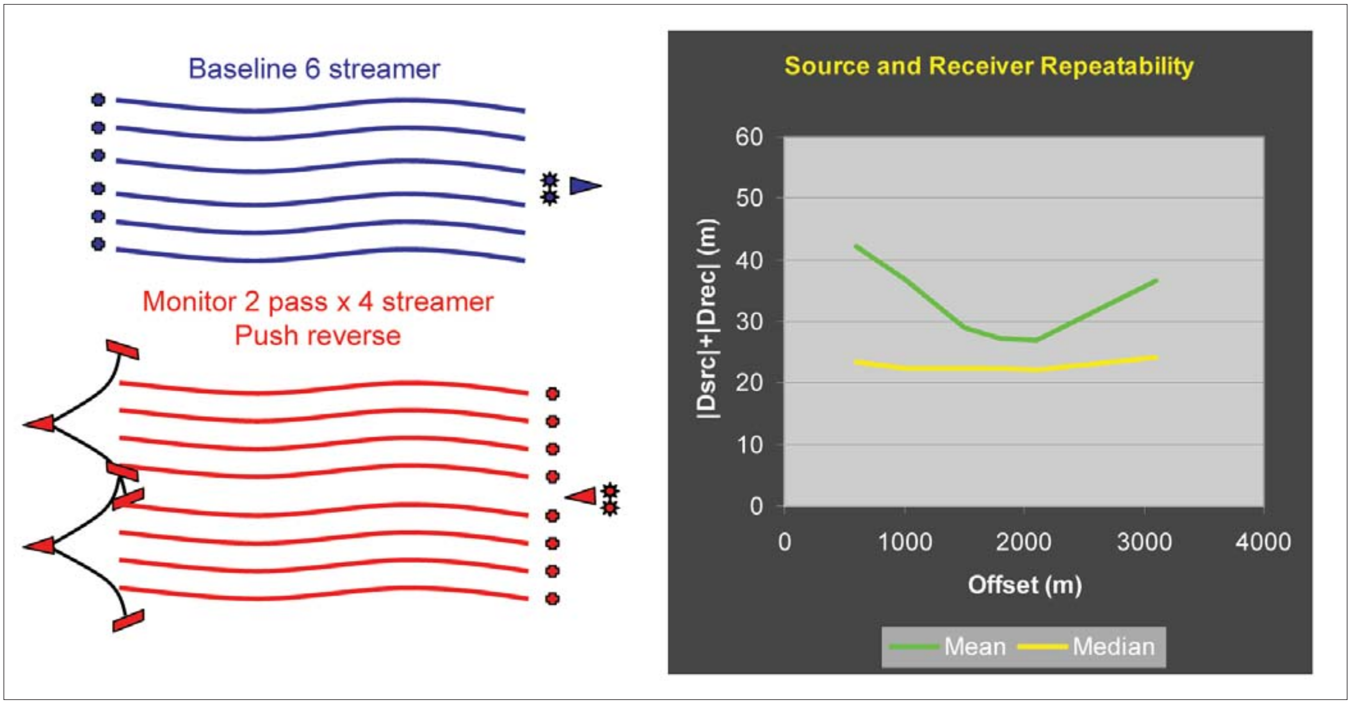

Figure 2. Acquisition geometry (left) and resultant |Dsrc|+|Drec| repeatability (right).

Woodside only had a four-streamer vessel available in the time frame to acquire the monitor. Thus, to replicate the six-streamer baseline coverage, we needed two passes for each source line, resulting in an effective eight-streamer coverage. Finally, we used a push reverse configuration in which the source boat follows behind the streamer boat in order to keep a safe distance between the two boats (Figure 2). Note that two-boat acquisition limits the minimum achievable near offset to around 500 m and makes the target offset of 1900 m actually ~1300 m behind the stern of the streamer vessel.

4D repeatability

We achieved good positional repeatability in the monitor survey with a mean |Dsrc|+|Drec| error of 27 m at the target offset of 1900 m (Figure 2). The source repeatability is very high for the two-boat operation because the source vessel is smaller and more maneuverable than a conventional 3D seismic vessel. Mean source crossline error for the survey is 5 m.

By decoupling the sources and receivers, the two-boat acquisition method allowed us to accurately target the desired far offsets. Additionally, as we were steering the center of the streamer spread, we reduced the effects of baseline to monitor feather mismatch (Figure 3). In contrast, in a one-boat mode we have to steer the vessel to the source track so we are only guaranteed good repeatability at the near offsets and any feather mismatch will have a significant impact on the repeatability for the far offsets.

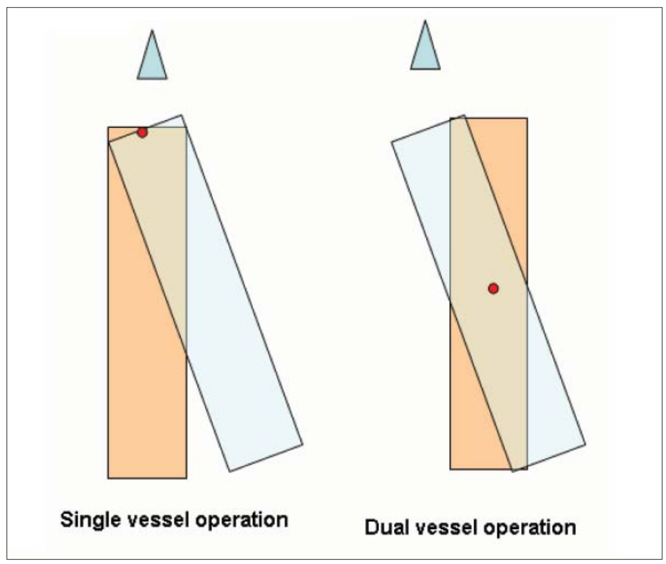

Figure 3. Feather mismatch between baseline and monitor for single vessel (left) and reduced effect of mismatch with two-vessel acquisition steering to the center of the spread (right).

Receiver motion reduces the repeatability of push-reverse, two-boat monitor surveys in comparison to a one-boat baseline survey because the receivers are moving through the water in opposite directions for base and monitor during the recording of each shot. We reshot a small section of this monitor survey to create a push reverse on the push reverse 4D data set. Comparing these results against the full monitor survey indicates that the effect of receiver motion is ~10% nrms and is effectively corrected in processing to around 2-3% nrms.

The 500-m minimum near offset reduces the effectiveness of SRME and other multiple suppression techniques. The multiples in this survey area are generally mild, but there are some areas with significant diffracted multiples due to seafloor canyons. Processing tests indicate that the effect of running SRME with a near offset of 300 m versus 500 m is on the order of 5% nrms. Matching the baseline and monitor minimum offsets during parallel processing reduces the

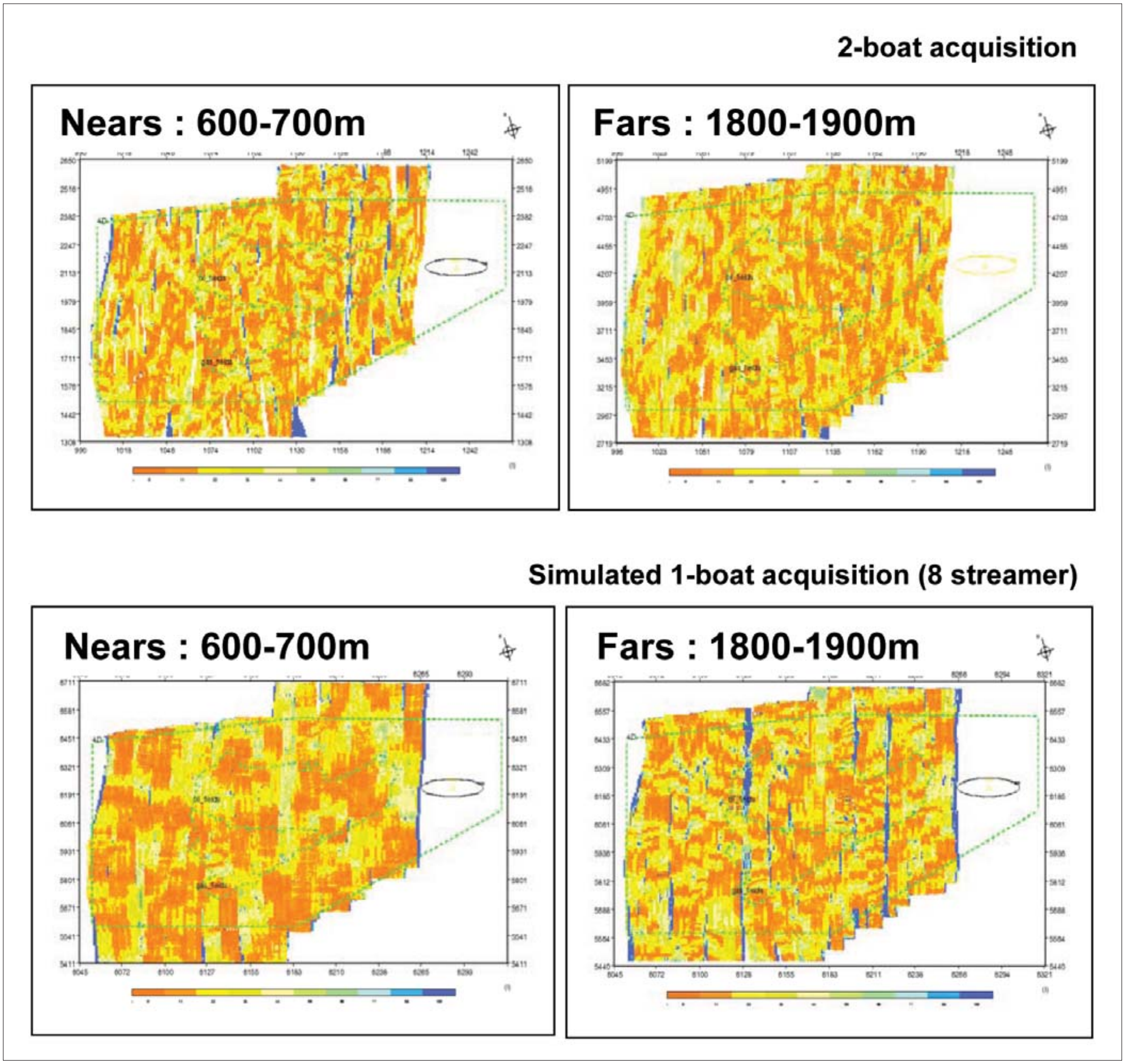

Figure 4. *Comparison of the actual two-boat 4D coverage (top) with the simulated one-boat coverage (bottom). Orange is good repeatability, blue is poor repeatability (as measured by |Dsrc|+|Drec|).*

effect of this on the 4D difference, and the final impact is only a couple of percent nrms except in the areas with diffracted multiples where residuals remain in the 4D difference volume.

In our 2008 4D acquisition campaign, we are planning to address the large minimum near-offset issue by improving the navigation displays available on the vessel and by minimizing the distance between the last active receiver and the tail buoys on the streamers. Furthermore, we are investigating advanced processing techniques to better deal with the missing near offsets.

We achieved an nrms of 20–25% with preliminary fast-track processing results delivered three weeks after the last shot. The final processed nrms is around 15%. The survey has already yielded important results based on high-quality 4D AVO products (Smith et al., 2008).

Coverage and infill

We used the CSL Line Prioritization technology in the survey planning and updated it in the field to ensure that the optimal lines were acquired throughout the acquisition. As a result, we only acquired 7% 4D infill in the monitor with no 4D-specific standby required for weather and currents. We successfully acquired infill lines on the first attempt due to the ability to steer the streamers to fill the missing coverage. Coverage at the target offset of 1900 m is excellent with very few data holes.

To compare these results to a conventional one-boat 4D monitor, CSL generated a repeatability simulation based on the actual feather conditions encountered in the survey and an eight-streamer configuration. The simulated one-boat survey required up to 30% infill to achieve the same coverage as the actual two-boat survey. Even with this extra infill, the

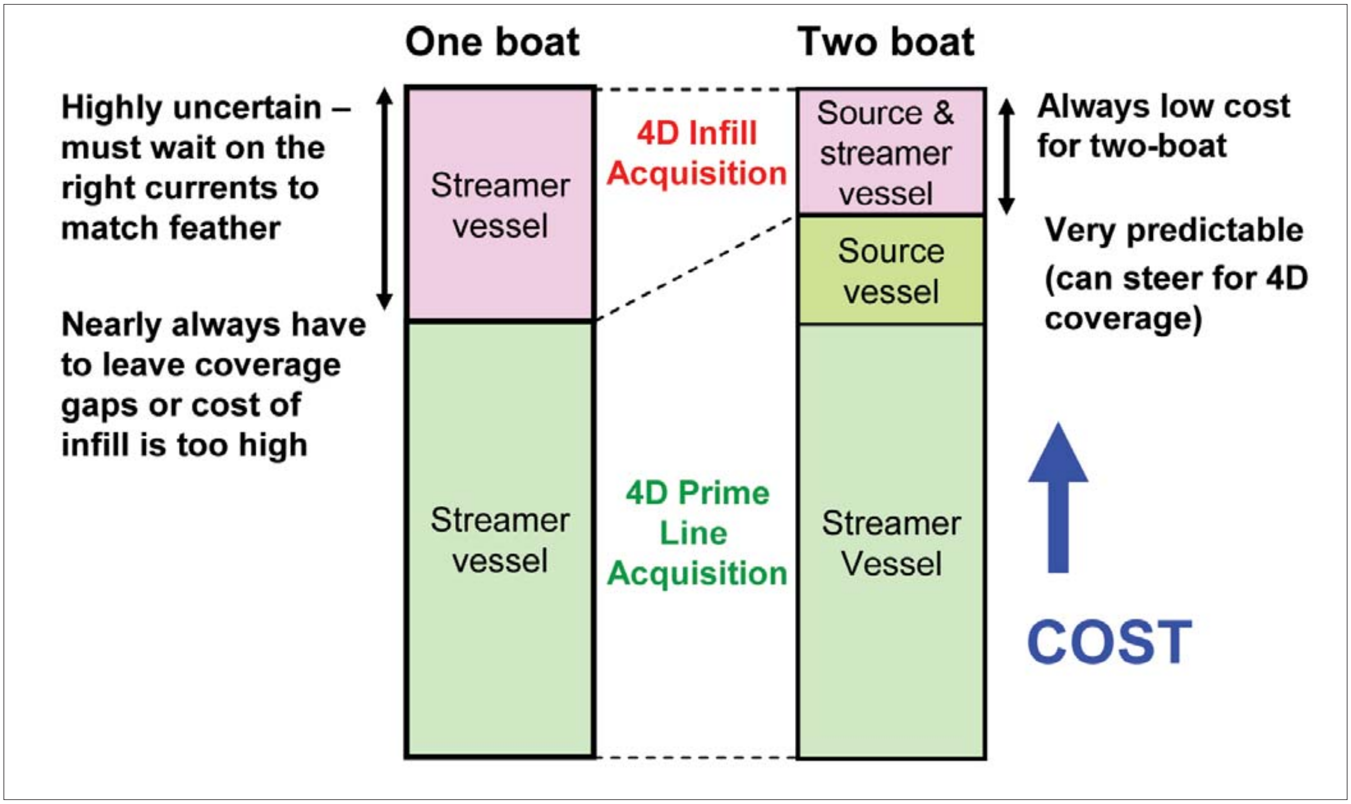

Figure 5. The break-even cost for one-boat versus two-boat surveys occurs when the increased day rate for a two-boat operation is offset by the reduced infill requirements.

repeatability at the target offset would be poorer than for the two-boat case. An additional practical limitation of one-boat acquisition is that successful acquisition of the infill would require favorable currents to match feather between baseline and monitor as the vessel must steer to the baseline source preplot. As a result of the unpredictability of the currents in this area, we believe it is unlikely that 4D infill can be successfully acquired with one vessel.

If cost or time limitations meant that the infill could not successfully be acquired with a single vessel, the mean |Dsrc|+|Drec| repeatability at the 1900-m target offset would have increased to 43 m, compared to 27 m for the two-boat case. Figure 4 shows how for the equivalent acquisition effort, two-boat acquisition maximizes repeatability at the target offset (the fars in this case).

The two-boat configuration also helps with the acquisition of lines close to surface obstructions such as production facilities. Both source and streamer boats can be independently steered to bring their equipment as close to the edge of the obstruction exclusion zone as possible.

Obstruction undershooting can also be easily incorporated but was not used in this survey.

Conclusions

Two-boat acquisition is valuable in survey areas with strong, unpredictable currents where source and receiver repeatability are difficult to achieve. Two-boat acquisition is most cost effective when high 4D infill would be required for a one-boat operation and when the incremental cost of two-boat acquisition is low (Figure 5).

The cost savings of two-boat acquisition could be improved by acquiring the baseline survey in this configuration. This would result in a baseline survey with straight source tracks and little or no infill, which will significantly reduce future monitor acquisition costs and improve source repeatability. Woodside is planning to conduct a 4D baseline survey with the two-boat configuration over the neighboring Vincent Field in 2008. This new baseline will include undershoot of infrastructure in the field.

In practice, budgetary considerations and currents during the survey will limit the 4D coverage that can be obtained in a one-boat survey. Two-boat acquisition is therefore an efficient way to improve 4D repeatability by maximizing 4D coverage. TLE

Suggested reading. "4D repeatability using dual vessel acquisition: Holstein field, Gulf of Mexico" by Barousse et al. (SEG 2007 *Expanded Abstracts*). "Using 4D seismic data to understand production-related changes in Enfield, North West Shelf, Australia" by Smith et al. (ASEG *Preview*, 2008).

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Corresponding author: tom.ridsdill-smith@woodside.com.au