Innovative logging techniques for Taranaki

Stephen McCormick

21 Hawke Crescent, Beachlands, Auckland. Tel. 09-5366621. Email stevemcc@xtra.co.nz

Abstract

Nature was unkind to New Zealand when it distributed our reservoir rocks. Hydrocarbon bearing sands in the Taranaki Basin range from the low contrast pay of the Mount Messenger Formation sands to the over-pressured, low porosity Mangahewa Formation gas accumulations. In these environments quantitative petrophysical evaluation of wireline logs is challenging and requires precision in both data acquisition and analysis. The difficulty in the Mangahewa Formation is compounded because much of the historical data is degraded as a result of hole conditions.

Since the mid 1980s our industry has evolved with a strong focus on costs and operational efficiency which is usually monitored in terms of rig time and equipment reliability, sometimes at the expense of data quality. In the Pohokura appraisal wells Shell Todd Oil Services recognised the historical data quality problems inherent to the Mangahewa Formation. They embraced a philosophy of detailed pre-job planning and on-site decision making to address these issues. The service company personnel were fully involved in this process which resulted in the development of many innovative methods to characterise the rock.

This paper presents two examples where logging operations have been modified to address particular data quality issues with dramatic results. These innovations have been made with little additional cost.

Introduction

The Kapuni Group sands are prone to stress related borehole breakout. The resulting rugose hole has degraded the log data quality on many wells. Particularly affected are logs that rely on good contact with the borehole wall, including the crucial density measurement. Quantitative log evaluation on these wells is seriously compromised.

The breakout is directional and the bore-hole is in perfect gauge on the orthogonal axis. Pad type sensors are forced against the borehole wall by means of a caliper, which will naturally seek the long axis. The challenge is to orient the tool to the smooth short axis.

Several bow-spring devices were trialed, but the most satisfactory results were obtained from a dual density arrangement. Here the sensors were oriented at 90 deg to each other. The upper density tool, with a narrow caliper tip, locates the long axis whilst the trailing tool logs the in-gauge short axis. The log data quality obtained on Pohokura using this method was a vast improvement over past wells.

Wellbore seismic on land wells suffer from inferior data quality caused by weak signal strength. On offshore wells, where the sea affords a "source pit" of unlimited depth, air-gun arrays are used and the source strength is considerably better. Analysis of VSP surveys carried out on deep land wells show that the source energy was just not getting into the ground.

From the shot data recorded on Pohokura South, projections of signal strength were made for the deeper Pohokura South-01A well. The analysis indicated that if the same source configuration was deployed the signal strength would be sub optimal. Hence a stronger seismic source was crucial to deliver a successful VSP result.

A deep, "small bore" pipe lined hole offered the best solution in terms of cost, environmental impact and a possible long term solution. A 1m diameter hole was cut by auger to a depth of 12m. This hole was partially lined with steel pipe and filled with 13ppg mud. The resulting shot strength was a marked improvement over previous land surveys. The Increased high frequency content resulted in a processed VSP with very fine resolution.

Such innovations are the result of a concerted team effort and could not have been realised without full cooperation from the service company and a willingness at Shell Todd Oil Services to 'push the boundaries'. Poor log analysis can be rectified but bad data quality is usually irreversible.

Short axis logging

Historically, interpreters have had difficulty quantifying the hydrocarbon potential of the low porosity Mangahewa and Kaimiro Formation. The uncertainty in log analysis is evidenced by the numerous and often fruitless well tests. Much of the well analysis relied heavily on shows and drilling rate which led to inaccurate subsurface analysis due to the typically large residual hydrocarbon column. Often an increase in fluorescence is more indicative of poor rock quality than producible hydrocarbon.

A review of log and core data prior to the drilling of Pohokura-01 indicated the problem was primarily due to data quality and not the log analysis. The main reason for poor quality logs in these Formations was borehole rugosity. Particularly affected are those log measurements which have a shallow depth of investigation (from the borehole wall) and use skid mounted sensors. Such measurements include the important Density and Rxo logs.

The tectonics of the Taranaki Basin has left some rocks with significant in situ stress. The Kapuni Group, in particular, is prone to stress related borehole breakout. This stress results in shear failure and breakout on the orthogonal axis leaving the borehole wall fractured and rough. On logging tools, pad type sensors are forced against the borehole wall by means of a caliper arm, which will naturally seek the long (rugose) axis. ***Fig1*** displays the density log in the Okoki-01 well. The breakout is indicated by the over-gauge caliper readings where the recorded density log is invalid. A reconstructed synthetic density log demonstrates the magnitude of the error. Only where the borehole is in-gauge and smooth does the density log read correctly. Note that the synthetic log displayed here is qualitative and should not be used for log analysis.

The orientation of this breakout for wells that penetrate the Mangahewa formation is displayed in ***Fig 2***. The major stress is horizontal, oriented in the SW-NE quadrant resulting in breakout in the orthogonal direction. The diagram shows a typical cross-section of the borehole. Controlling factors which influence breakout are rock strength, mud weight and time.

- **Rock strength.** Generally the coarse grain rock, with better permeability has higher compressive strength and hence is less prone to breakout. It is the low permeability rock that is most affected. Although such rock can only produce at low rates, it still contributes to hydrocarbon reserves.
- **Mud weight.** Increasing the mud weight will counteract the compressive rock forces but at the expense of damaging the formation. High mud weights will also

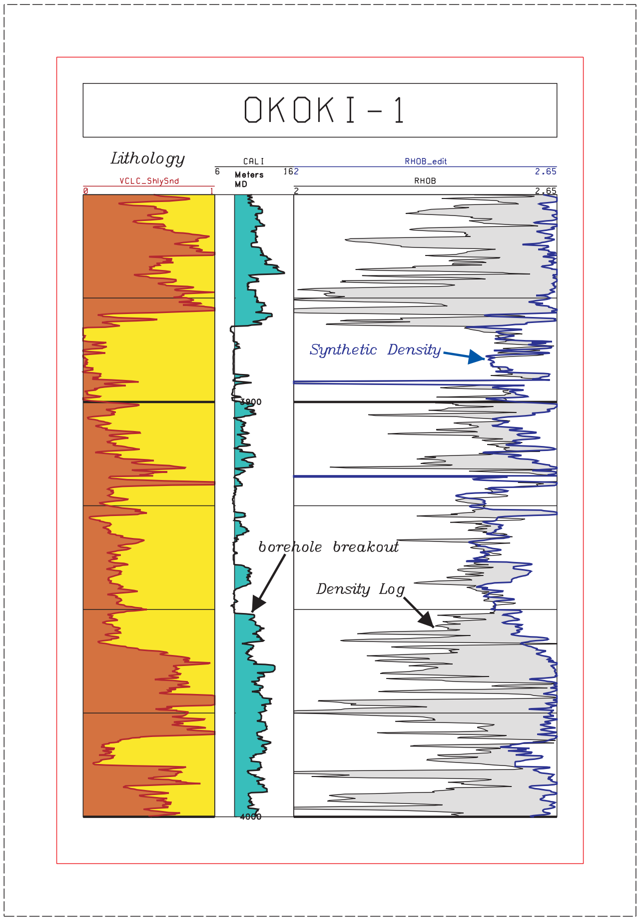


Fig 1. Typical wireline log data from the Kapuni group sands. Shown is the Density log from Okoki-1 with Caliper and Vshale. The synthetic density, reconstructed from other logs, shows that the majority of the density log data is invalid.

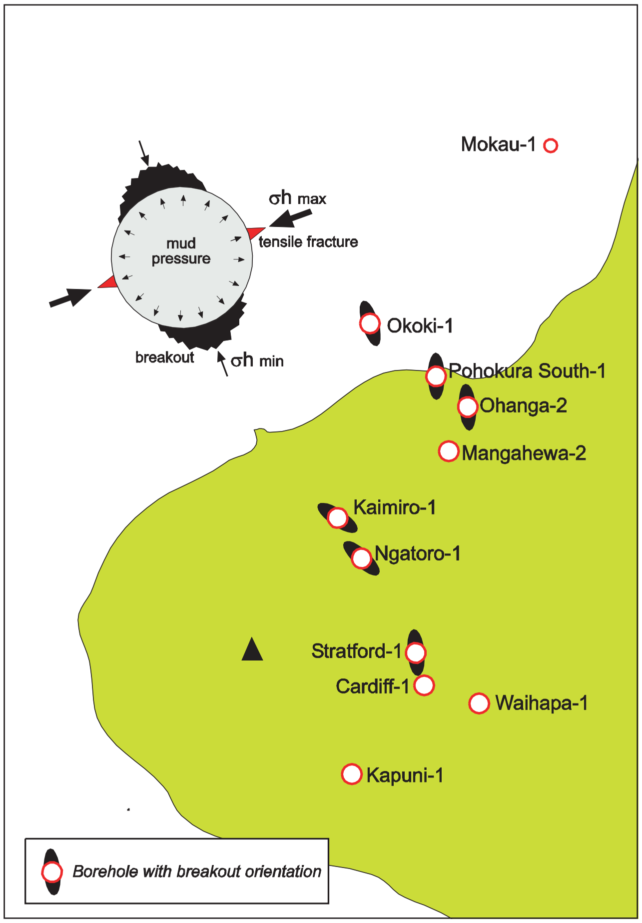


Fig 2. Borehole Stress and Breakout in the Kapuni group sands of the Taranaki basin.

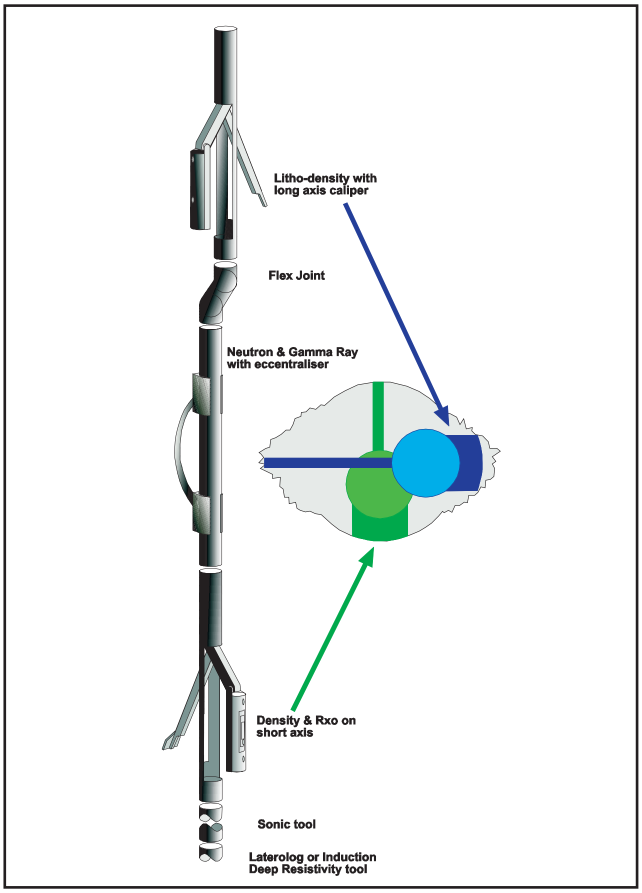


Fig 3. Dual Density tool configuration. The upper Density caliper "locks-in" to the long axis enabling the trailing Density and Rxo logs to record on the smooth orthogonal axis.

result in drilling induced fractures oriented in the major stress axis.

- **Time.** The extent of breakout is dependant on the time the hole is left open. Recording logs promptly after drilling will result in improved data quality. On Ohanga-2 an "insurance log" was recorded midway through the 8 ½" hole section. The same zone logged 20 days later at TD showed significant deterioration in borehole and log data.

Dual axis caliper measurements, recorded by dipmeter tools, show the borehole is in-gauge and smooth perpendicular to the breakout direction. The challenge is to orient the tool to this smooth, short axis. Several bow-spring devices were trialed, but the most satisfactory results were obtained from a dual density arrangement. Here the sensors were oriented at 90 deg to each other by means of a modified adapter. The upper density tool, with a narrow caliper tip, locates the long axis whilst the trailing tool logs the in-gauge short axis. A schematic of the tool configuration is shown in ***Fig 3***.

A density log recorded with this setup is shown in ***Fig 4***. In track 1 the short axis density is displayed with the Neutron log. The associated short-axis caliper, displayed in track 2, is in perfect gauge. Note the coarsening upward sequence identified by the neutron-density separation (shaded brown). In track 3 the long axis density is displayed with the same Neutron log. Its caliper, displayed in track 2, is tracking the long axis which is very rugose. In track 4 both density logs are overlaid on the same scale. Apart from the few sections where the hole is in-gauge the majority of the long axis density data is unusable. ***Fig 5*** displays another section of typical log data. Note that where there is no breakout the two density logs agree well. The good hole in at the top of the log is likely attributable to rock with higher compressive strength.

The technique is not without its own set of difficulties. Parasitic effects include Neutron standoff, incorrect orientation and tool sticking. Careful wellsite monitoring of data quality will identify and rectify these problems. Often, the final "perfect" log is achieved by splicing at wellsite several depth matched log passes with appropriate environmental corrections (in particular Neutron standoff corrections).

- **Neutron standoff**. The upper Density caliper lifts the Neutron tool away from the borehole wall. Because the Neutron measurement is very sensitive to standoff, this results in erroneously high readings. To quantify and compensate for this effect a second log pass is made with the upper Density caliper closed.
- **Incorrect orientation**. There is no orientation effect where the borehole is in-gauge. The toolstring will usually rotate slowly due to torque build-up in the logging cable. Thus the upper caliper can log up into a section of bad hole oriented in the smooth axis and the trailing density sensor becomes locked into the long axis. The log is then stopped and the section repeatedly re-logged until good data is acquired. The downhole

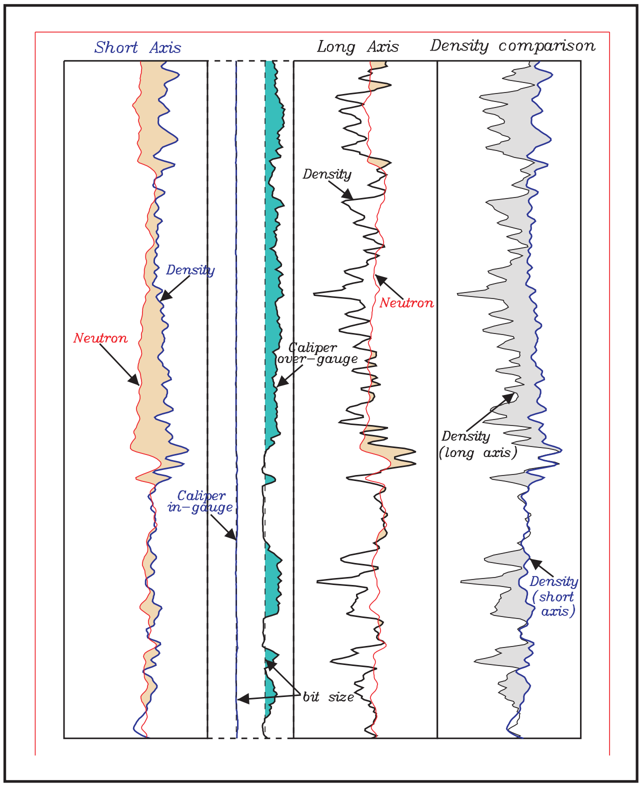


Fig 4. Comparison between short and long axis Density measurements – typical data from the Mangahewa Formation. The coarsening upward sequences are clearly identified on the "short-axis" logs. Quantitative log analysis is not possible with conventionally acquired "long-axis" log data.

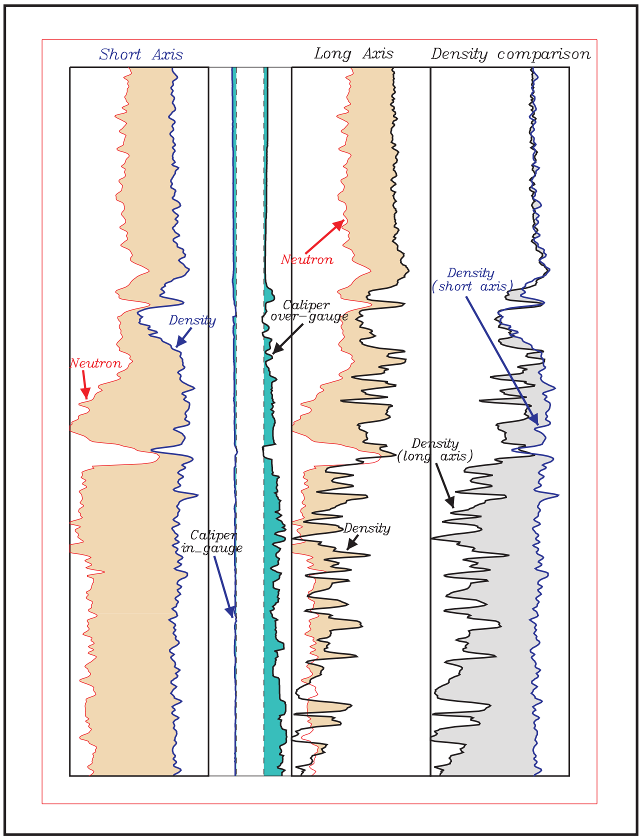


Fig 5. Comparison between short and long axis density measurements – typical data. The good hole in the rock at the top of the log is likely due to higher compressive strength.

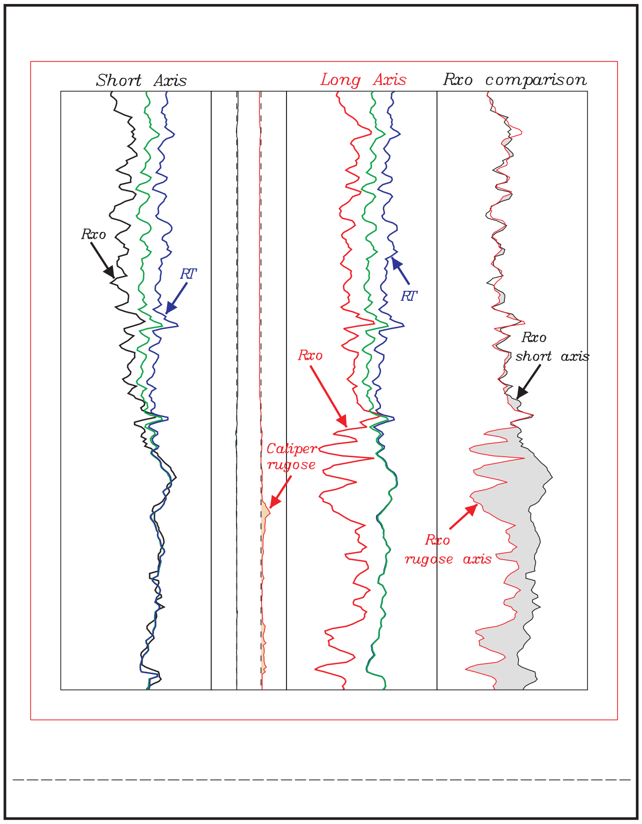


Fig 6. Comparison between short and long axis Rxo measurements – typical data. The bad Rxo log section is due to borehole wall rugosity which is barely detectable on the caliper. Maximum hole size is only 1" over-gauge.

calipers can be opened selectively and in some situations only the upper caliper is opened until the correct orientation is achieved.

- **Increased drag.** The extra caliper induces more drag, particularly in rugose hole. This can result in sticking or tool yo-yo where the tool does not move at uniform speed whilst logging. Where this occurs a different logging speed will alter the harmonics. Alternatively the upper caliper can be partially closed to a diameter slightly greater than the bit size resulting in reduced drag in the washed out hole section. Sticking or tool yo-yo results in a substantial data loss and it may be necessary to record an additional log pass with all calipers closed.

The same technique will also work with Rxo logs. Separation between Resistivity logs is a direct indication of permeable rock and a valid Rxo log enables invasion correction for the determination of true resistivity RT. ***Fig 6*** displays the short and long axis Rxo measurements – typical data. Note the bad Rxo log section is due to borehole wall rugosity which is barely detectable on the caliper. The maximum hole size is only 1" over-gauge.

The technique was also used to orient the Nuclear Magnetic Resonance logging tool (CMR) which has an extremely shallow depth of investigation (circa ½"). This measurement is used to determine rock permeability and proved to be very successful on the Pohokura wells.

Note the method described here is only applicable in vertical wells. Different techniques, not covered in this paper, are required where the well is deviated.

Design of source pit for land-based well seismic

Historically, wellbore seismic jobs on land wells have suffered from inferior data quality in Taranaki. On offshore wells, where the sea affords a gun pit of unlimited depth and multiple air-guns can be utilised, source strength is considerably better. Analysis of VSP surveys carried out on Pohokura-01, Pohokura-02 and Pohokura South-01 (land) wells led to the following observations

- Signal strength on the two offshore wells was very similar and 7x stronger than the land well at equivalent depths.
- The signal strength decreased normally (in proportion to the square of the depth) and was not due to any strong subsurface reflector. In conclusion, the source energy was not efficiently transmitted into the ground on the land well.
- From data recorded on Pohokura South, projections of signal strength were estimated for the proposed Pohokura South-01B well. If the same source configuration was deployed, downhole gain will be maximum and signal strength (P-P) sub optimal.

Typically, on land wells, a large pit is dug and filled with water. The air-gun is lowered by crane into the water filled pit and fired below the water surface to provide a seismic source.

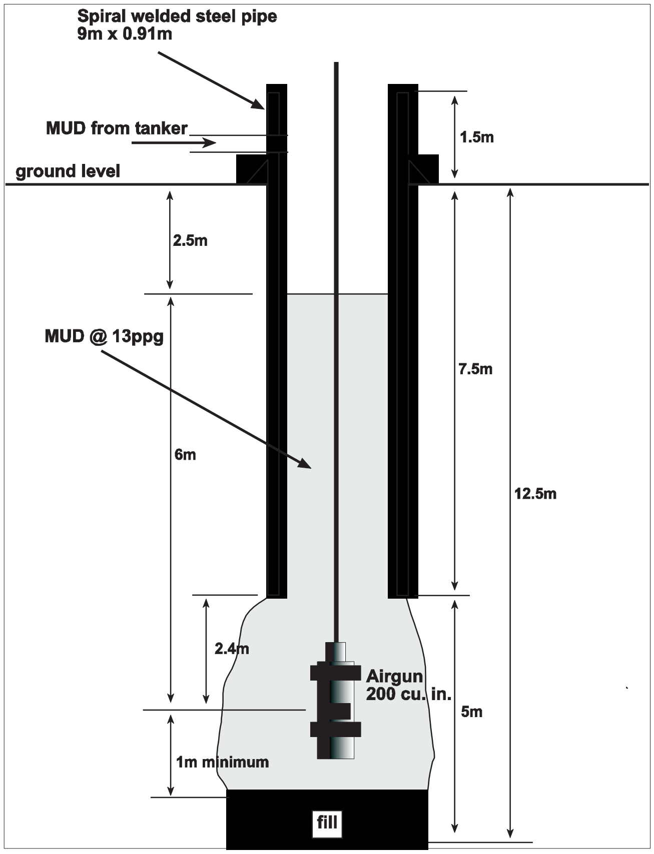


Fig 7. Diagram of "small-bore" gun pit design.

Ideally the airgun should be at least 3m below water level (5m is optimum) and 1m above the bottom. To prevent collapse the pit walls need to slope at 30 degreees and be sufficiently wide at the base. The water level in the pit must remain constant during the job, otherwise the source signature will alter and affect data processing. Thus, in sandy soils, the pit must be lined with an impermeable membrane (plastic or rubber). The "ideal" pit is 5m deep, 4m wide at the base with 30 degree sloping sides – 150m^3 of soil to excavate! The reality is that, despite best efforts, the pit is not built to a suitable size and invariably suffers from leakage and wall collapse.

For the Pohokura South-01B well, several source options were considered.

- Vibroseis trucks were one option, but were considered to be relatively expensive. Moreover, the continued availability of these trucks in NZ was uncertain and an inexpensive solution was sought which could be applied to all future wells in Taranaki.
- Increasing source strength by utilising an array of air guns would necessitate an even larger gun pit.
- A deep, "small bore", pipe lined pit offered the best solution in terms of cost, environmental impact and a solution for future wells.

With the 'small bore' source pit it was anticipated that signal strength would be improved from a combination of the following effects.

- The high density mud will improve acoustic coupling between the airgun and the surrounding formation.

Fig 8. "Holes-R-Us" drilling the gun pit. The steel liner for the hole is in the foreground. Behind the truck mounted Auger unit is the tanker with spare mud.

- The gun is placed adjacent to the bottom of the pipe and will be covered with 5m of mud. This is the optimum gun depth for maximum signal strength and is not practically achievable in conventional gun pits.
- The gun will be 7.5m below ground level firing in more consolidated formation, below the normal water table. In conventional gun pits, such depths are not practically achievable and the gun is usually located well above the water table.

A 1.0m diameter hole was cut by a truck mounted auger to a depth of 11m. This hole was partially lined with steel pipe to prevent wall collapse. Spiral welded steel (9.0m x 0.914m x 9.5mm WT) was lowered 7.5m into the hole, supported on steel feet, leaving 1.5m protruding above ground level. The hole was partially filled with 13ppg mud. After small initial losses the mud eventually sealed the ground. A backup tanker of mud was available to maintain the fluid level in the hole. The pit design is shown in ***Fig 7***. The "small-bore" gun pit was dug by "Holes-R-Us" (***Fig 8). Fig 9*** shows the steel liner being lowered into the gun pit. The spiral welded steel pipe weighed 2 tons.

A pre-survey trial was conducted during the surface logging job with the following observations:

Fluid/gun ejected when air-gun fires

Due to the heavy, viscous nature of the mud and high sides (mud level was 4m below the top of the pipe), fluid and airgun was not explosively ejected from the pipe. However there was a delayed surge from the pipe annulus resulting in

Fig 9. Lowering the Steel pipe into the gun pit. The spiral welded pipe is 9m x 0.91m x 10mm and weighs 2 ton.

fluid loss. There was no need for a lid but an earth levee was built around the pit allowing ejected mud to drain back into the hole.

Excessive fluid loss

A bladder to line the pit was contemplated. It was considered that there would be a high likelihood of such a liner tearing at the base of the pipe due to the proximity of the airgun and inevitable hole collapse at this level. It was found that the mud effectively sealed the formation. A small tanker with approximately 5m^3 of mud was onsite to keep the hole topped up. About 2m^3 was used during the job, mainly as a result of fluid ejection.

Hole collapse

Partial hole collapse was anticipated. For this reason the hole was drilled well beyond the minimum required depth (3.5m below pipe). The pit required cleaning out prior to the job but it did remain intact during the job (circa 750shots). The pipe liner was modified to enable the truck mounted bucketing system to clean out the hole.

Safety

The area was fenced off and the hole securely covered when not in use (steel lid and padlock). Job safety concerns were addressed with a pre-job "JSA" from the contractor and relevant STOS personnel.

Several gun positions were trialled and, as expected, the best signal was obtained with the air-gun positioned clear of the steel liner at the bottom of the hole. The "slim-hole" source pit improved both signal strength and high frequency content of the signal.

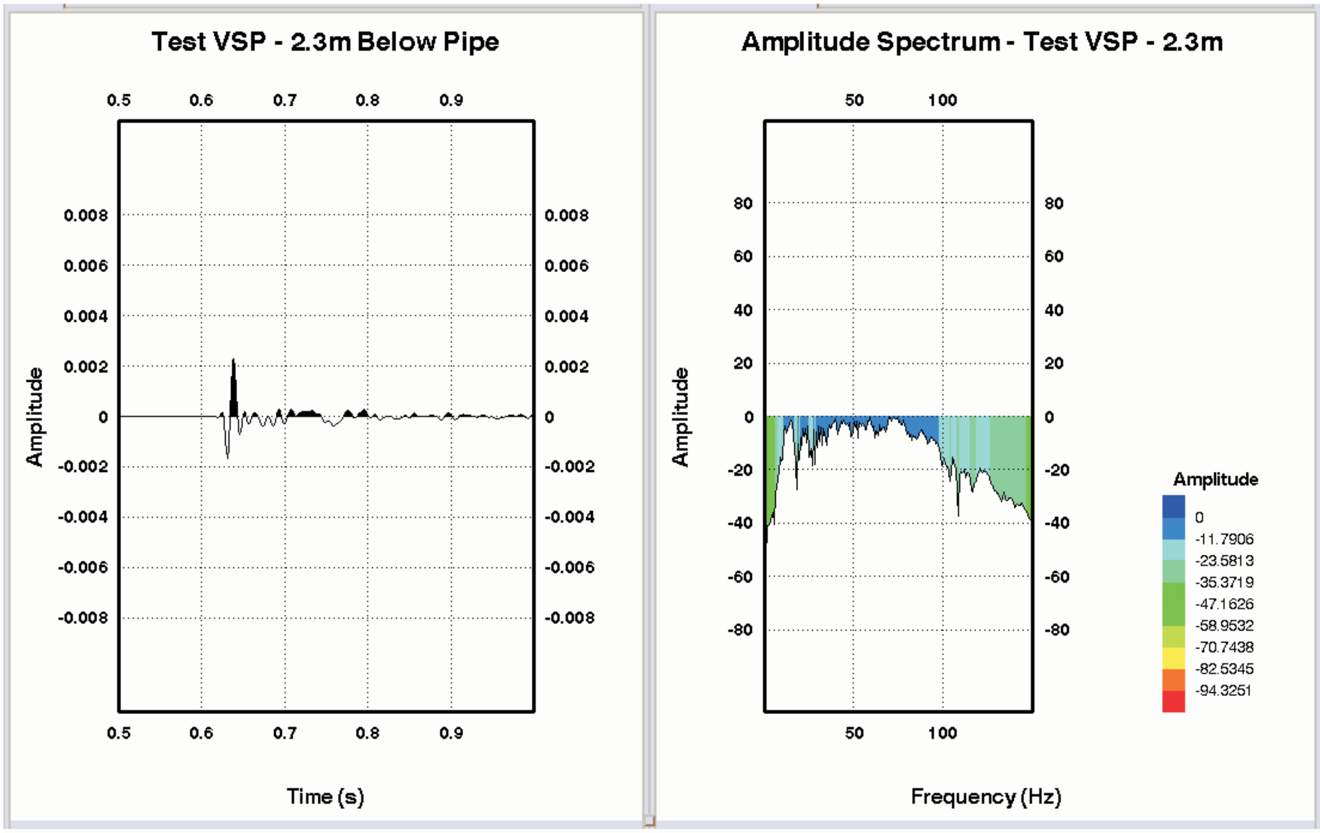
Geophone signals from the original Pohokura South-01, typical offshore well and the pre-survey trial are compared in ***Fig 10 & Fig 11.*** A band pass filter (10-90Hz) has been applied to present only the useable frequency range. The amplitude spectrum is scaled in dB and normalised to the maximum reading for each stack. There is increased high frequency content with the "small bore" pit. With the airgun in the 2.3m position, the amplitude in the 10 -100Hz range is relatively constant. Whereas the original VSP, recorded on Pohokura South-01 with a conventional pit, has reduced high frequency content. The 0.4m position represents the fall-back scenario in the event of pit collapse but still shows some improvement over a conventional pit design. Even after filtering of the very high frequencies the P-P signal from the 2.3m position is 1.6x stronger than Pohokura South-01 (recorded with a conventional pit). The deeper gun position does not show the strong bubble oscillations that can be seen on the 0.4m data and the Pohokura South-01 data. This is good as long as the signal remains consistent across all levels. During acquisition the downhole signal (and more complex near field QC signal) needs to be carefully monitored. The signal is very sensitive to hole geometry and if the pit wall collapsed during the job, the signature would change rapidly, requiring some levels to be re-shot. Note the source signature from the 2.3m position is similar to that achieved with a G-gun array offshore.

The chart in ***Fig 12*** shows the downhole seismic raw (unfiltered) P-P amplitudes on the Pohokura wells. Pohokura-01, -02 and -03 are offshore wells recorded with a G-gun array. Pohokura South-01 was recorded with a 200cu Bolt airgun in a conventional pit and Pohokura South-01B used the new "small bore" pit with the Bolt airgun. Raw signal strength is doubled with the "small-bore" pit over conventional configurations.

The processed VSP data quality was excellent. It helped resolve interpretation uncertainty in the onshore offshore transition zone where three seismic surveys of different vintages have been merged. ***Fig 13*** compares the VSP seismic line with 3D data. Note the improved resolution and coherency with the VSP processing.

The "small bore" source pit offers improved signal strength and higher frequency content. There are less environmental issues and remedial work is inexpensive. In does require a lot of planning and data quality must be carefully QC'd during the job. Source pit collapse is the biggest concern and the pit condition requires constant monitoring before and during the job.

Onshore Geophone Signature with "small bore" pit and airgun 2.3m below pipe



Onshore Geophone Signature with "small bore" pit and airgun 0.4m below pipe

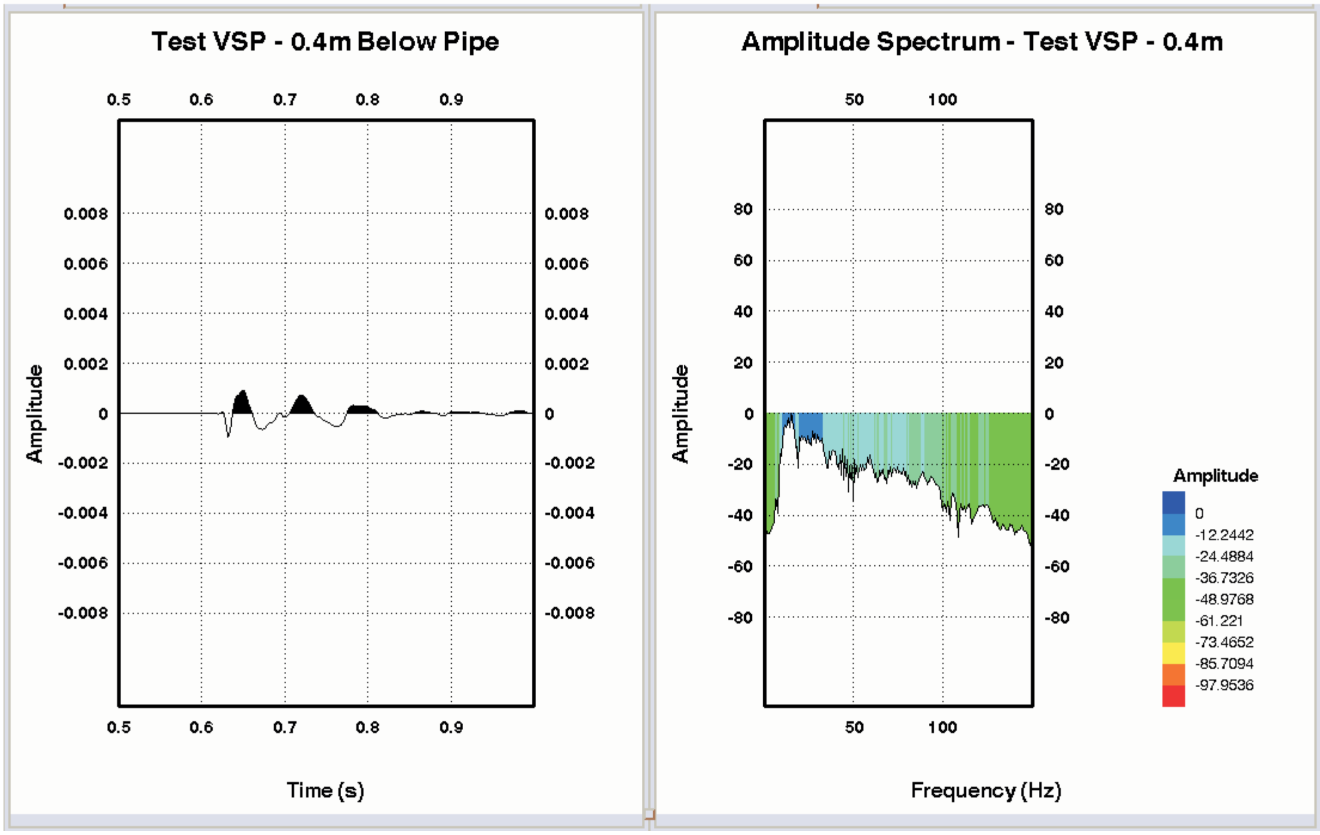
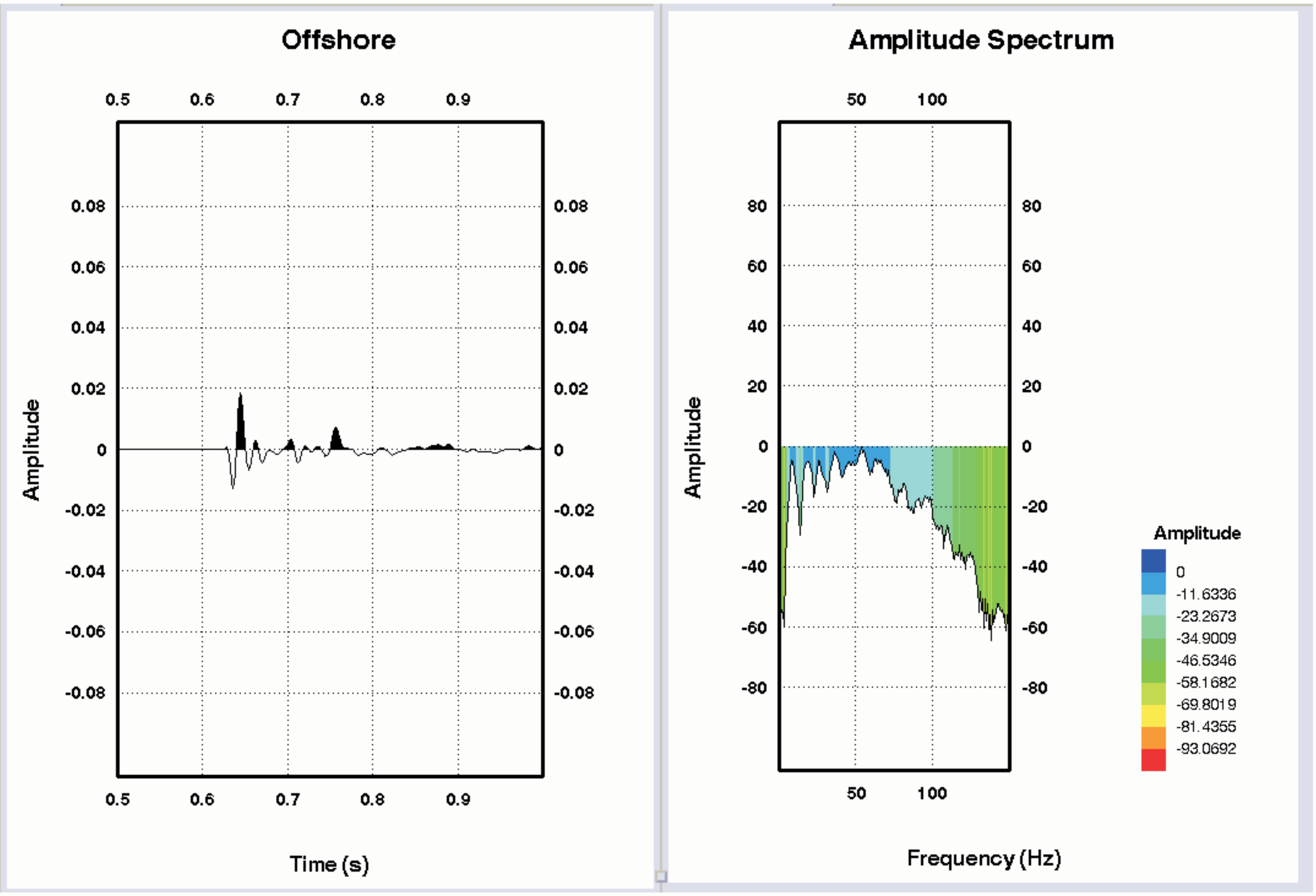


Fig 10. Source signature and frequency spectrum from onshore “small-bore” air-gun configurations

Offshore Geophone Signature using G-Gun Array



Onshore Geophone Signature with conventional pit

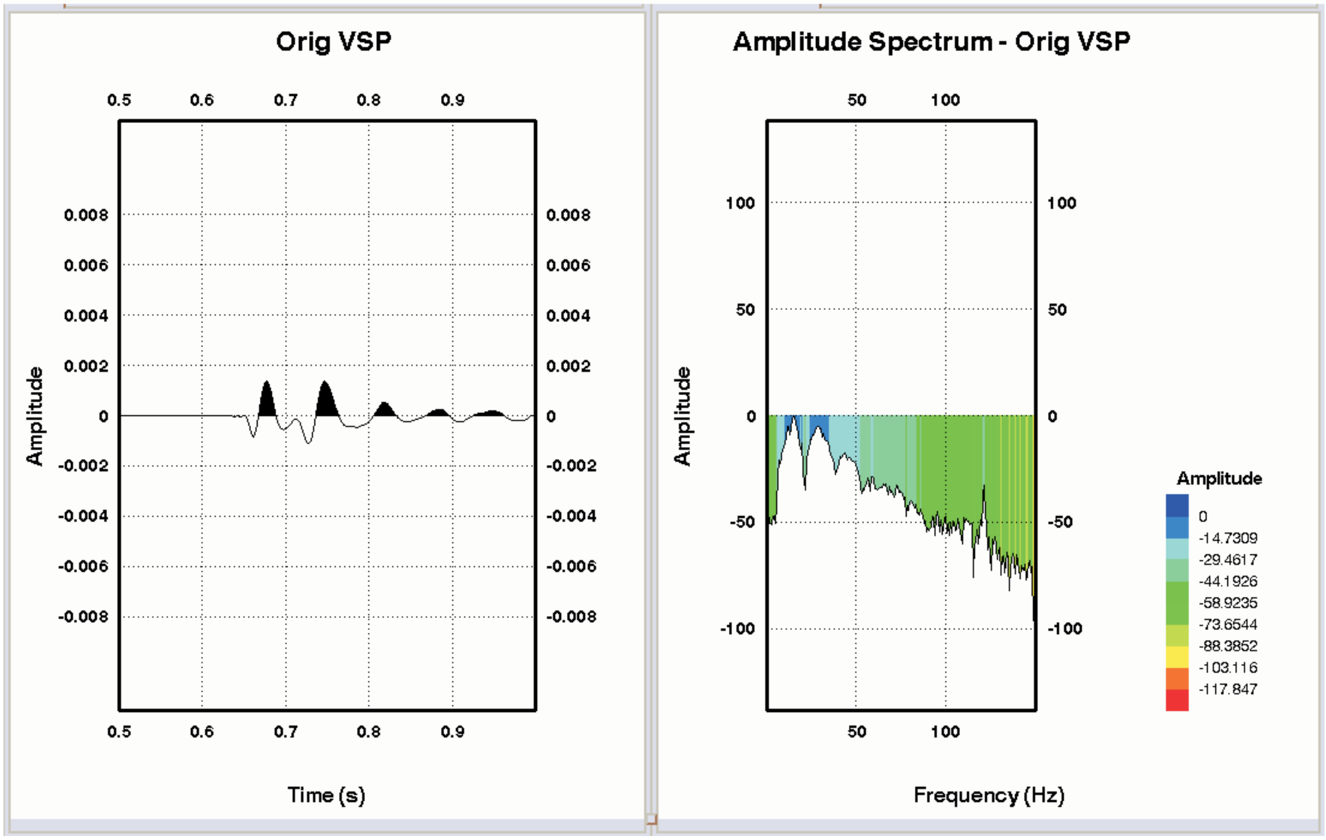


Fig 11. Source signature and frequency spectrum from conventional onshore & offshore air-gun configurations

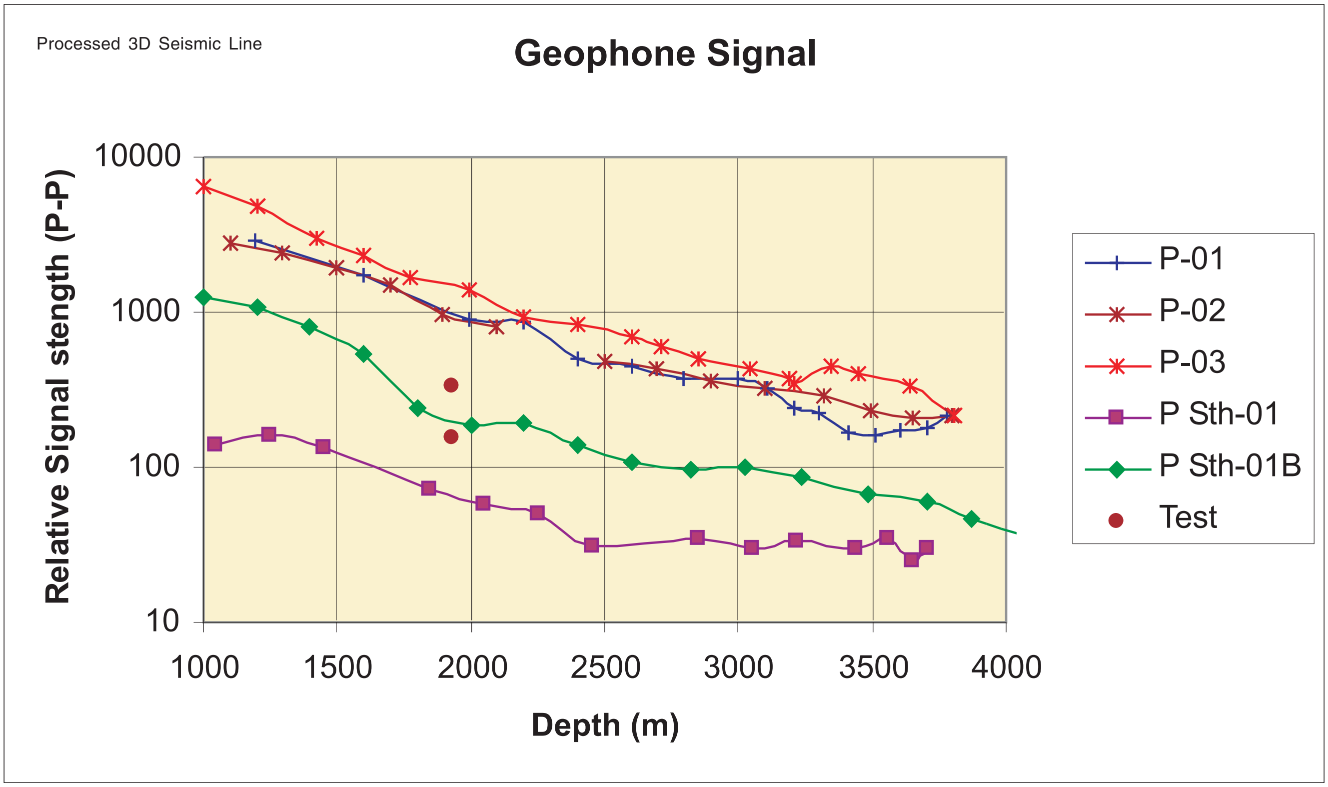


Fig 12. Geophone signal strength (P-P) from various air-gun and pit configurations. Data is raw (unfiltered). P-01, P-02 and P-03 are vertical offshore wells. P Sth-01/01B are deviated onshore wells. P Sth-01B was recorded using the "small-bore" gun pit design.

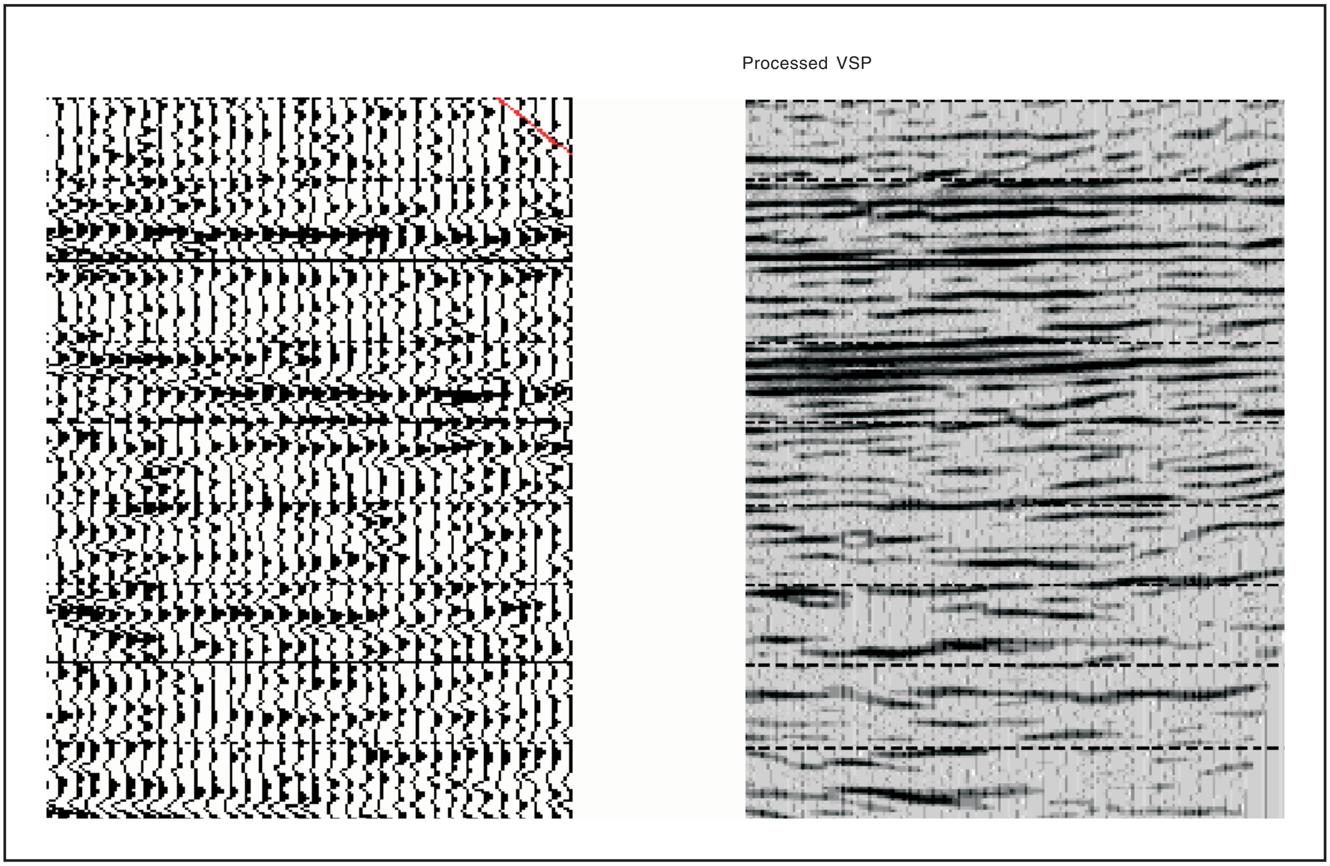


Fig 13. Comparison between processed 3D and the wellbore VSP recorded in the transition zone. The "small-bore" signal has good high frequency content resulting in fine subsurface definition.

Acknowledgements

Much of my work of the last four years has been carried out on behalf of the Pohokura Joint Venture Partners (Shell Petroleum Mining Company Ltd, Todd Petroleum Mining Company Ltd, Preussag Energie and laterly OMV NZ Ltd) who are thanked for their generous permission to publish this paper.

Schlumberger Wireline Services have contributed significantly with technical support, equipment modifications and financial concessions to facilitate trials.

Lastly, the Pohokura sub-surface and well delivery teams are thanked for their unequivocal support.

Author

STEPHEN MCCORMICK is a consulting Petrophysicist and holds a BE 1st class Hons from Auckland University. He worked for Schlumberger Overseas between 1977 and 1986 in Malaysia, Indonesia, Thailand, Dubai and Egypt as field engineer, manager, log analyst and trainer. Steve has been an independent Petrophysicist to Oil Companies since 1987, primarily in SE Asia. Since returning to New Zealand 5 years ago he has worked principally for Fletcher Challenge Energy and Shell Todd Oil Services.