Seismic reflection data acquisition in the Taupō Volcanic Zone: Reprocessing of Broadlands-Ohaaki 1984 seismic data.

Callum Kennedy[1], Stuart Henrys[2] and Regan Kennedy[3]

[1] OMV New Zealand, Wellington, New Zealand

[2] GNS Science, Lower Hutt, New Zealand

[3] Earth Signal Processing, Calgary, Canada

callum.kennedy@omv.com

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ABSTRACT

Reflection seismic data is used to provide a high-resolution image of the earth's crust by recording the response of elastic waves reflected by subsurface structure. It is used widely in the oil and gas industry but rarely used in geothermal areas. The Broadlands-Ohaaki seismic survey, acquired in 1984 (Henrys and Hochstein, 1990), is one of only a few reflection seismic surveys to have been acquired in the Taupō Volcanic Zone (TVZ) and where field data are still available. The OHAAKI-84 data used dynamite sources detonated in shallow holes and recorded on a rolling 48 receiver array spaced 20 m apart.

In 2023 we reprocessed seismic data from the OHAAKI-84 survey using modern imaging technologies to determine if the original processing could be improved upon and to help inform any future seismic reflection surveys in the TVZ for geothermal energy exploration or understanding of exiting fields. We recreated the shot and receiver geometry and applied a contemporary processing sequence that has improved on the continuity of the reflectors and provided more detailed P-wave velocity information.

The near-surface volcanic deposits in the TVZ provide a challenging environment for seismic acquisition but our reprocessing has highlighted the value of seismic reflection and we make a number of recommendations for new seismic reflection acquisition including using a modern vibroseis source with longer source to receiver offsets.

1. INTRODUCTION

The Broadlands Ohaaki seismic survey was acquired in 1984 (Henrys 1987), with six lines totalling 26 km being acquired across the Ohaaki geothermal field (Figure 1). The survey was acquired after exploration drilling but before the field was developed in 1989. The survey remains one of the only reflection seismic surveys acquired in the TVZ and the only one for which a complete set of seismic acquisition data have been preserved.

The survey was affected by low frequency surface noise that was unable to be adequately removed during the original processing (Figure 2). The resulting sections were very noisy but with the help of boreholes a geological interpretation was made. The survey was reprocessed by Calman (1996) with some improvements and a comment that advances in seismic acquisition and processing are continually developing.

In the oil and gas industry 3D surveys are now the norm both on and offshore. Advances in computational power along with wireless and GPS technologies have allow much larger surveys to be acquired. Processing has developed substantially with Pre-Stack Depth Migration (PSDM) processing providing exceptional images of the subsurface in the datasets used in the oil and gas industry.

Despite its age and limited coverage, the Broadlands-Ohaaki survey is still able to be reprocessed as all field data and supporting documentation have been retained. This allowed one line, Line 4, to be reprocessed using modern processing workflows. Line 4 was chosen as it was considered to be the line with the highest signal to noise ratio and so most likely to provide the best result. Line 4 straddles the eastern boundary of the geothermal field and north of the main producing region.

This reprocessing was carried out to see if a modern reprocessing workflow could provide an improved image, compared to the 1980s, and to see if any lessons could be learned for future acquisition in the Taupō Volcanic zone.

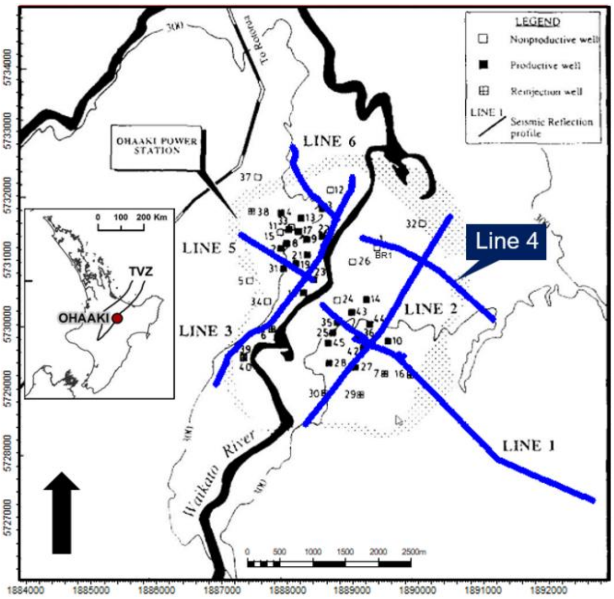

Figure 1: Location of the OHAAKI-84 survey (modified from Henrys and Hochstein 1990)

2. OHAAKI-84 ACQUISITION

The seismic data was acquired in November of 1984 using dynamite sources recorded on a 48-channel receiver array. Six lines totalling 26 km of 12-fold seismic were acquired with 490 shots (Henrys 1987).

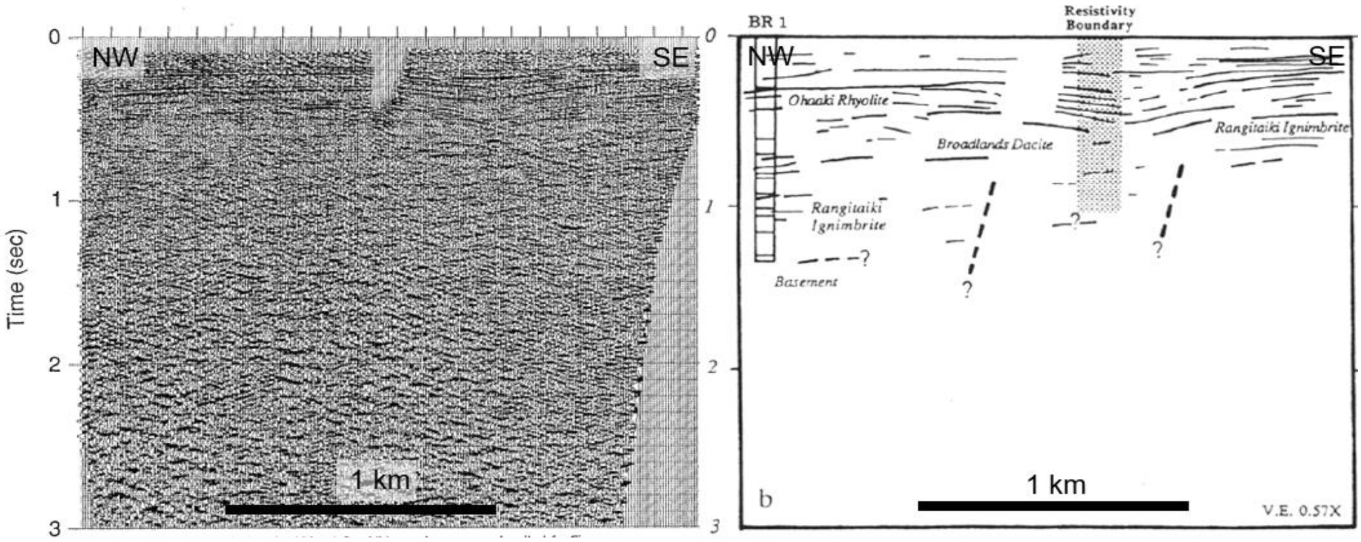

Figure 2: a) Original processing and b) interpretation of OHAAKI-84 Line 4 (Henrys and Hochstein, 1990).

Shot-holes were usually drilled to depths of less than 5 m and always to a depth below or at the water table. 495 and 330 gm dynamite charges were used. Station locations were accurately surveyed and details of each shot-point and receiver array were recorded in observers logs, that have allowed the survey geometry to be understood and recreated four decades later.

The survey was recorded using the DSIR Sercel HR 338 48 channel system with a record length of three seconds. The receivers were spaced 20 m apart, which was limited by the 20-m-long cables connecting them, providing a maximum array length of 960 metres when all 48 channels were in operation.

The acquisition approach for OHAAKI-84 was for the shot to be fired adjacent to the first receiver with the 48th receiver being the furthest offset. This provides a maximum offset of 960 m when all 48 channels were in use.

3. 2023 REPROCESSING

In 2023, Line 4 of the OHAAKI-84 dataset was reprocessed. The geometry of the line was regenerated from the navigation files and observers logs. SEGY navigation merged shot records were then delivered to Earth Signal Processing for seismic imaging.

The processing sequence followed that shown in Table 1. The sequence includes modern noise reduction techniques that were unavailable at the time of the original processing. The coherent surface noise reduction is likely to have provided a good improvement, but as many of the processes were applied quickly and efficiently by a very accomplished processor, it is not entirely clear where the major benefits are and the entire processing sequence and the parameters chosen for each process have all contributed to the final result.

Table 1: Processing sequence for OHAAKI-84 line 4

Exponential Scaling
Geophone Inversion
Surface Consistent Amplitude Scaling
Surface Consistent Deconvolution
Zero Phase Frequency Domain Trace Deconvolution
Coherent Noise Reduction for Ground Roll Removal
Laterally Variant Residual Scaling
Refraction Statics, Residual and Velocities - Output Stacks
Random Noise Reduction with TX Deconvolution on Shot Records - Testing of Singular Spectrum Analysis - Testing of Frequency-Space -4 Components noise reduction - Testing of Tau-P space noise reduction
Mute, Stack, Post Stack Migration - Output stacks
Data Regularization to Ostrander gathers
FXY Noise Reduction on Ostrander gathers
Pre-Stack Time Migration - Output stacks with and without the noise reduction
Filter, Plot, and Scale

Deliverables included stacked seismic sections with various processes and noise reduction applied as well as the velocity dataset generated by flattening of gathers prior to stacking.

Several pre and post stack migration sections were provided with different frequency filtering and noise reduction applied. The stacked sections provided are generally similar but provide different amounts of signal to noise and differing event continuity. A good seismic interpreter will be able to identify noise and will often prefer a processing result that

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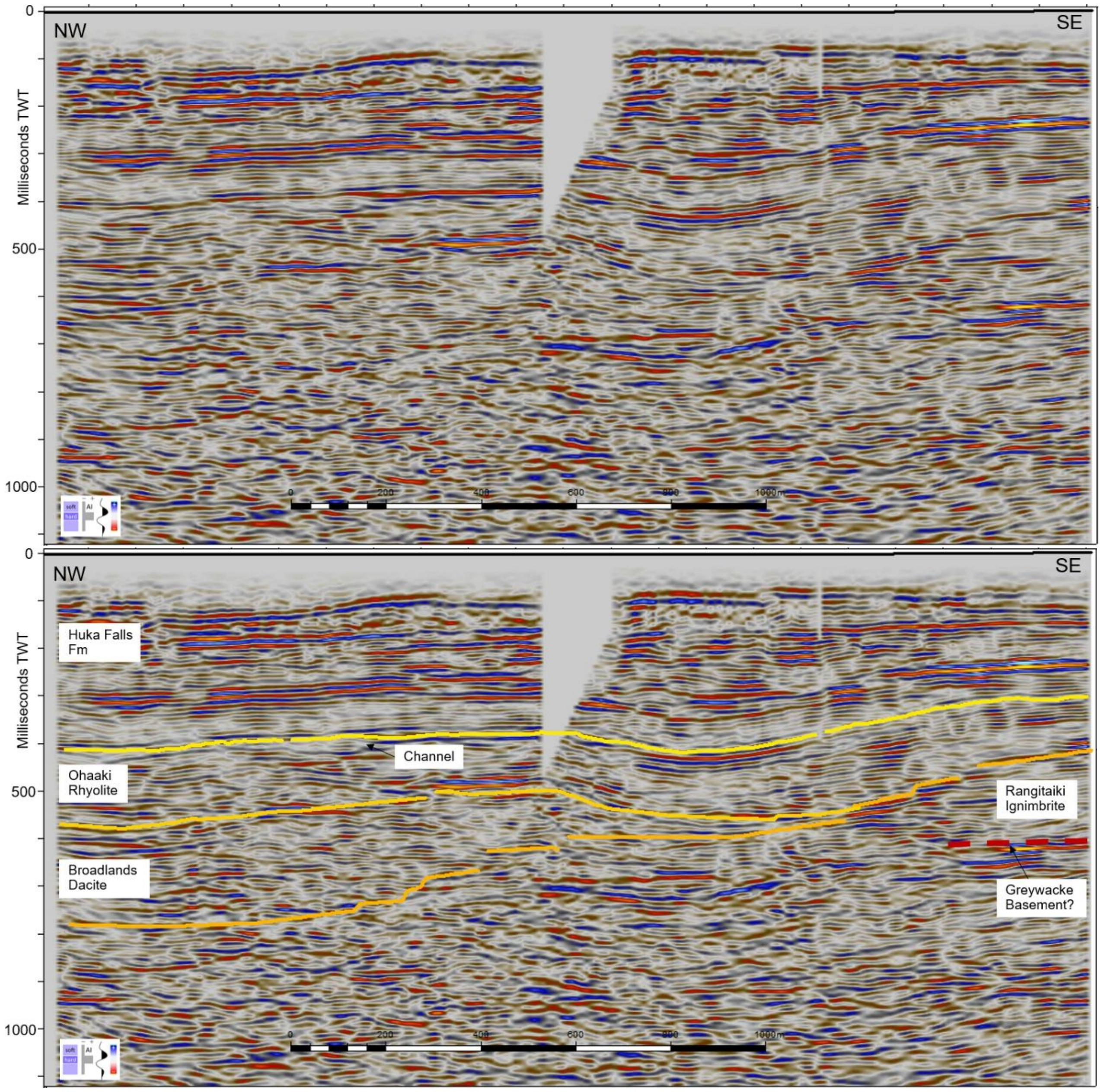

Figure 3: OHAAKI-84 2023 reprocessing without interpretation above and interpreted below

retains some noise and is not overly smooth so long as the available signal is retained. The images shown here are a filtered pre-stack time migration with noise reduction.

4. RESULTS AND INTERPRETATION

Both the reprocessed seismic reflection and velocity profiles provide information about subsurface geology. The reprocessed seismic reflection profiles show better event continuity and reduced noise when compared to the original processing as well as better discrimination between rock formations (Figure 3).

Sections are presented in two-way travel time (TWT) and not depth. In this instance velocity information indicates that 1 s TWT is approximately 1 km depth, though this will change with depth as the velocity increases due to compaction and may change laterally across changes in structure and lithology. To convert to depth the TWT seismic would be depth converted by analysing the P-wave velocity data from the processing and tying seismic events to formation intersections in wells. This was not done here as the focus of this reprocessing was on imaging.

The new imaging (Figure 3) is an improvement over the original processing (Figure 2). The reprocessing shows better event continuity, less noise and greater differences between the amplitude content of the different interpreted rock formations.

The interpretation shown in Figure 3 is based on Henrys & Hochstein (1990) and is not a new interpretation. The goal of this interpretation is to ascertain if the features noted in the original interpretation can be seen more clearly.

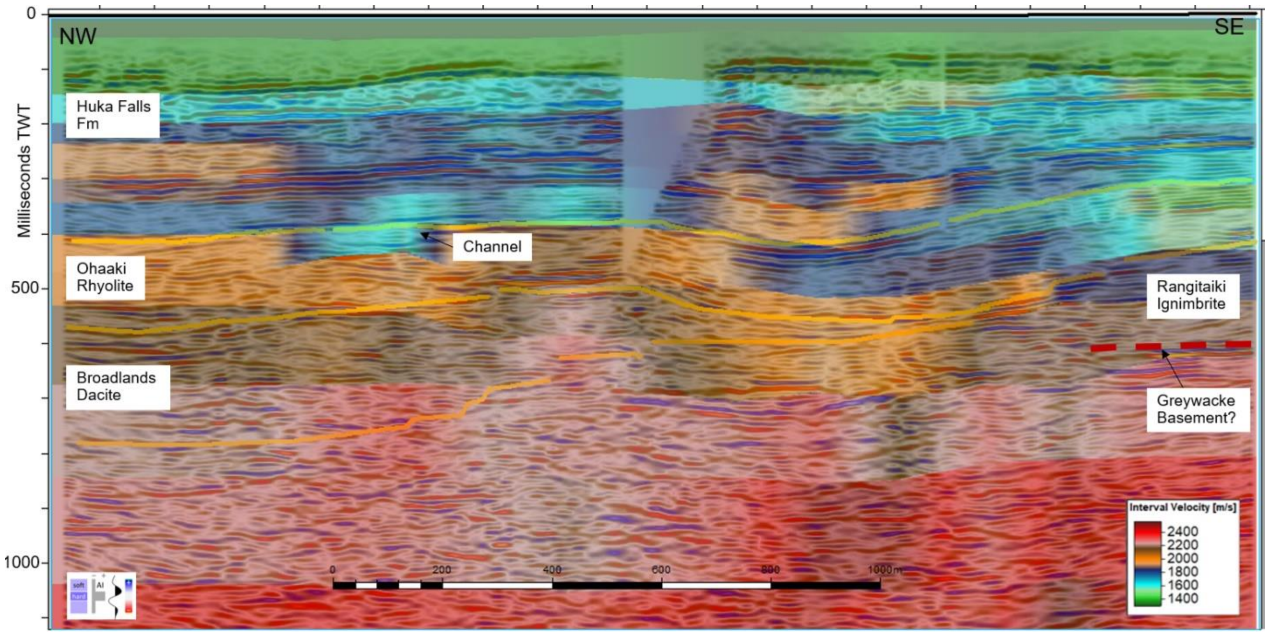

Figure 4: OHAAKI-84 2023 reprocessing displayed with interval P-wave velocity overlay.

The top ~300 ms of the section are interpreted to be sands and silts of the lacustrine Huka Falls Formation. This unit is characterised by smooth continuous reflectors consistent with a lacustrine depositional environment. Underlying this Formation is the Ohaaki Rhyolite with brighter amplitude response and less continuous reflectors. At the top of the Ohaaki Rhyolite there is a channel like feature with some bright amplitudes at its base, and with a low velocity response in the interval P-wave velocities suggesting a lower density and possibly higher porosity (Figure 4).

A low velocity response can indicate the presence of gas in a reservoir in a hydrocarbon setting, while in geothermal areas modelling has indicated that lower velocity areas may be able to indicate hot water and steam (Henrys 1987). Any affect is likely to be subtle and the dominant driver of rock velocity is likely to be lithology.

Below the Ohaaki Rhyolite, Henrys and Hochstein (1990) have interpreted the Rangitaiki Ignimbrite with a wedge of Broadlands Dacite in the NW. These have a discontinuous seismic character and it is possible that the Rangitaiki Ignimbrite is more discontinuous than the Broadlands Dacite. The stratigraphic relationship between the Rangitaiki Ignimbrite and Broadlands Dacite is not resolved with reprocessing.

The greywacke basement has been intersected by wells at Ohaaki but there is no obvious basement reflector seen. It is possible that there is no discernible velocity and density boundary between the greywacke basement and overlying strata in this region of the eastern boundary of the geothermal field. Alternatively, the dynamite sources (<500 gm) used in the OHAAKI-84 survey were insufficient to propagate to basement depth.

5. FUTURE SEISMIC ACQUISITION IN THE TVZ

The reprocessing of the OHAAKI-84 seismic reflection data using a modern processing sequence is an improvement over the original processing and further processing is unlikely to improve the imaging. Better images of the TVZ subsurface will require new seismic acquisitions.

The reprocessing showed that the dynamite sources provided a good seismic source with an appropriate frequency range for the geology, however it is unlikely that a dynamite source would be used for any future survey as drilling shot holes is time consuming and dynamite has an environmental impact. A vibroseismic source can provide a controlled sweep of seismic frequency that is transferred to the ground by a vibrating unit mounted on an all-terrain vehicle. These can operate considerably faster and with less environmental impact that a dynamite source.

The OHAAKI-84 acquisition was limited by the 48-channel seismic receiver array that was connected by 20 m cables. With seismic reflection the maximum offset is likely to be approximately similar to the maximum reliable imaging depth. For the OHAAKI-84 data, where the maximum receiver array length was 960 m the maximum resolvable depth of imaging is restricted to <1.0 km.

It is likely that a new seismic acquisition would be a 3D dataset with hundreds of wireless receivers configured to sample multiple azimuths of signal through the earth with greater geological sampling redundancy (higher fold). Each subsurface location would be sampled multiple times, with soundwaves travelling at different angles to sample each location multiple times increasing the likelihood that deeper layers can be well imaged even though a complicated overburden.

Modern processors have advanced imaging techniques and computers to reduce noise and maximize signal. Pre-stack depth migration approaches can use tomographical modelling to ensure reflectors are correctly positioned and to provide detailed velocity information that can be used for depth conversion and geological interpretation.

An example of where seismic data may be able to help with geothermal exploration is where there is evidence of a geothermal system, but no geothermal reservoir is evident from test drilling. Seismic reflection may be able to identify porous rock containing hot water that would likely give a negative impedance contrast with the rocks indicating a potential reservoir. A low velocity zone and signal attenuation may also be present.

Seismic reflection data could also complement the interpretation of magnetotelluric (MT) surveys. Seismic has a much greater resolution than MT and it may be possible to identify faults or other boundaries that could be providing the conduit for a plume identified by MT. Seismic may also be able to assist with MT processing: MT survey imaging by inverse modelling is non-unique (pers. com. Ted Bertrand) and seismic data may be able to complement MT models by providing information about unit thicknesses for resistivity modelling, for example.

Oil and gas drilling frequently needs to hit targets with just a few metres of accuracy and commercial hydrocarbon columns may be just a few metres thick. The seismic datasets and depth conversion used need to be very accurate to allow this, especially in modern exploration where remaining targets are often subtle. In conventional high temperature geothermal systems upwelling hot water plumes provide a much larger target that has been utilised successfully without imaging as accurate as required in oil and gas. If future geothermal exploration and field management prove to be more challenging, a better understanding of the subsurface will be required prior to drilling. Deeper targets, where the upwelling fluids make a smaller target may be better imaged with seismic, especially where there are permeable fluid pathways such as faults. drilling into supercritical steam and hot parts of the crust is another area where a more detailed geological understanding assisted by seismic could reduce risk and increase confidence of hitting a target.

Within the TVZ and other high temperature geothermal areas seismic reflection appears to be rarely used. This reprocessing has shown that seismic reflection methods can image the subsurface of geothermal areas and utilising new acquisition and processing methods would provide a valuable contribution to geophysical techniques employed in future New Zealand geothermal developments.

ACKNOWLEDGEMENTS

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