Always finding faults: New Zealand 2016

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Summary

CREWES participated in two collaborative seismic surveys that were conducted in New Zealand in early 2016. The target of interest in the Whataroa valley (South Island) is the Alpine Fault, which forms part of the boundary between the Australian and Pacific Plates in southern New Zealand, and has the potential to produce M8+ earthquakes. The Deep Fault Drilling Project (DFDP) drilled and instrumented borehole DFDP-2b prior to the seismic program.

The Hauraki Rift survey (North Island) crossed the northern Kerepehi fault, which has previously been inferred from gravity data. The Kerepehi fault is considered to be active, and is thought to have produced M6+ earthquakes in the past. The primary objective of both programs was to better define seismic velocities and geometries of faults that are known to be earthquake risks.

Initial processing of surface seismic data has provided relatively good images of sediments, the base of sediments and, we believe, the Alpine and Kerepehi faults.

Introduction

CREWES participated in two collaborative seismic surveys that were conducted on the North and South Islands of New Zealand in early 2016 (Figure 1). The target of interest in the Whataroa valley is the Alpine Fault, which forms part of the boundary between the Australian and Pacific Plates in southern New Zealand. This fault delineates the steep western front of the Southern Alps over a distance of approximately 500 km. Slip on the fault is responsible for lifting up the Southern Alps and for offsetting rocks laterally by hundreds of kilometres. During the last two million years, the central portion of the Alpine Fault has slipped at an average rate of approximately 27 mm/yr horizontally and 10 mm/yr vertically. In the Whataroa Valley the surface trace is near the range front of the Southern Alps and the Alpine Fault dips ~45˚ to the SE beneath the mountains (GNS Science Public Wiki, 2016).

The Hauraki Rift survey was conducted along the top of a stop-bank (dike) over unconsolidated river and marine sediments within the rift, and consisted of a single 1C-2D crooked line. This seismic line crosses the northern Kerepehi fault, which has previously been inferred from gravity data (Hochstein and Nixon, 1979). The Kerepehi fault is considered to be active, and is thought to have produced M6+ earthquakes in the past.

This abstract presents preliminary processing and interpretation results for the 1C-2D surface seismic lines.

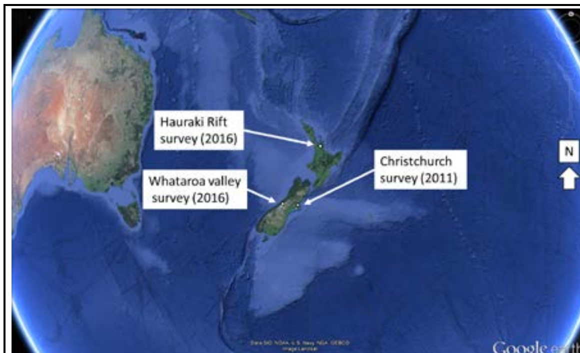

Figure 1: Location of New Zealand seismic surveys CREWES has participated in (Google Earth, 2016). Data: SIO, NOAA, U.S. Navy, NGA, GEBCO. Image: Landsat. The Christchurch survey is documented by Lawton et al., 2012 and Lawton et al., 2013.

Method

An IVI Envirovibe was used for both surveys, running sixteen-second linear sweeps with a four-second listen time for acquisition. The Whataroa valley survey used 10-200Hz sweeps for the zero-offset VSP, 10-60Hz and 10-150 Hz for the walkaway VSPs and 10-150 Hz for the surface seismic data. 10-100Hz sweeps were used for the Hauraki Rift survey. The 1C-2D surface seismic data were acquired with a 10 m source interval with a nominal 4 sweeps per vibe point, and with a 10 m receiver interval using single 10 Hz Inova SM-24 geophones.

Whataroa Valley Survey

Previous seismic surveys are summarized by Townend et al., 2016. In general, they were able to provide deep (>1 km) and shallow (<500 m) information, but it has proved difficult to image the Alpine Fault in the target 500-1000 m depth range due to energy scattered from the steep valley sides. A clear image of the main Alpine Fault reflector with a dip angle of around 50° has been obtained in the depth range between 1-2 km by Lay et al. (2016). from the WhataDUSIE seismic reflection data acquired in 2011.

The Deep Fault Drilling Project (DFDP) aims to determine the ambient conditions in a continental fault zone late in its typical cycle of large (M~8) earthquakes. A borehole (DFDP-2b) was drilled in the Whataroa valley with intent to intersect the Alpine fault (Sutherland et al., 2015). The drillers encountered approximately 240 m of gravels, silts and diamictites before penetrating a metamorphic sequence of schist, proto-mylonite and mylonite. The borehole is near-vertical at the surface but deviates to become normal to the predicted fault-plane. The borehole did not intersect the fault-plane due to anomalously high temperatures at bottom-hole. A casing failure during drilling caused the bottom of the borehole to fill with cement. However, the top half of the borehole remains open and can be well-logged. A six-strand fiber-optic cable was cemented into the borehole over the entire length of the well.

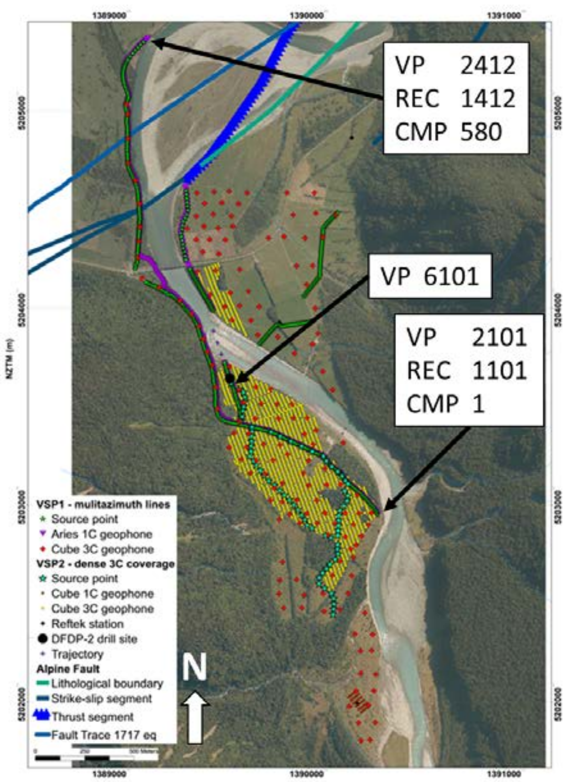

Figure 2: Whataroa valley seismic survey layout. Map courtesy TU Freiberg. VP 6101 is at the surface location of DFDP-2b

The 2016 seismic survey consisted of a number of zero-offset and walkaway VSP surveys in the DFDP-2b borehole using the permanent fiber as well as a clamped string of 4x3C geophones. In addition, 1C-2D, 1C-3D and 3C-3D and sparse-3D common source surveys were conducted on the surface using cable and nodal systems (geophones and seismometers; Figure 2). As previously reported, there is a good qualitative match between unprocessed vertical component borehole geophone data and distributed-acoustic-sensing (DAS) fiber-optic data (Constantinou et al., 2016).

Based on field tests, we chose to use four sweeps per vibe point for this survey before beginning production. If we use all available sweeps for a given vibe point, acquired on different days and with different weather conditions as vibe points were repeated for different VSP tool positions in the well and for different 3D receiver patches, we can significantly improve our data quality. Figure 3 shows a comparison between a single sweep (top) and a diversity stack with 128 vertical fold (bottom). Figure 4 shows a summary of the mean, median and standard deviation of signal-to-noise ratio calculated for a variety of vertical folds, for conventional and diversity stacking methods. The signal-to-noise ratio increases for both stacking methods from 2 to 32 sweeps, with the diversity stack being a little bit better than the conventional stack. However, while the signal-to-noise ratio continues to improve as we add sweeps to the diversity stacks, the conventional stacks degrade after 32 sweeps (Figure 4).

We attempted to process the Whataroa line to achieve an interpretable migrated section. There is a lot of noise in the data and probably some sideswipe. Repeated sweeps for different VSP geophone tool levels and for 3D receiver patch moves allow up to 136 vertical fold for some vibe points. We applied standard processing, which included true amplitude recovery, air blast attenuation, radial filtering, and Gabor deconvolution. Refraction statics were calculated from the first break picks and applied using a final datum of 100 m with a replacement velocity of 2350 m/s. We stacked the line using crooked line binning. After stacking the data, we migrated the section using post-stack finite difference time migration. There is a lot of noise in the stacked section below 1.5 s so the data do not migrate well here. To interpret the data and tie it to borehole information, we converted the time migrated section to depth using velocities obtained from the VSP data (Schlumberger Internal Report) for the top 800 m and velocities from data processing below that depth. Figure 5 shows this depth-converted section with the location of the deviated borehole DFDP-2b and our interpretation. We interpret the location of the Alpine Fault from the observed contrasting dips of reflections. The depth of the Alpine Fault matches well the depths documented in published work (Norris et al., 2012) for the Whataroa area. The deviated

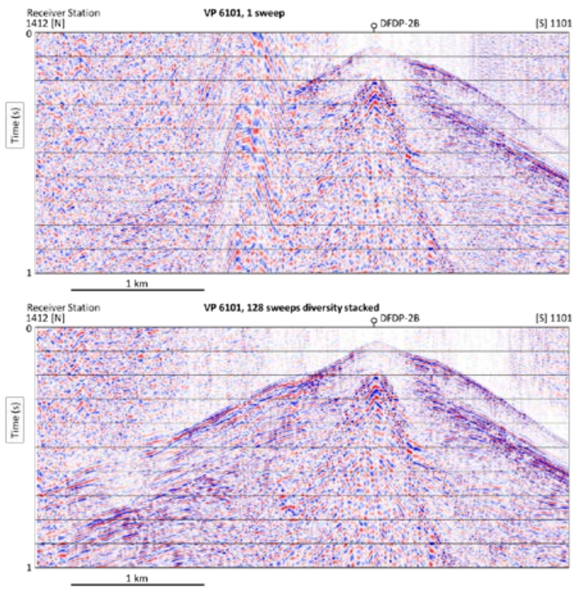

Figure 3. Single source gather (vertical fold=1) from VP 6101 (top), and diversity stack (vertical fold=128; bottom). AGC has been applied for display.

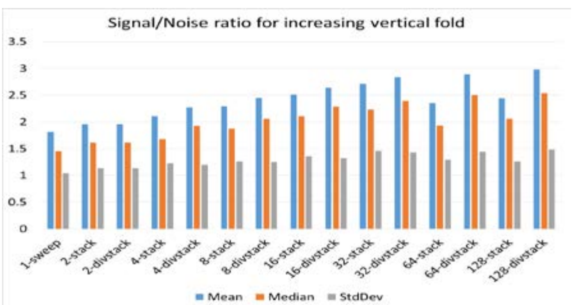

Figure 4. Summary of signal to noise ratios calculated for each trace in conventional and diversity stacked source gathers for 1, 2, 4, 8, 16, 32, 64, and 128 vertical fold.

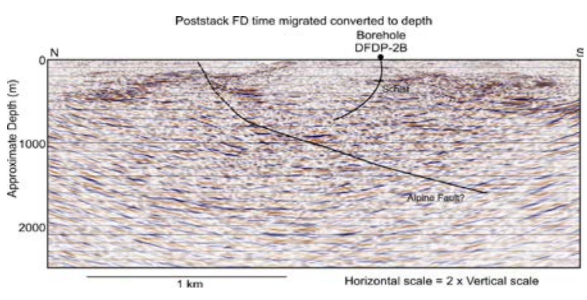

Figure 5: Top 2500 m of the depth-converted poststack time migrated section with the location of the DFDP-2B borehole and our interpretation of the Alpine Fault.

DFDP-2b borehole reached a depth of 893 m (724 m TVD) and terminated in mylonitic rocks which are inferred to be within 200–300 m of the principal slip zone (Townend et al., 2016). The location of our interpreted Alpine Fault fits this scenario.

Hauraki Rift Survey

Geological and geophysical studies of the Hauraki Rift (Schofield, 1967; Hochstein and Nixon, 1979; Edbrooke, 2001; Haywood and Grenfell, 2010) show it to be part of an active continental rift structure which started to form after the collision of the Indian and the Pacific plates. It is a ~30 km wide onshore-offshore extensional structure located 30 km to the east of the Auckland and Hamilton metropolitan areas (Hochstein et al., 1986). Individual 20+ km long fault segments mapped to date are thought to produce >M6-7 events; each segment with a recurrence interval of 2500-9000 years (de Lange and Lowe, 1990; Chick et al, 2001; Persaud et al., 2016). This tectonic feature is deemed to represent the primary seismic risk to the Auckland and Waikato regions (Hull et al., 1995; Wright et al., 2009). It is over 220 km in length, extending from the Taupo Volcanic Zone (SSE) to potentially offshore Whangarei (NNW; Hochstein and Nixon, 1979; Hochstein et. al., 1986), and contains the known active Kerepehi Fault. The Kerepehi Fault is only well defined at the surface as far north as Ngatea (Persaud et al., 2016), although gravity modelling indicates continuity of the deeper structure to the north (Hochstein and Nixon, 1979). Recent active fault mapping and analysis of tilting of geomorphic surfaces also suggests that the Kerepehi fault extends up to the coast under younger undeformed alluvial and coastal sediments (Persaud et al., 2016).

The southern part of the Hauraki Rift is filled with about 3 km of Quaternary and Neogene sediments and is bounded on the western side by Jurassic metagreywackes. In the near surface the thin water-saturated low velocity layer is underlain on each side of the Piako River by up to 500 m of Quaternary sediments having a velocity of 1520-1570 m/s. The velocities of the deeper Neogene rocks are 2200-3000 m/s, and the velocity of 3770 m/s measured in the central uplift is typical of shallow greywackes observed elsewhere in New Zealand. Refraction seismic data showed the average velocity of the basement rocks to be 3450 m/s (Hochstein and Nixon, 1979). The Kerehepi Fault, which dips at 70-80° to the west, controls the major central basement uplift (Houghton and Cuthbertson, 1989). The 2016 seismic line investigates the lesser known northern Kerepehi Fault segment as modelled by Hochstein and Nixon (1979; Figure 6) and interpreted as active by Chick et al. (2001), allowing the northward trend of activity to be determined.

We processed the Hauraki line to attenuate noise and enhance signal. We applied true amplitude recovery, air blast attenuation, predictive deconvolution, and Gabor deconvolution. Surprisingly, given how flat the region is, source gathers show irregularities in the first breaks caused by lateral velocity changes and out-of-plane events. Refraction statics (Figure 7) were calculated from the first break picks and applied using a final elevation datum of 37 m with a replacement velocity of 1000 m/s. The velocities mapped here agree with those of Hochstein and Nixon (1979), who calculated velocities of 500-800 m/s for the low velocity layer, and 1520-1570 m/s for the underlying Quaternary sediments. We stacked the line using crooked line binning and migrated the data using post-stack finite difference time migration, prestack Kirchhoff time migration and prestack Kirchhoff depth migration. Figure 8 shows the post-stack finite-difference migrated seismic line (in time) with our interpretation of the major structural features annotated. The central basement ridge and Kerehepi Fault are seen clearly in the east. The top of the basement, although not well imaged, can be seen to dip from west to east. In the centre of the line are reflectors representing the Neogene sedimentary graben fill, which are tilted to the east and appear to be wedge shaped, with the thick end of the wedge to the east. This implies the sediments have been continuously deposited while the Kerepehi fault was active (growth fault).

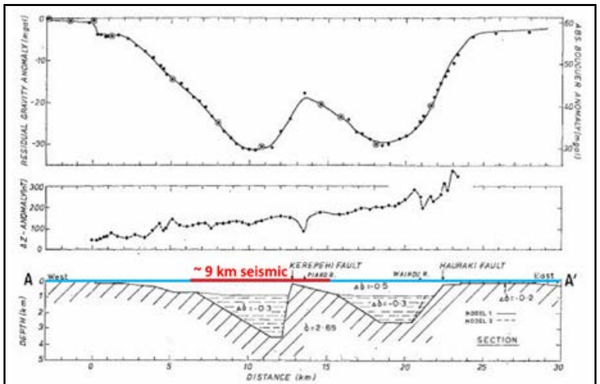

Figure 6. Observed and computed Bouguer gravity anomalies (top), observed magnetic anomalies (middle), and approximate location of 2016 seismic line on A-A' gravity model (bottom) (from Hochstein and Nixon, 1979).

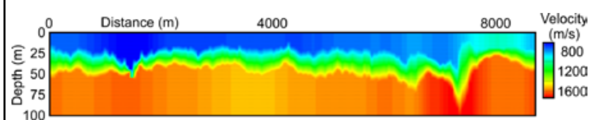

Figure 7. Near-surface velocity model obtained from refraction statics analysis.

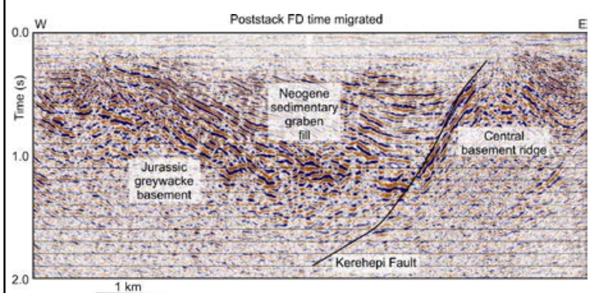

Figure 8. Interpretation of the Hauraki line with the main structural features annotated.

Conclusions and Future Work

Whataroa valley zero and multi-offset VSP geophone and fiber-optic data need be processed, matched to the surface seismic data, and interpreted. The 1C-3D and 3C-3D and sparse-3D data also need to be considered. We obtained reasonably good images of the base of sediments and, we believe, of the Alpine Fault. Further processing to see if clearer images can be obtained should be conducted. Sections shown in this abstract should be interpreted in greater detail. The Hauraki Rift survey has produced decent images of structure within the Hauraki Rift, particularly of the base of sediments and of sediments deposited in the hanging wall of the Kerepehi fault. These data may also benefit from further processing, and certainly require a more detailed interpretation and integration with other geophysical data available in the area.

Acknowledgements

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