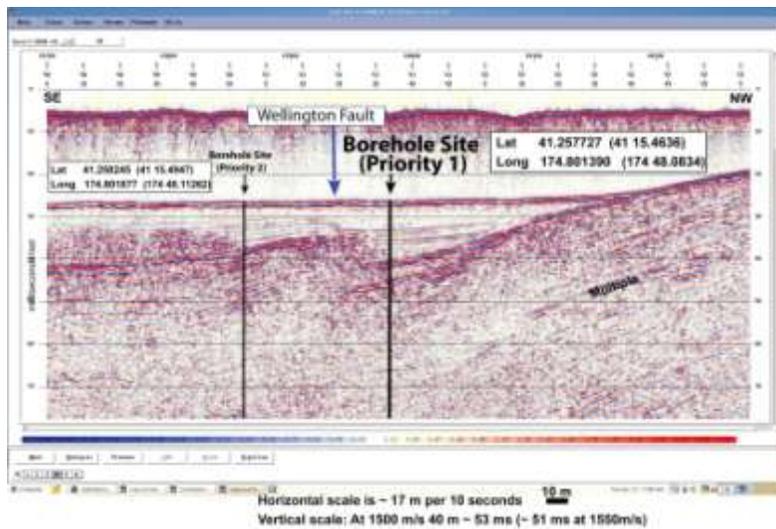

Applying Novel Sub-Bottom Boomer Technology to the Submerged Wellington Fault, New Zealand



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Abstract

The Wellington Fault is an active dextral strike/slip fault that runs through central Wellington and along the north-west edge of Wellington Harbour. Erosion-led regression of the uplifted coastal hills has left the fault rupture zone under several metres of sediment, about 400m offshore, in 20m water depth. Little or no expression of the fault is visible in the bathymetry.

In December 2010 a sub-bottom profiler (SBP) data set was collected in Wellington Harbour using the 'S-Boom' System from Applied Acoustic Engineering Ltd (Great Yarmouth, UK). This uses a novel 3-plate high power synchronised sound source to improve resolution and penetration; it is the first time such a system has been used to survey a major active fault.

This paper presents three aspects of the investigation:

1. A description of the innovations in sub-bottom technology deployed.
2. An overview of the survey methodology and data processing.
3. A comparison of the data quality from the 'S-Boom' with other SBP data.

An analysis of the system beampattern, signal to noise, waveform stability, and wavelet shape are presented. The Wellington data demonstrates efficient power transmission in the 100Hz-5kHz band using 1000J pulses at 3 pings/second, with the short (~400 μ s) pulses showing less than 10% reverberation. The resulting sub-bottom resolution and penetration seen in the Wellington data compares favourably with the design expectations. Other trials data is compared with the Wellington data set to illustrate several site-specific geophysical imaging issues found in Wellington Harbour, and to show achievable performance under different field conditions.

The Wellington Harbour data demonstrated the ability of novel SBP technology to improve the mapping of active submerged faults in non-ideal imaging conditions. A geophysical interpretation of the Wellington S-Boom lines is being undertaken by New Zealand's National Institute of Water and Atmospheric Research (NIWA) as part of a fault geohazard analysis project, and will be presented separately.

1. Introduction

The City of Wellington in New Zealand stands on the boundary of the Pacific and Australian tectonic plates. One surface expression of this tectonic boundary is the Wellington Fault, which forms a major topographic feature in the city's landscape. Northeast from the city the fault passes along the northwestern edge of Wellington Harbour, with

the submerged section emerging near the ferry terminal and trending northeast past Kaiwharawhara, as shown in Figure 1 (from Lewis and Mitchell, 1986). It is an active dextral shear fault, with the landward side to the northwest generally moving northeast and upwards relative to the harbour side, although recent movement shows some upthrow on the southeaster

(harbour) side (Lewis 1989). Buckling has resulted in the development of several major basins along the fault including Wellington Harbour and the Hutt Valley. Erosion of the uplifted coastal hills at Kaiwharawhara has led to coastline regression, leaving the centre of the faultline rupture zone a few hundred metres offshore in about 20m water depth.



Photograph by D.L. Homer

Figure 1. The Wellington Fault at Kaiwharawhara, looking southwest (from Lewis and Mitchell, 1986).

Sedimentation in the harbour has mostly covered the seabed expression of the fault, although multibeam survey data shows signs of a subtle fault scarp less than 1m high near Kaiwharawhara.

The fault area off Kaiwharawhara was chosen to be one of the Shallow Survey 2012 Common Data Set survey targets (designated as Area 7). In December 2010 a novel sub-bottom profiling system from Applied Acoustic Engineering Ltd (Great Yarmouth, UK) was deployed from the NIWA Survey Vessel *Ikatere* to collect a series of profiles over the fault and elsewhere in Wellington Harbour. The surface-towed S-Boom system uses a highly synchronised 3-plate boomer sound source to improve acoustic source levels and hence achieve greater

penetration than single plate sources while maintaining higher resolution than possible with sparker sources. This is the first time such a system has been used to investigate a major active fault. High resolution seismic investigation of the shallow rupture zone will be useful in future regional geohazard assessments.

The raw data from the S-Boom survey have been made available from NIWA as part of the Shallow Survey 2012 Common Data Set.

Previous sub-bottom surveys of the area were carried out in the 1980's using a EG&G Uniboom 230 system with a maximum output of 300 Joules per pulse centred at 800Hz, as described in Lewis (1989) . These located the fault but identified various issues with seismic profiling in the harbour. The surveys found a highly reflective horizon about 5m below the seafloor over much of the area, attributed to the presence of water or gas saturated porous sediment. It also identified faulting in the post-glacial sediment in zones several hundred metres wide in the fault area. One objective of the present work was to investigate how the higher power 3-plate S-Boom source could improve seismic data collected in this difficult environment.

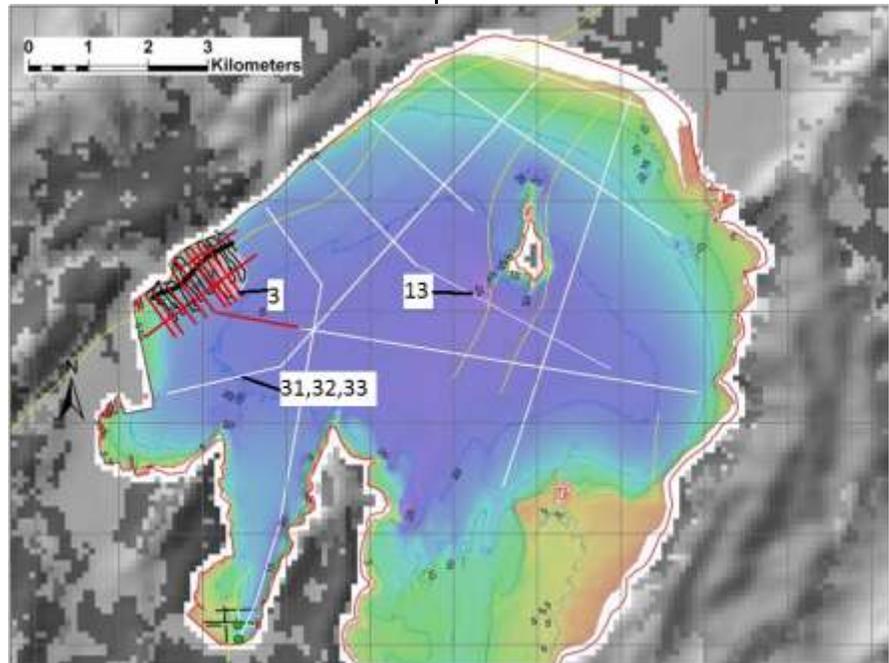


Figure 2. Lineplan for the S-Boom Survey. Survey line numbers are given for the profiles shown later in the paper.

This paper first presents details of the S-Boom sub-bottom technology deployed in collecting the data set, including the acoustic characteristics of the S-Boom system and power source, and the new 3-plate catamaran towbody. The expected performance advantages of this technology over previous systems are discussed. In the results section of this paper the seismic profiling data quality from the S-Boom system is presented and compared with single-plate and sparker data also collected in December 2010. Geophysical interpretation of the data is not included here: further analysis of the geophysics around the fault using the S-Boom data, including relating the results to a nearby borehole sequence, are given separately in NIWA's presentation at Shallow Survey 2012 (Barnes et al. 2012). More details of data processing to optimise the data using CODA Seismic is presented separately by CODA at the conference (Carsley 2012).

2. Aim

The purpose of this survey was to investigate the capability of the novel S-Boom 3-plate boomer sub-bottom profiling system around a fault rupture zone in shallow water, and provide high resolution seismic profiles of the fault and surrounding area. Prior to acquisition a line plan was drawn up together with the assistance of NIWA, covering the Wellington fault area of the harbour and other areas of sub surface interest (see Figure 2).

Table 1. SBP Equipment Installed on the S/V Ikatere.

Equipment	Model
<i>SBP source:</i>	<i>S-Boom system: 3 x AA202 Boomer Plates CAT 300 Catamaran Towbody HV3000 Power Cable</i>
<i>Power Source:</i>	<i>Model CSP-S1250 Seismic Power Supply</i>
<i>Hydrophone:</i>	<i>Model AH150/20</i>
<i>Data Collection:</i>	<i>Coda DA2000</i>
<i>Other Equipment:</i>	<i>Model CSP-D2400 Seismic Power Supply</i>
	<i>Squid 500 Sound Source</i>
	<i>Geometrics Geo-Eel 8 Channel Streamer Hydrophone</i>
	<i>Geometrics Geode Data logger</i>

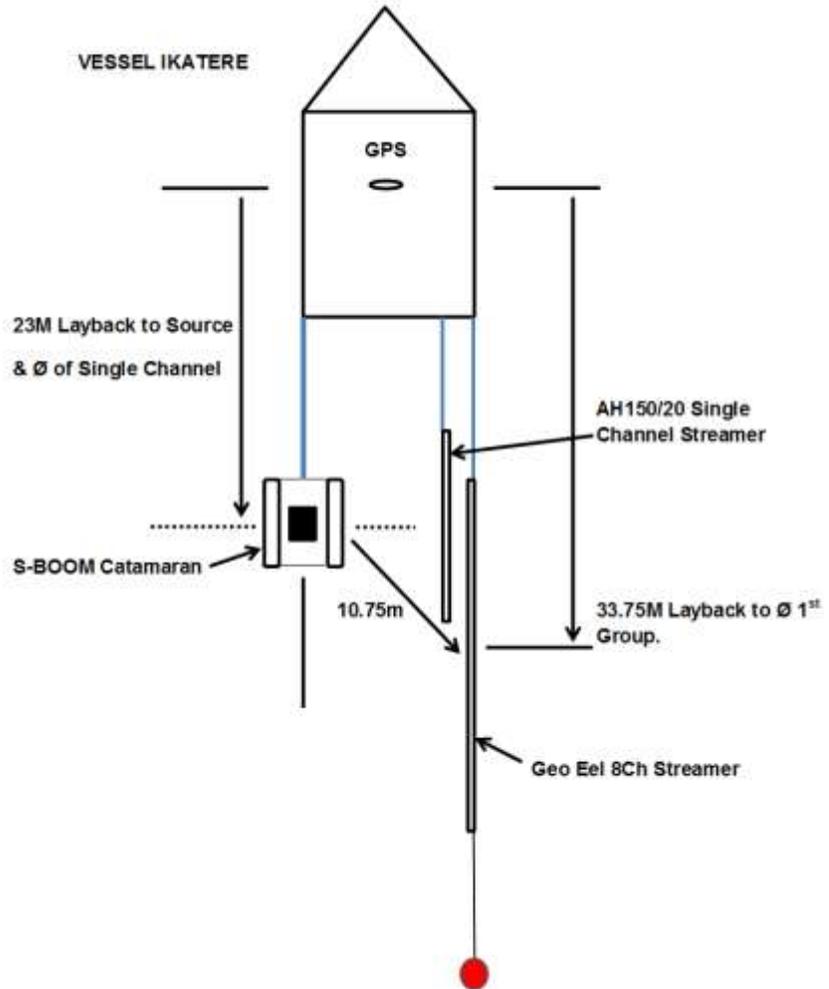


Figure 3. S-Boom towing configuration on the S/V Ikatere.

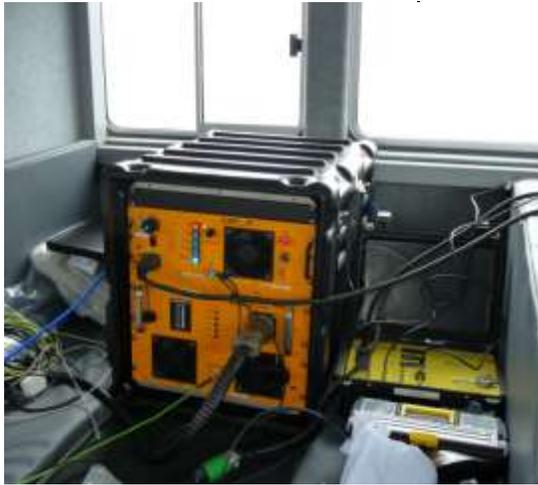


Figure 4a. CSP-S1250 Power source.



Figure 4b. System control screens

The lines were chosen to investigate the system capability and to assess the expected improvements in penetration, signal to noise and resolution of horizons from the 3-plate technology.

3. Methods

The survey data was acquired over a period of 4 days, including mobilisation and demobilisation, from the 6th to

9th December 2010. The equipment used was an Applied Acoustics 3-plate S-Boom surface-towed sound source and either a standard AH150/20 single element hydrophone or a multi-channel streamer. Several survey lines were collected using different power and pulse rate settings, and comparison survey lines were also collected using a single AA201 boomer plate and a Squid 500 sparker source.

The equipment was deployed on NIWA's research vessel 'Ikateru', with the boomer source towed to port and the receive hydrophones to starboard (see figures 3, 4 and 5). Data was logged on a CODA DA2000 and a Geometrics

Geode Data Logger. Full equipment installation on the vessel (listed in Table 1) took less than 2 hours.

4. Equipment Description

The S-Boom sub-bottom profiler uses a highly synchronised array of 3 boomer plates, with the acoustic signals from the 3 plates closely aligned using a matched high current, high repetition rate

power source. The potential signal level advantages of a multi-plate boomer have long been recognised. Compared with sparker sources a triple plate boomer system has a significantly more stable pulse output and no exposed electrodes. However earlier attempts to develop multi-plate boomer systems suffered from issues with consistent timing and synchronisation of the multiple sound sources, especially when using separate energy sources for each plate. The resulting unreliable acoustic signal generation gave inconsistent beamforming and poor horizon resolution, with interference between the plates leading to degradation of the acoustic pulse.



Figure 5. S-Boom system under tow.

The power source developed for the S-Boom was the High Capacity CSP-S1250 unit from Applied Acoustics. This system was designed to minimise timing problems while providing one kilojoule per shot, divided between the three plates. Bench tests show less than 2 microsecond timing difference between the three plates, which will not degrade the beamforming or

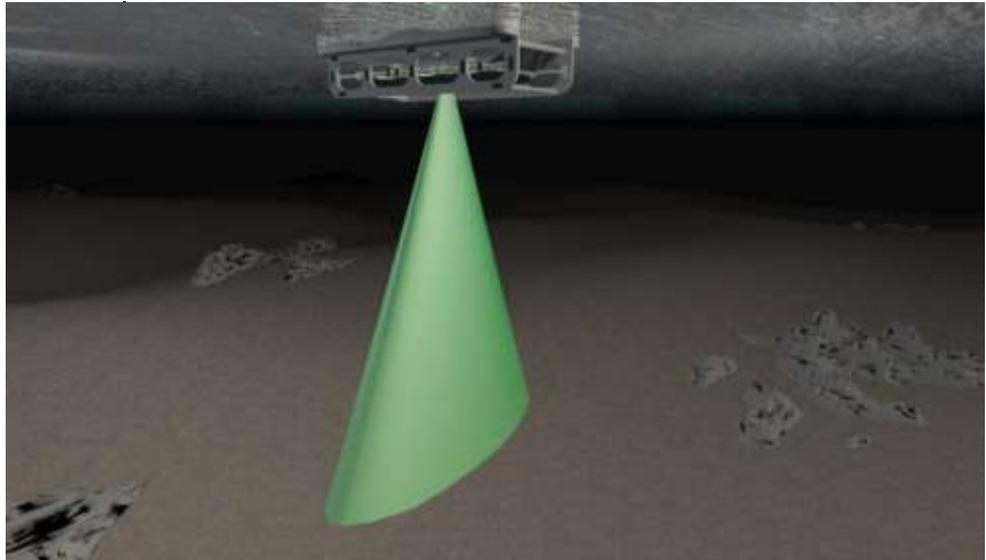


Figure 6. S-Boom beam pattern: 30 degrees across-track, 15 degrees fore-aft.

received traces. Another design criteria for the High Capacity CSP unit was its high charge rate. This was implemented using twin HV chargers incorporating high current thyristors, giving 3200 Joules per second peak recharge rate. This allows the system to operate at 1000J per shot at up to 3 pulses per second (pps). This high charge rate also allows lower power pulses to be generated at higher repetition rates, and the CSP will operate at up to 6pps at 500J/shot. In suitable sub-bottom environments this gives better signal to noise and increased speed over ground compared with earlier, lower power, slower ping rate systems.

The 3 plates of the S-Boom system constitute a beam-formed towed array which is designed to concentrate the acoustic energy in a cigar shaped footprint with an approximate 6dB Directivity Index (DI) improvement over a

single boomer plate. Consistent beamforming relies on the high levels of synchronisation of the plates' pulses, and results in higher directionality of the acoustic energy in the water. This increases the effective source level, with calculations showing achievable signal levels of 223dB re 1 μ Pa at 1m. The calculated beamshape is shown in Figure 6. This source level allows operation in water depths from 2 metres up to around 1000 metres, and provides enough power to penetrate the seabed to over 200m. Trials in the North Sea have shown penetration records of 200 milliseconds in a sand and limestone environment (Fig 10).

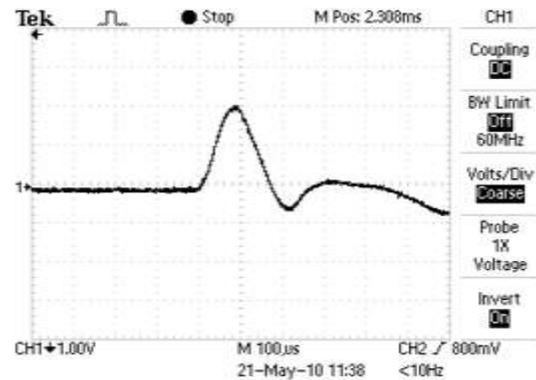


Figure 7. Pulse output of the CSP-S1250



Figure 8. Frequency Spectrum of the CSP-S1250

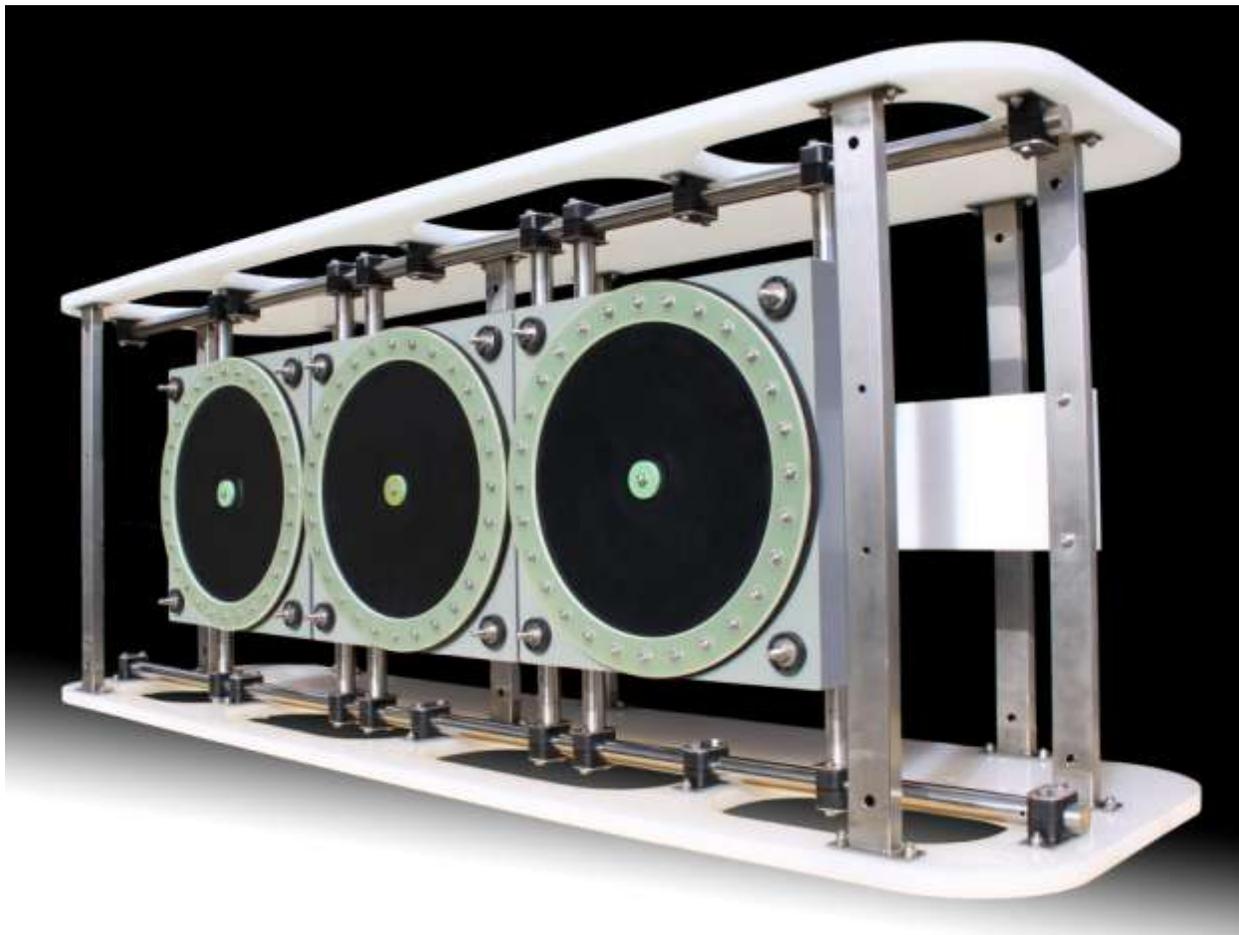


Figure 9. The S-Boom triple plate system mounted on the CAT300 surface tow mount.

In order to obtain the best resolution from a boomer system a repeatable clean, sharp pulse is required. The S-Boom pulse is measured at 300 to 500 microseconds, giving a vertical resolution of better than 0.25 metres. Figure 7 shows the pulse output while Figure 8 shows the frequency spectrum, indicating efficient power transmission in the 100Hz-5kHz band with peak power around 1kHz, ideal for the combined objectives of penetration and resolution in shallow geophysical investigations.

The S-Boom system was deployed on a novel catamaran, the CAT 300, see Figure 9. This was designed for improved tow

performance in the 3-plate configuration and is suitable for extended surveys from vessels of opportunity. The improved tow performance along with higher pulse repetition rate allows faster survey speeds without degrading system performance. The towbody pitch stability combined with the beamforming described above results in increased ability to separate features along the survey track, along with reduced sensitivity to the presence of waves and swell.

During the Wellington survey the catamaran performance was tested in slight chop and 20kt winds from the south on the 6th and 7th December, and

calm seas on the 8th and 9th. No degradation of performance was seen in chop, although one line on the 7th had to be aborted due to large swell causing pitching of the vessel. Further trials in the North Sea have demonstrated continued operation up to sea state 4 – 5 depending on vessel safe working practices.

The data was acquired using a CODA DA2000 applying high and low cut filters and time varying gain (TVG) whilst online for QC and acceptance. The data was also offline processed using CODA software applying filtering and TVG for presentation, typical filter settings were 200Hz LC and 4000Hz HC.

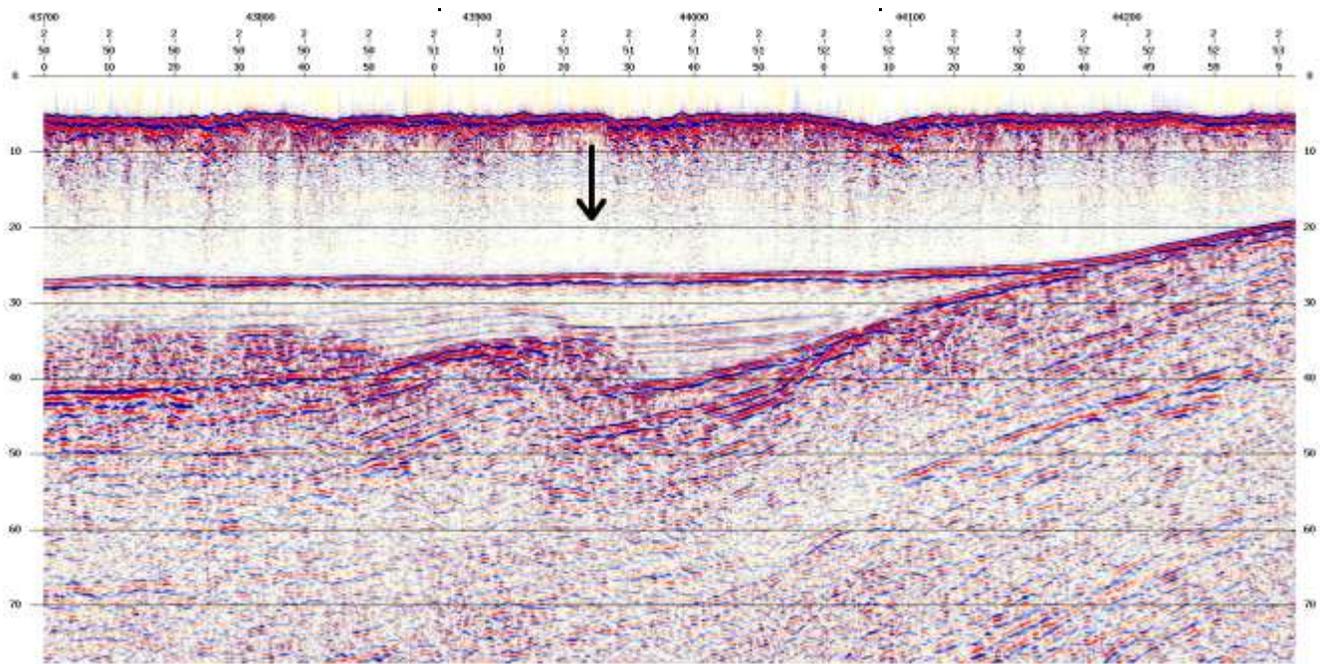


Figure 10. Line 003: East-west S-Boom Profile to 80ms over the Wellington Fault (arrowed).

5. Results

Multiple lines were collected over the Wellington Fault as well as several lines elsewhere in the harbour. This paper presents some of the profiles from a selection of these lines. The full data set and detailed line information files are available as part of the Common Data Set available from NIWA.

The ability of the S-Boom system to image the fault rupture zone and resolve the sediment layers is illustrated in Figure 10 (from Survey Line 003). Geophysical analysis of the lines over the fault are given in the NIWA paper so are not presented here. The NIWA paper also compares the profiler data with a nearby borehole (Barnes et al. 2012).

One of the S-Boom survey lines just south of Somes Island is shown in Figure 11 (Line13), showing good resolution of the sediment and underlying layers away from the fault.

The S-Boom can be set to

energise one, two or all three plates, and this was used to collect comparison data illustrating the advantage of the higher power triple-plate arrangement over comparable single plate data.

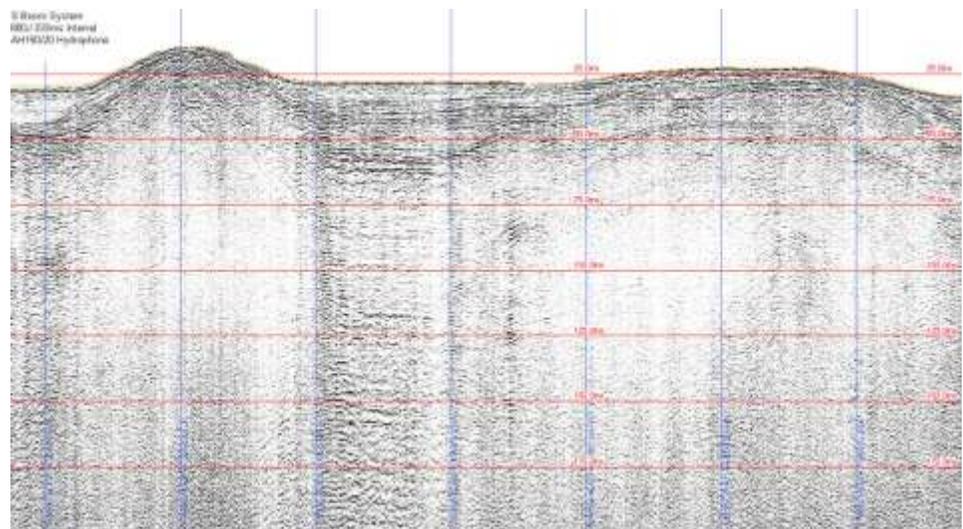


Figure 11. Line 013: West-east profile to 200ms to the south of Somes Island

Figures 12, 13 and 14 (from survey Lines 31, 32 and 33) were collected over the same east-west track near the port using triple-plate, single plate and a Squid-500 sparker source respectively. Although blanking from the gas layer can be seen in all traces, the S-Boom data appears to show more penetration over more of the survey line when compared with the single boomer line, with enhanced registration of some of the deeper horizons.

The comparison also shows that the S-Boom maintains the high resolution of a boomer while allowing greater penetration than possible with the single plate arrangement. The horizon resolution seen in the profiles confirms that the synchronised source for the three-plate system does not compromise the transmitted waveform.

The Wellington data can be compared with North Sea trials data, where the better sub-bottom environment allowed up to 200ms penetration, as shown in Figure 15. Comparing the system performance in the two areas confirms previous papers' conclusions that the Wellington Harbour area has site-specific geophysical issues making it a difficult environment for sub-bottom profiling, with submerged gas resulting in blanking and the hard layer limiting penetration. There is evidence that the higher power of the S-Boom has allowed some improvement of data in the difficult areas.

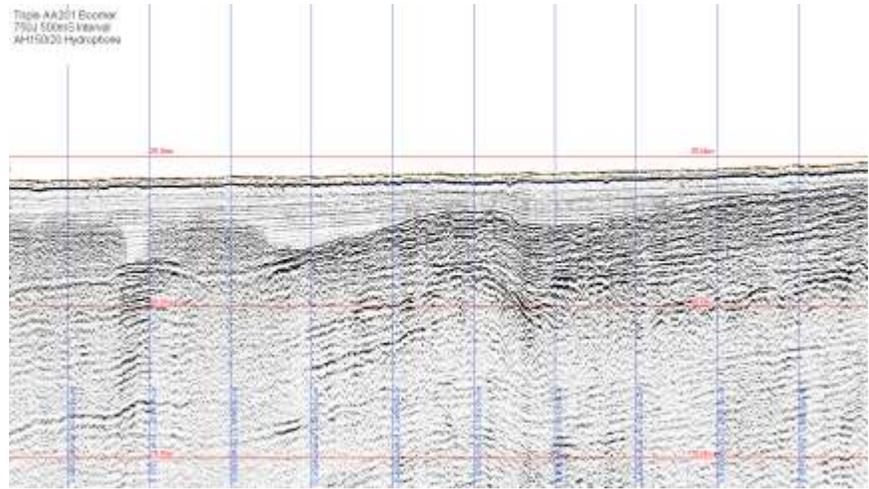


Figure 12. Line 031: S-Boom line to 80ms showing penetration and resolution, for comparison with figs 13 and 14.

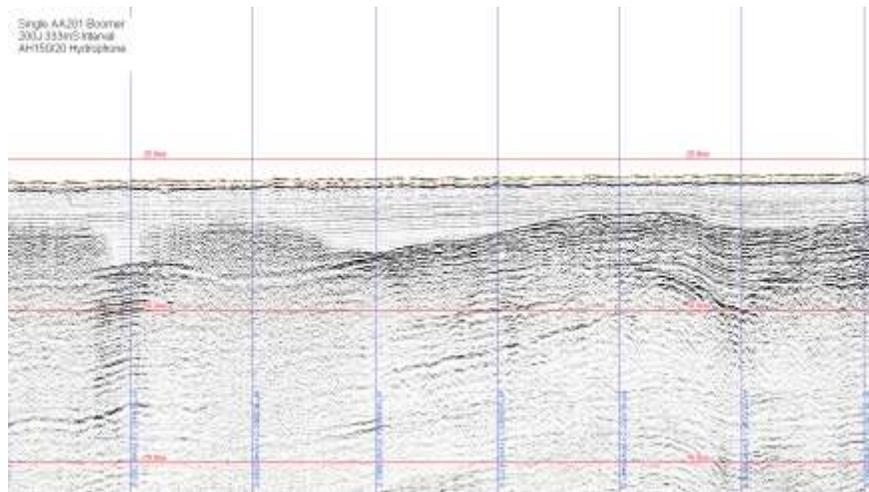


Figure 13. Line 032: Single Boomer profile showing poorer penetration.

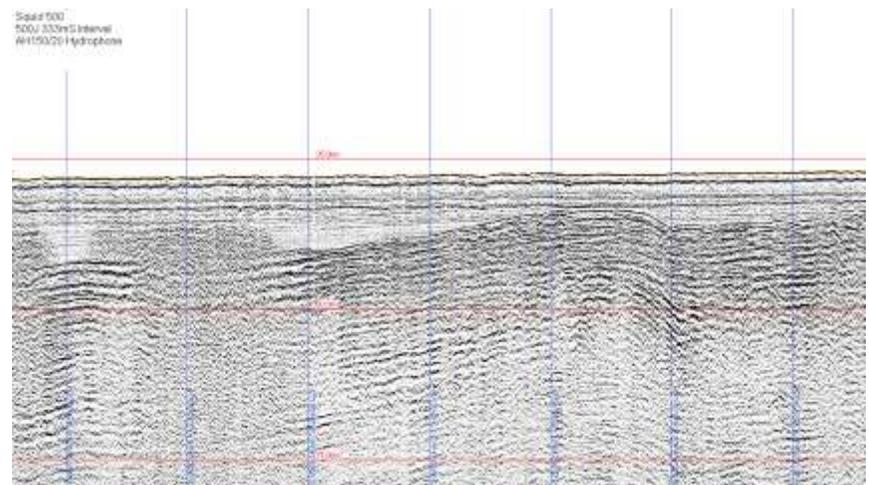


Figure 14. Line 033: Squid 500 profile showing good penetration but lower resolution.

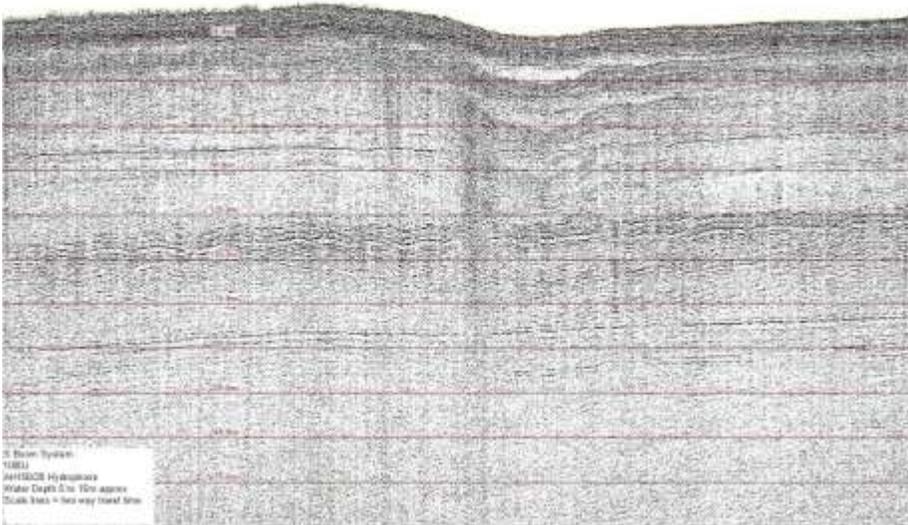


Figure 15. Profile from the North Sea showing over 200ms penetration.

expected from a single plate boomer system. The trials data in the North Sea shows up to 200ms penetration in a less difficult sand/limestone environment. The sub-bottom resolution and penetration seen in the Wellington data and in North Sea trials compares favourably with design expectations.

The data presented here demonstrates the capability of the S-Boom system in the context of geohazard investigations of fault rupture zones. The seismic profiles collected in December 2010 will be used to aid NIWA in the development of a high resolution record of the Wellington Fault fault activity over the past 10,000 years. When combined with borehole and other regional data this will help inform the local geohazard analysis for the City of Wellington.

6. Conclusions

Several sub-bottom profiles were collected over the Wellington Fault and Wellington Harbour. These demonstrated improved resolution and penetration of the 3-plate S-Boom system over other sub-bottom techniques, although the difficult environment did limit the system performance. Imaging issues previously identified in Wellington Harbour were seen, with evidence of gas or fluid masking in many of the survey lines. The seismic imaging of the soft sediment layers over the fault fracture zone show about 25cm resolution as expected. The

synchronised 3-plate source increased the total power without compromising the resolution of layers, while the increased directivity has improved penetration and along track footprint. In environments where highly attenuating sands can limit seismic energy penetration the S-Boom can help overcome survey problems without compromising vertical resolution.

Compared with single plate systems the innovations employed in the S-Boom allow higher penetration, operation in noisier environments, and less sensitivity to vessel noise, while maintaining the high resolution

7. Acknowledgements

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