A 3D seismic velocity model of Canterbury, New Zealand for broadband ground motion simulation

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1. Background and Objective

This poster presents the on-going development of a new 3D seismic velocity model of Canterbury, New Zealand. The intention of the model is to provide the 3D crustal structure in the region at multiple length scales for seismic wave propagation simulations, both broadband ground motion and more localized shallow site response analyses.

Figure 1a illustrates the 10 major earthquake events (Mw4.7-7.1) in the region which were recorded over a dense array of strong motion stations.

Multiple datasets were used to develop geologic surfaces and material velocities, as depicted in Figure 1b.

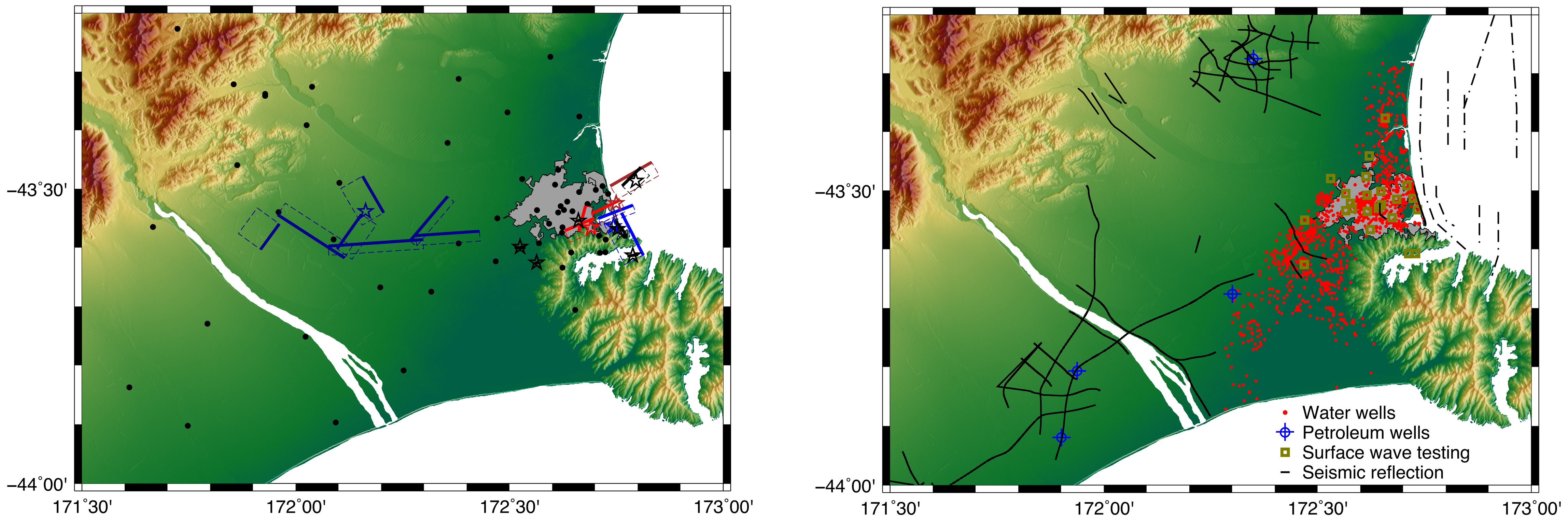

Figure 1: (a) The Canterbury region in the context of the 10 major events (Mw4.7-7.1) in the 2010-2011 Canterbury earthquake sequence and strong motion stations; (b) Data sources used in the development of the Canterbury Velocity Model (CVM).

2. Modelled geologic surfaces

The 3D velocity model adopts a surface-based methodology in which velocity variations are individually prescribed within different geologic units. Table 1 illustrates the various geologic surfaces considered, and the regional units that comprise them. A total of 8 different units are considered (column 1), and the Quaternary unit is further differentiated into 10 different units for high-resolution representation of the shallow structure.

- Seismic reflection profiles and petroleum well logs over the past 50 years (Figure 1b) are the principal means by which the considered units were developed over the Canterbury region.
- Existing reflection profiles were reinterpreted to identify the critical seismic facies representing important lithological changes, e.g. using 3 units for the Miocene because of the strong impedance constrasts for the Miocene volcanics, yet only a single unit for the Paleogene.
- Figure 2 illustrates the currently incorporated reflection profiles. Several offshore profiles (dashed lines in Figure 1b) are yet to be incorporated. The weakest coverage is in the urban Christchurch area.

Table 1: Modeled geologic units in the Canterbury Velocity Model (CVM)

<table>
<tr><th>CVM Unit</th><th>Period</th><th>Epoch</th><th>Waipara</th><th>Ashley</th><th>Christchurch</th><th>South Rakaia</th></tr>
<tr><td>Quaternary</td><td>Quaternary</td><td>Holocene Pleistocene</td><td colspan="4">Canterbury gravels</td></tr>
<tr><td>Pliocene</td><td rowspan="4">Neogene</td><td>Pliocene</td><td colspan="4">Kowai Fm.</td></tr>
<tr><td>Upper Miocene</td><td rowspan="3">Miocene</td><td>Tokama Siltstone/Mt Brown Fm.</td><td>Undiff</td><td>Undiff</td><td>Tokama Siltstone</td></tr>
<tr><td>Miocene Volcanics</td><td rowspan="2">Waikari Fm.</td><td>Starvation Hill Basalts</td><td>Banks Peninsula Vol. Group</td><td rowspan="2">Waikari Fm.</td></tr>
<tr><td>Lower Miocene</td><td>Undiff</td><td>Undiff</td></tr>
<tr><td rowspan="4">Paleogene</td><td rowspan="4">Paleogene</td><td>Oligocene</td><td colspan="4">Amuri and Otekaike Limestone</td></tr>
<tr><td rowspan="2">Eocene</td><td colspan="4">Homebush Sandstone</td></tr>
<tr><td colspan="2">Ashley Mudstone</td><td>View Hill Vol. Group</td><td>Ashley Mudstone</td></tr>
<tr><td>Paleocene</td><td colspan="3">Loburn Mudstone / Waipara Greensand Fm.</td><td>Loburn Mudstone</td></tr>
<tr><td rowspan="2">Late Cretaceous</td><td rowspan="2">Late Cretaceous</td><td rowspan="2">Late Cretaceous</td><td colspan="2" rowspan="2">Conway Fm. / Broken River Fm.</td><td colspan="2">Conway Fm. / Broken River Fm.</td></tr>
<tr><td colspan="2">Mt Somers Vol. Group</td></tr>
<tr><td>Basement</td><td>Jurassic/ Triassic</td><td colspan="5">Torlesse composite terrane (Greywackes)</td></tr>
</table>

<table>
<tr><th>Period</th><th>Christchurch</th></tr>
<tr><td rowspan="2">Holocene</td><td>Springston Fm.</td></tr>
<tr><td>Christchurch Fm.</td></tr>
<tr><td rowspan="8">Pleistocene</td><td>Riccarton Gravels</td></tr>
<tr><td>Bromley Fm.</td></tr>
<tr><td>Linwood Gravels</td></tr>
<tr><td>Heathcote Fm.</td></tr>
<tr><td>Burwood Gravels</td></tr>
<tr><td>Shirley Fm.</td></tr>
<tr><td>Wainoni Gravels</td></tr>
<tr><td>Undiff</td></tr>
</table>

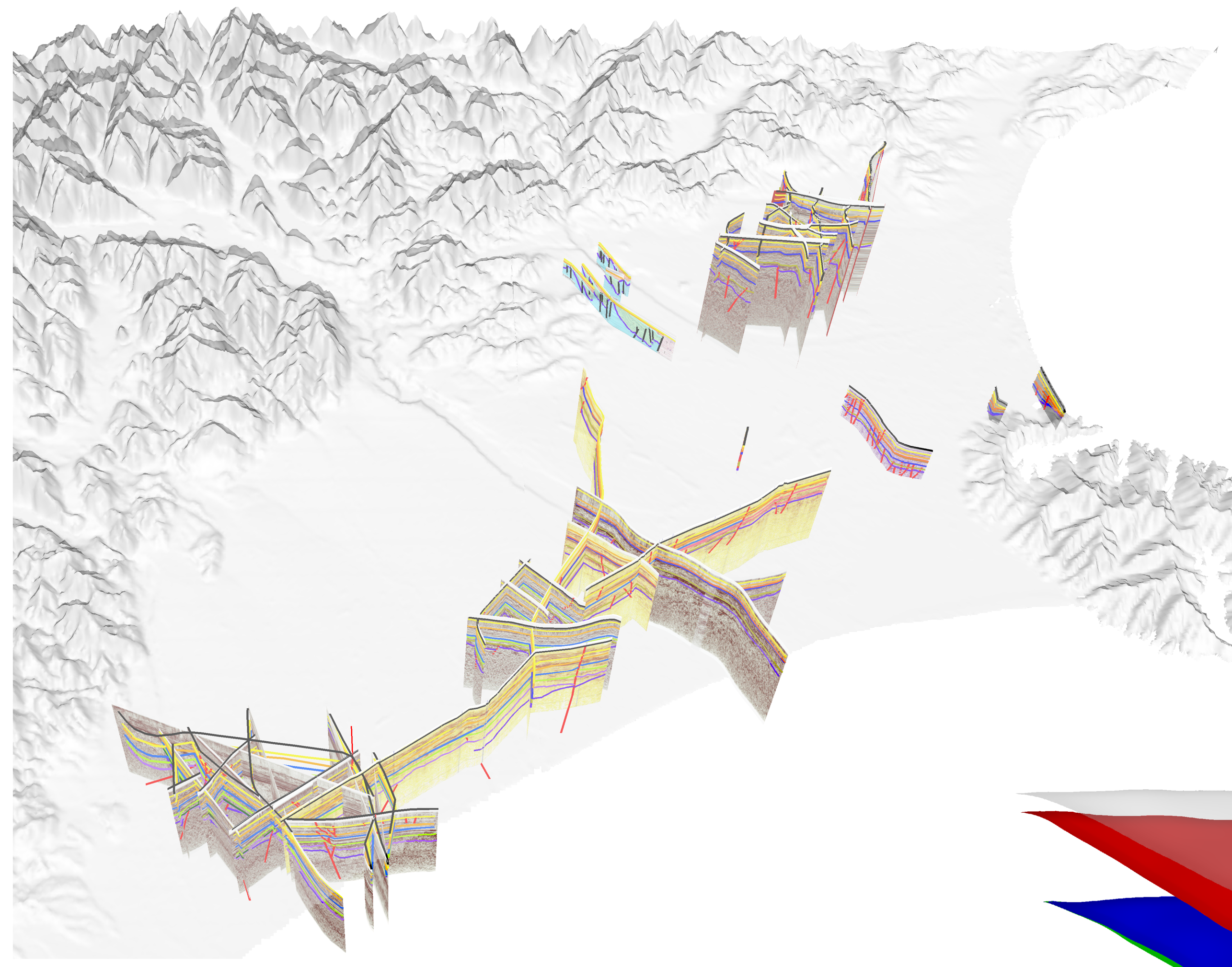

Figure 2: Interpreted seismic reflection lines used in the development of geologic surfaces shown in Table 1. Several additional reflection profiles (dashed lines in Figure 1b) have yet to be included.

The shallow Quaternary structure in the model of the urban Christchurch area is particularly detailed with 10 different units, 9 of which comprise the top 150m of surficial sediments.

Figure 1b illustrates the 1,700 water wells in the region used to constrain the complex inter-bedded stratigraphy in Figure 3 (gravels, sands, silts, organics etc) near the coastline, including beneath urban Christchurch, which has resulted from fluvial deposition and marine regression and transgression in the Quaternary.

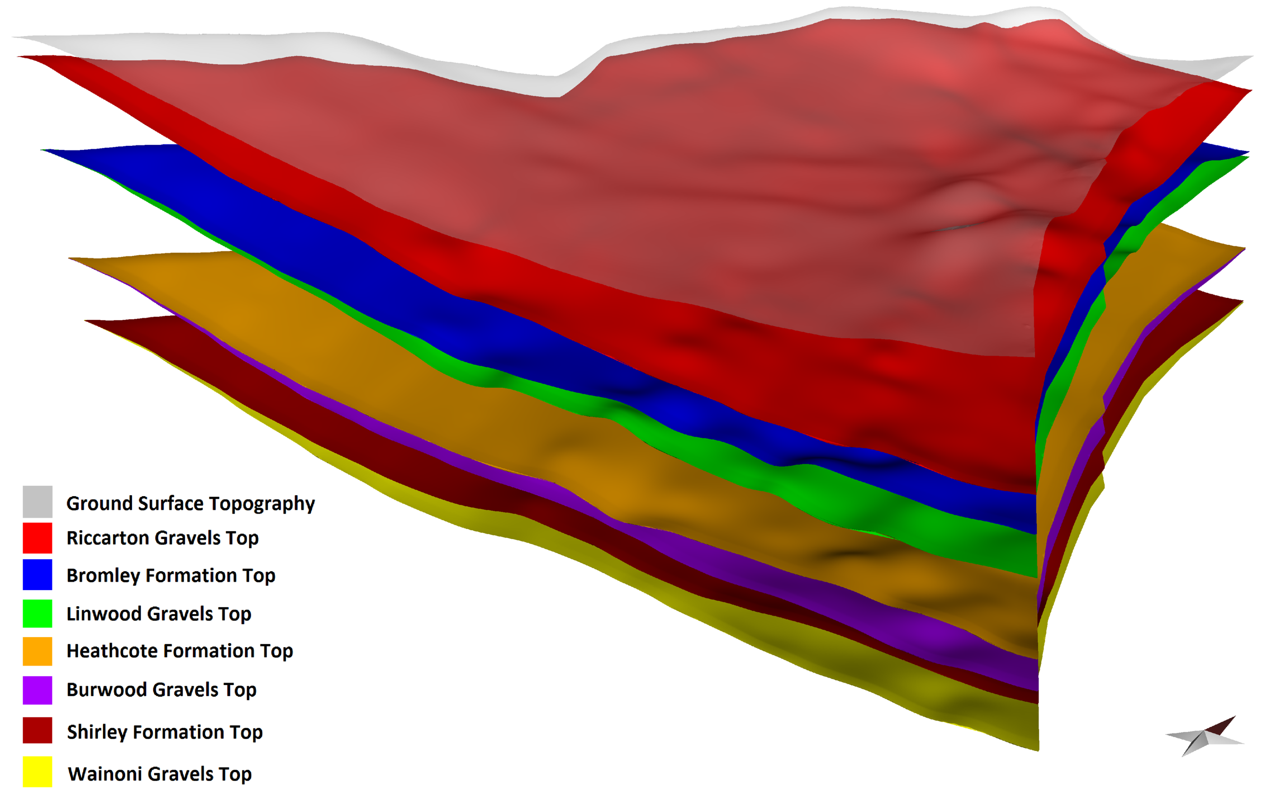

Figure 3: Geologic surfaces of the shallow inter-bedded Quaternary structure beneath Christchurch developed from water well logs (Figure 1b).

3. Seismic velocities

Five different datasets are utilized for representing seismic velocities within each of the various geologic surfaces

- Basement properties (V_p, V_s, ρ) are controlled by 3D regional tomographic data (Eberhart-Phillips et al. 2010).
- P-wave velocities in all units were obtained from seismic reflection profiles via a combination of: (1) sonic well logs; (2) reflection stacking velocities; and (3) the combination of well lithology and interpreted reflection TWTT's where sonic logs and stacking velocities were not available/documented (principally for older wells/profiles).

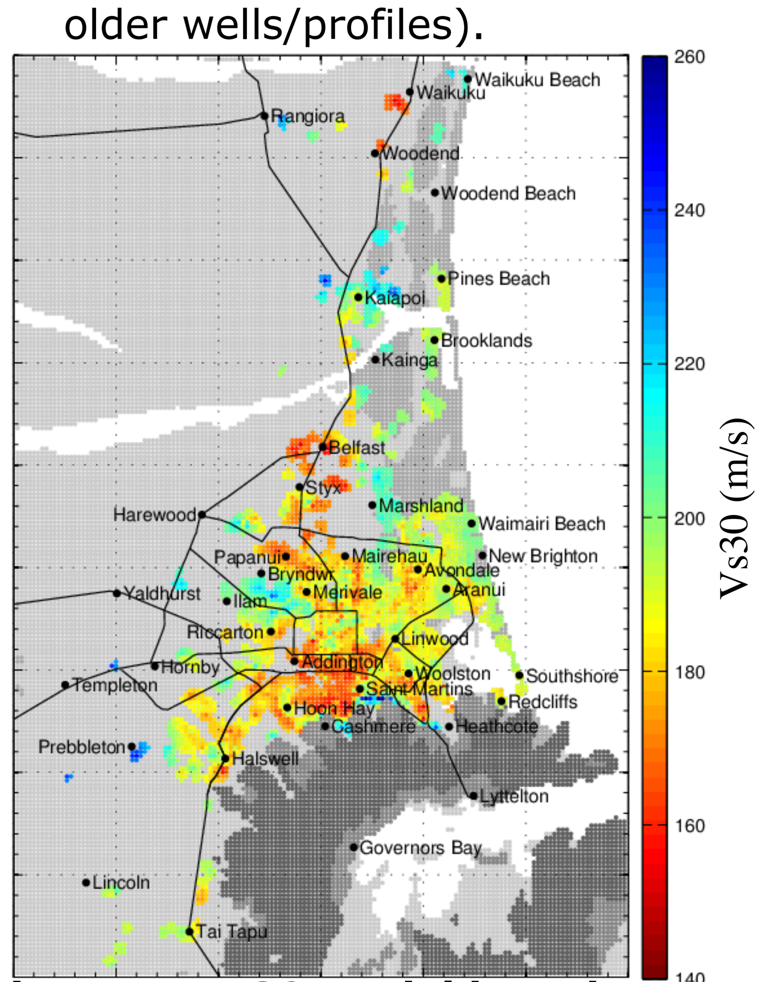

Figure 4: Vs30 model based on over 15,000 CPT logs

- In deep (z>1km) geologic units, V_s is obtained from the empirical correlation of Brocher (2005). This correlation was validated for New Zealand conditions based on the 3D tomographic model data of Eberhart-Phillips et al. (2010). The ρ-V_p of Brocher (2005) is also adopted throughout the model domain.
- In shallow (z<1km) geologic units, V_s is obtained directly from active- and passive-surface-wave data (Cox et al. 2013). Active data includes that obtained with the NSF TRex vibroseis. Active data was processed using MASW, while passive data was processed using both HFK and MSPAC method. Geopsy was used for velocity inversion of the dispersion data allowing for velocity reversals in the interbedded Quaternary stratigraphy. The geologic surfaces (Figure 3) were utilized as constraints in the velocity inversion of disperson data.
- For the near-surface Springston and Christchurch Formations in the Christchurch urban area (z<50m), high-spatial resolution seismic velocities (including Vs30) were obtained from over 15,000 cone penetration tests combined with a recently developed CPT-Vs correlation. Figure 4 illustrates the Vs30 model which was derived from this CPT-based dataset (McGann et al. 2014).