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A new scheme for joint surface wave and earthquake travel-time inversion and resulting 3-D velocity model for the western North Island, New Zealand

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ABSTRACT

We have developed a joint inversion of surface wave group velocity (U) and local earthquake travel-time (LET) data and applied it to the North Island, New Zealand, to improve the existing New Zealand wide 3-D seismic velocity model. This approach takes full advantage of the differing sensitivities of surface and body waves. The data are complementary, particularly at shallow depths where LET tomography suffers from vertical smearing and surface wave tomography is susceptible to horizontal smearing. The employed U observations are 2-D models at discrete periods which were developed for Rayleigh wave dispersion curves measured from the 1744 interstation Green's Functions obtained by stacked cross-correlations of broadband ambient noise data. In the volume surrounding each U observation, we distribute numerous points for relating the U observation to the gridded 3-D tomography model, analogous to points along a raypath. The partial derivatives at the points are computed using the U sensitivity kernels for Vp and Vs, with Vs related to Vp and Vp/Vs perturbations. Thus, the U observations are included along with the travel-time observations in a joint inversion to best fit the data and the existing tomography model. The resulting model favors the U where there is little travel-time resolution. The combined inversion used 2949 U observations at 6–16 s period and LET from 1509 earthquakes that extend to 370 km depth, and improved the model fit by reducing the U residual data variance by 62% and the LET by 9%. The resulting model generally has better constrained depth of shallow anomalies, with decreased velocity in the upper 2 km in the western North Island, and slight focusing of crustal high velocity features at 8 km depth. Significantly, the increased resolution in the shallowest 5 km of the model improves the utility of the 3-D model for use in seismic hazard assessment, wave propagation studies, and studies comparing seismic velocities to geological mapping.

1. Introduction

The North Island of New Zealand contains the active Hikurangi subduction zone with earthquakes >300 km depth, and rifting along the Taupo Volcanic Zone (TVZ), with abundant crustal seismicity in the TVZ and along the eastern North Island (Fig. 1b). Numerous offshore seismic reflection profiles above the shallow forearc also define structure (Bell et al., 2010). The NZ-wide 3-D velocity model, which extends to 300-km depth in the North Island, integrates several regional velocity studies and uses local earthquakes and onshore recording of offshore active source data (Eberhart-Phillips et al., 2010; Eberhart-Philips and Bannister, 2015). This has uneven resolution, with abundant data and detailed resolution in the eastern North Island, and sparse data and weaker resolution in the western North Island. The Northland area of northwestern-most New Zealand has limited information which has been compiled from studies of receiver functions (Horspool et al., 2006), and sparse shallow seismicity. Where there is less dense coverage, the velocity model may provide reasonable average velocity, over approximately 30 km distance and 15 km depth, but have less detailed information on the vertical and spatial extent of features such as basins and tectonic belts. Lack of such shallow resolution is particularly limiting for comparison of the velocity model with surficial mapping of geology. The current model contains details of the velocity structure proximal to the plate interface that may be related to heterogeneous seismic coupling, with regions of overpressured subducted sediment imaged with high Vp/Vs and low Vp. The nationwide model is currently used for earthquake location and geodetic modeling. Its application

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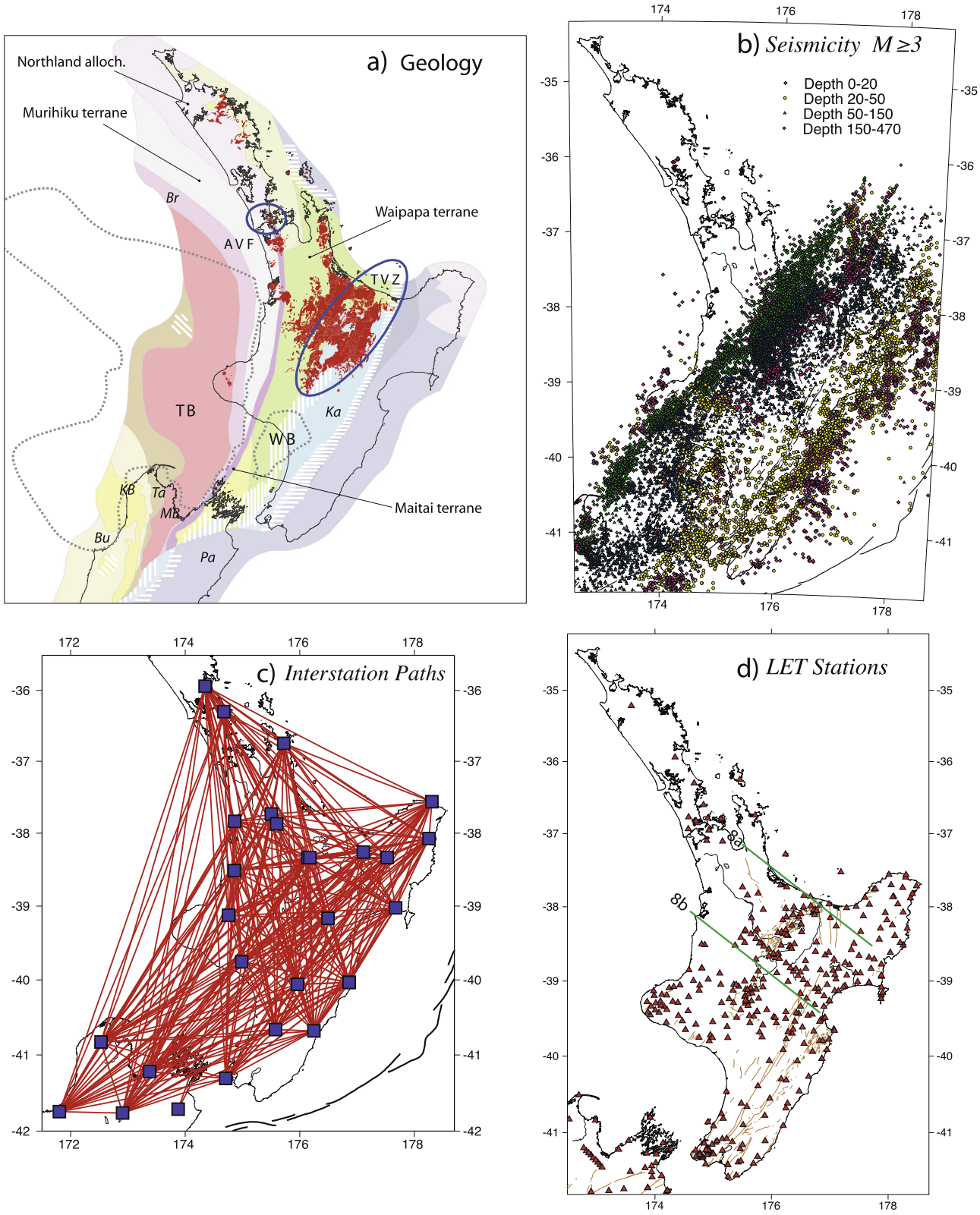

Fig. 1. a) Geology: Quaternary-Pliocene volcanics shown in red (Leonard et al., 2010); and simplified basement geological terranes of the North Island, after Mortimer (2004), Waipapa terrane shows Morrinsville facies, Waipapa composite terrane, Matai terrane includes Junction magnetic anomaly, other terranes shown are Northland allocthon, Murihiku, Brook Street (Br), Median batholith (MB), Takaka (Ta), Karamea batholith (KB), Buller (Bu), Kaweka (Ka), Pahau (Pa). Dashed lines outline the >2-km depth areas of the Taranaki (TB) and Wanganui (WB) Basins. Blue ellipses indicate locations of Taupo Volcanic Zone (TVZ) and Auckland Volcanic Field (AVF). White lines indicate schist (vertical lines), and Esk Head melange (horizontal lines). b) Earthquake depth distribution (0–470 km depth) illustrates the shape and location of the subducted slab and overlying crustal seismicity. Shown are magnitude 3 and larger earthquakes 2001–2011, relocated with the NZ-wide velocity model (Reyners et al., 2011), subduction thrust at trench (heavy line), active faults, lakes and rivers. c) Broadband stations used for ambient noise, with interstation paths. Dots show locations of grid for 2-D group velocity inversions. d) Stations used for travel-time data. Green lines, locations of cross-sections in Fig. 8. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)