Unraveling the effects of upper plate lithology and stress on seismic velocities at Hikurangi

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The Hikurangi margin, which parallels the East Coast of North Island, New Zealand, is a convergent margin with a prolonged accretionary history. The margin underwent two major phases of convergence, from ~120-85 Ma and ~22 Ma to present, separated by a period of passive margin sedimentation. As a result of this history, the eastern North Island is a 150-200 km wide accretionary wedge, with three major sedimentary units that include (1) an Early Cretaceous metasedimentary basement, (2) Late Cretaceous-Paleogene passive margin sediments, and (3) Miocene-Present sediments that extend to the offshore deformation front (e.g., Bland et al., 2015). Within the overriding plate, where and how transitions between these three units occur remains unclear, particularly in the offshore accretionary prism where lithology could control the permeability and elastic stiffness of the upper plate and have a major impact on subduction earthquakes.

At convergent margin forearcs, seismic velocities typically increase towards the interior of the overriding plate, indicating a variation in compaction and metamorphic grade, or a transition to igneous basement. Active-source seismic tomography and multi-channel seismic imaging results from the SHIRE project indicate distinct structural domains in the northern Hikurangi margin prism (Fig. 1; Gase et al., in review). The outer ~35 km of the overriding plate is a low-velocity frontal prism of off-scraped trench-fill sediments. A network of irregular thrust faults that outcrop at Tuaheni Ridge separates the frontal prism from a higher velocity inner prism. This abrupt landward increase in seismic velocity can be explained by the exhumation of stronger sediments within the hanging wall of the Tuaheni thrust and/or a boundary between stronger Late Cretaceous-Paleogene sediments and weaker Miocene-Present sediments.

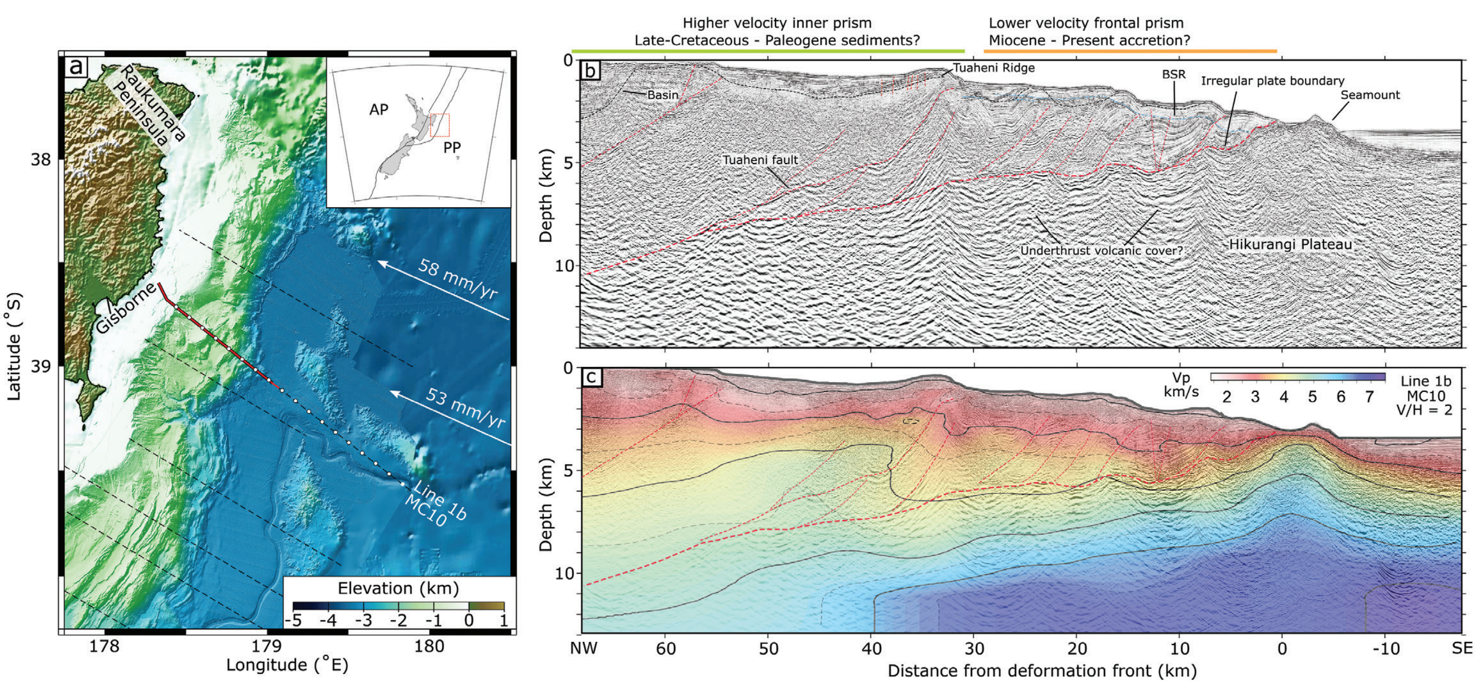

Figure 1. a) Map of SHIRE seismic Line 1b/MC10 (red line), high-resolution bathymetry from NIWA. b) Interpreted seismic reflection image of SHIRE seismic Line 1b/MC10 from Gase et al., (in review) showing faults (red dashes), bottom simulation reflector (blue dashes), and slope cover sediments (black dash). c) Overlain seismic velocity model from joint OBS and streamer tomography and seismic reflection image with fault interpretations.

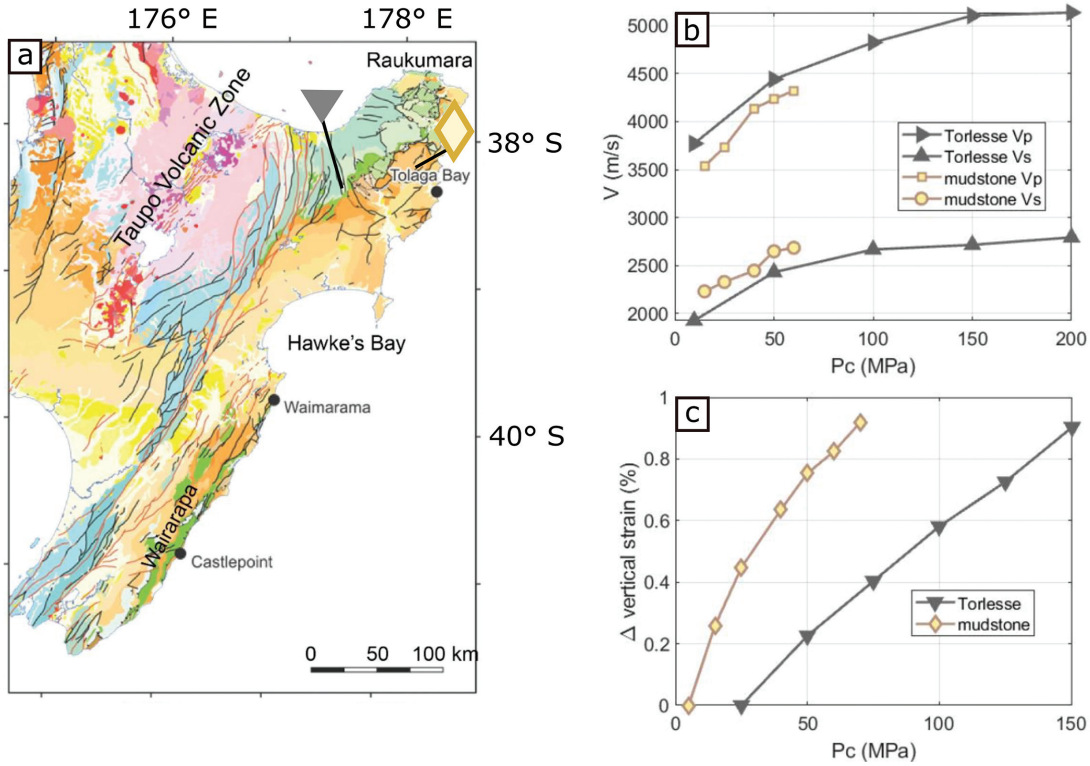

Figure 2. Geologic map of North Island, New Zealand (QMAP, GNS), and measurements on dry samples as a function of confining pressure (Pc). a) Relevant geologic units have the following colors: Early Cretaceous - Turquoise, Late Cretaceous-Paleogene - Green, Miocene-Eocene - Orange. Sample sites for rocks presented in b) (Cretaceous Torlesse graywacke) and c) (Miocene-Eocene mudstone) are indicated by gray inverted triangle and yellow diamond. b) Ultrasonic velocities. c) Relative vertical deformation.

In addition, analyses of seismic traveltimes (Bassett et al., 2014) and ground-motion from the 2017 Kaikoura earthquake (Kaneko et al., 2019) reveal large contrasts along the margin, with faster velocities in the southern margin, and slower velocities in the northern margin. These observations could result from variations in fluid controlled effective stress (Bassett et al., 2014), but may also indicate differences in the extent of upper plate lithologies. Older, stronger, rocks of the Early Cretaceous accretionary wedge could be more prevalent along the southern margin, whereas less consolidated Late-Cretaceous-Paleogene sediments may form the interior of the northern margin.

CRUSH, a new GeoPRISMS funded project, will test the effects of lithology and stress through geomechanical experiments on rocks from across the Hikurangi forearc. Rock samples will be tested under varying confining and fluid pressures, and differential stresses, while measuring ultrasonic velocities, permeability, and strain. Preliminary experiments on dry (1) Cretaceous Torlesse grackwacke from the western Raukumara Peninsula, and (2) Miocene-Eocene Mudstones from near Tolaga Bay show that under increasing confining pressure, the mudstone deforms more, although the two examples exhibit only minor differences in Vp and Vs (Fig. 2). Results of these ongoing experiments will be integrated with seismic tomography and imaging along the Hikurangi margin to help us understand the hydromechanical controls of lithology and its impact on earthquake hazards. ■

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