REVISED GEOLOGICAL MAP OF THE NELSON-RICHMOND URBAN AREA

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The following is modified from the Supplemental File 3 of the paper

Structural evolution, segmentation and activity of the onshore-offshore Waimea-Flaxmore Fault System in south-eastern Tasman Bay, South Island, New Zealand

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New Zealand Journal of Geology and Geophysics

https://doi.org/10.1080/00288306.2023.2260768

This Supplemental File and other related material are available for download using the link: https://doi.org/10.6084/m9.figshare.23612340.v1

The description refers to the “Revised Geological Map of the Nelson-Richmond Urban Area”, and associated Cross Sections, all downloadable from the main web page.

Role of mechanical weakness on selective reactivation of the Waimea-Flaxmore Fault System (W-FFS)

Selective reactivation of individual steep reverse faults of the W-FFS in onshore Nelson and eastern Tasman Bay is potentially related to mechanical weakness of the fault zones and fluid overpressure (cf. Sibson 1985; 1995; Alder et al. 2016). Belts of serpentinites and sheared low-competence units (Otu Ultramafics, Wakapuaka Phyllonite, Patuki Mélange, Figure 1) are interposed between fault-bounded terranes. This setting is also highlighted by the Stokes magnetic anomaly in the Nelson area, with two distinct peaks associated with highly magnetic Dun Mountain Ultramafics and Brook Street Volcanics imbricated along the W-FFS and Pelorus Shear Zone (Wellman 1959; Hatherton 1967; Hunt and Woodward 1971; Hunt 1978).

The low coefficient of friction and low density of serpentinised peridotites (frictional coefficient μ_f = 0.3 and density ρ= 2.4-2.5 g/cm^3 vs. the average μ_f = 0.6 and ρ=2.7 g/cm^3 of continental crustal rocks) facilitate strain localisation, diapiric buoyancy and exhumation in zones of persistent lithospheric weakness where overpressured fluids are eventually channelled (Hirth and Guillot 2013; Festa et al. 2020; Vannucchi et al. 2020).

The Otu Ultramafics intruded in the Lower Permian Brook Street Volcanics emerge in a narrow sliver on D’Urville Island (Waterhouse 1964; Coleman 1966) and are bounded by the Flaxmore Fault (Transect T1 in Ghisetti et al. 2024 and Figure 1).

The serpentinites of the Patuki and Croisilles mélanges, genetically related to subduction processes at the Gondwana margin (Robertson 2019), outcrop in sub-vertical belts with pervasive scaly fabric along the Pelorus Shear Zone (Figure 1). The Pelorus Shear Zone is dextrally offset of c. 480 km by the Alpine and Wairau faults (Wellman 1953) relative to the equivalent Livingstone Shear Zone in Southland, interpreted as a plate-boundary-scale belt of localised, fluid-assisted brittle deformation (Tarling et al. 2019).

Reverse reactivation of the Waimea-Flaxmore Fault System in onshore Nelson (W-FFS) and fluid overpressure

Ghisetti et al. (2024) have reconstructed a different deformation history of the W-FFS from Nelson City to D'Urville Island with decrease of Quaternary activity of the fault system along the eastern margin of Tasman Bay (Figure 1).

Reactivation of individual faults within the structural array depends on multiple factors (e.g. variations in fault geometry, mechanical weakness, fluid overpressure, cf. Sibson 1985; White et al. 1986; Smith et al. 2017). However, the diminishing activity of the W-FFS occurs along strike, for faults that had a coeval history of reverse reactivation in the Miocene (from c. 19 to 7 Ma), maintain similar geometry and orientation in the present-day stress field, and bound the same lithological units.

Figure 1 shows that the along-strike changes in activity of the W-FFS from Nelson City to eastern Tasman Bay occur north of Pepin Island-Cape Soucis, where crosscutting c. E-W dextral faults (Croisilles Fault Zone, Cross Point and D'Urville faults) cause total offset of c. 27 km of the W-FFS.

We interpret the Croisilles Fault Zone, Cross Point and D'Urville faults as the northernmost – and likely - the oldest - strands of the Marlborough Fault System that contributed to accommodate components of dextral transfer across the northern Marlborough crust concurrent with southward migration of the Hikurangi margin (Figure 2).

Geological mapping and paleo-seismic trenching (Johnston 1979; Johnston and Nicol 2013; Fraser et al. 2006; Johnston et al 2022; Wiffin 2023) document activity of the southern strands of the W-FFS in the present-day stress field, with σ_1 oriented c. 295° (Pettinga and Wise 1994; Balfour et al. 2005; Townend et al. 2012). However, the faults have steep dips (>60°) ° suggests that they are not favourably oriented, and close to frictional lock-up (Sibson 1998).

3D seismic velocity models for the northern South Island (Eberhart-Pillips and Bannister 2010) show a significant change in fault-normal Vp/Vs between a transect across northern Marlborough-D'Urville Island (Figure 2B), relative to a transect further south across the Nelson-south Marlborough area (Figure 2C). The transects across Nelson-Marlborough show high Vp/Vs (> 1.75) between the Wairau and W-FFS (Figure 2C), in a volume that extends from the subducted Pacific slab at depth of c. 70 km up to the surface (Eberhart-Phillips and Bannister 2010). This high Vp/Vs anomaly is consistent with overpressured, slab-derived fluids confined in the actively shortened crust, where steep reverse faults are unfavourably oriented for reactivation. Intermittent fault rupture eventually results from high fluid overpressure lowering frictional resistance during tectonic loading (Sibson 2012; Okada et al. 2019).

The demise of Quaternary activity of the W-FFS along eastern Tasman Bay that we ascribe to segmentation by c. E-W dextral faults corresponds with conditions of normal Vp/VS (< 1.72) in the transect across D'Urville Island-north Marlborough (Figure 2B), consistent with hydrostatic fluid conditions and higher intra-crustal permeability (Eberhart-Pillips and Bannister 2010).

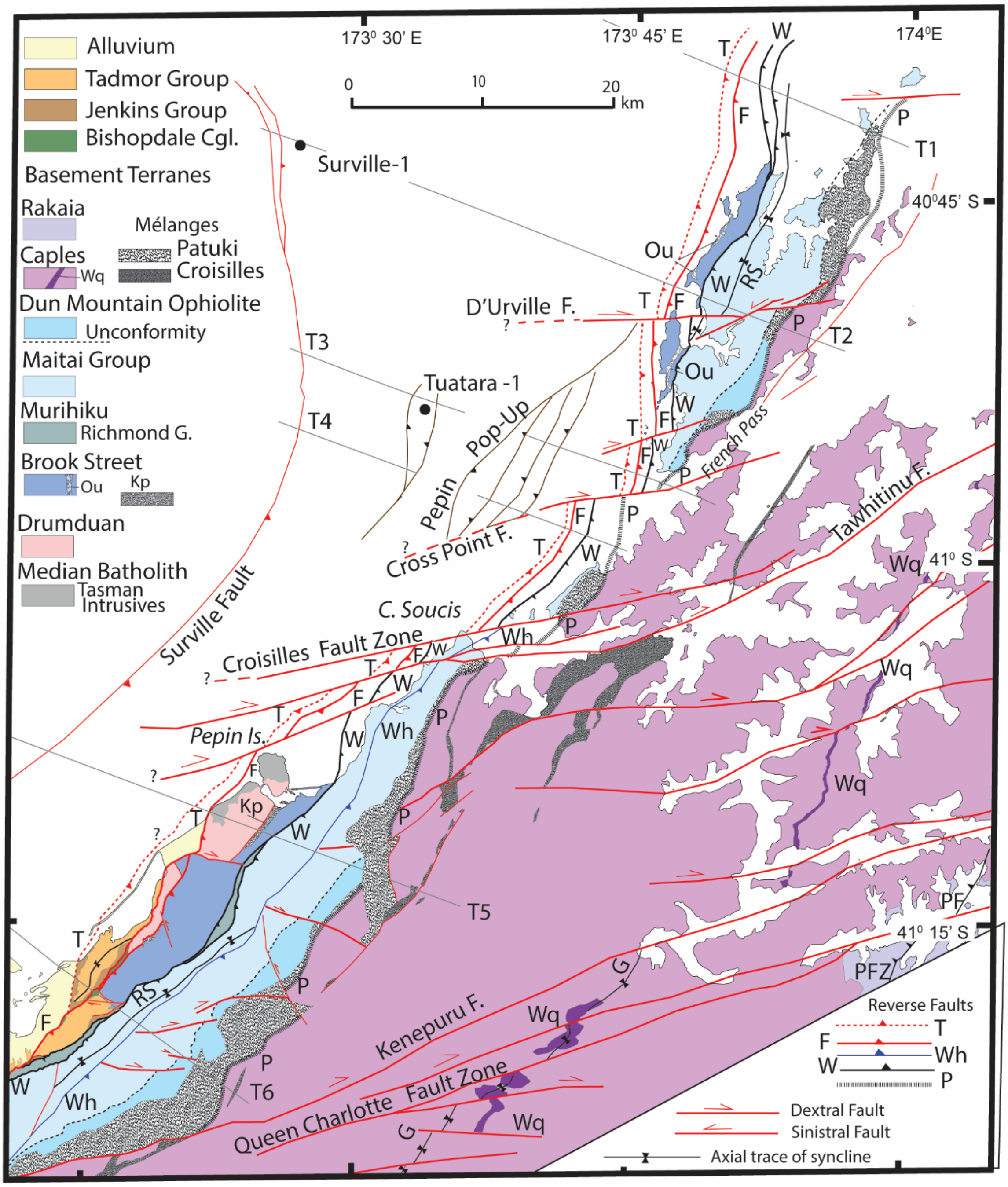

Figure 1 - Interpreted geometry of the W-FFS in Nelson City and Tasman Bay, with the crosscutting Croisilles Fault Zone, Cross Point and D'Urville dextral faults, and associated Malvern-1 and Pepin pop-ups. Traces of T1-T6 of Ghisetti et al. (2024) shown for reference. T: Tahunanui Fault; F: Flaxmore Fault; W: Waimea Fault; Wh: Whangamoa Fault; P: Pelorus Shear Zone (triangles on hanging wall). Inferred fault traces are dashed. Structural markers include the basal unconformity of the Maitai Group; the axial traces of the Roding Syncline (RS) and Goulter Synform (G); the Wakamarina Quartzite (Wq); the Patuki and Croisilles mélanges; the Otu Ultramafics (Ou), the Wakapuaka Phyllonite (Kp), and the Picton Fault Zone (PFZ). Base geology modified from Johnston (1994; 1996); Rattenbury et al. (1998); Begg and Johnston (2000); Johnston et al. (2024).

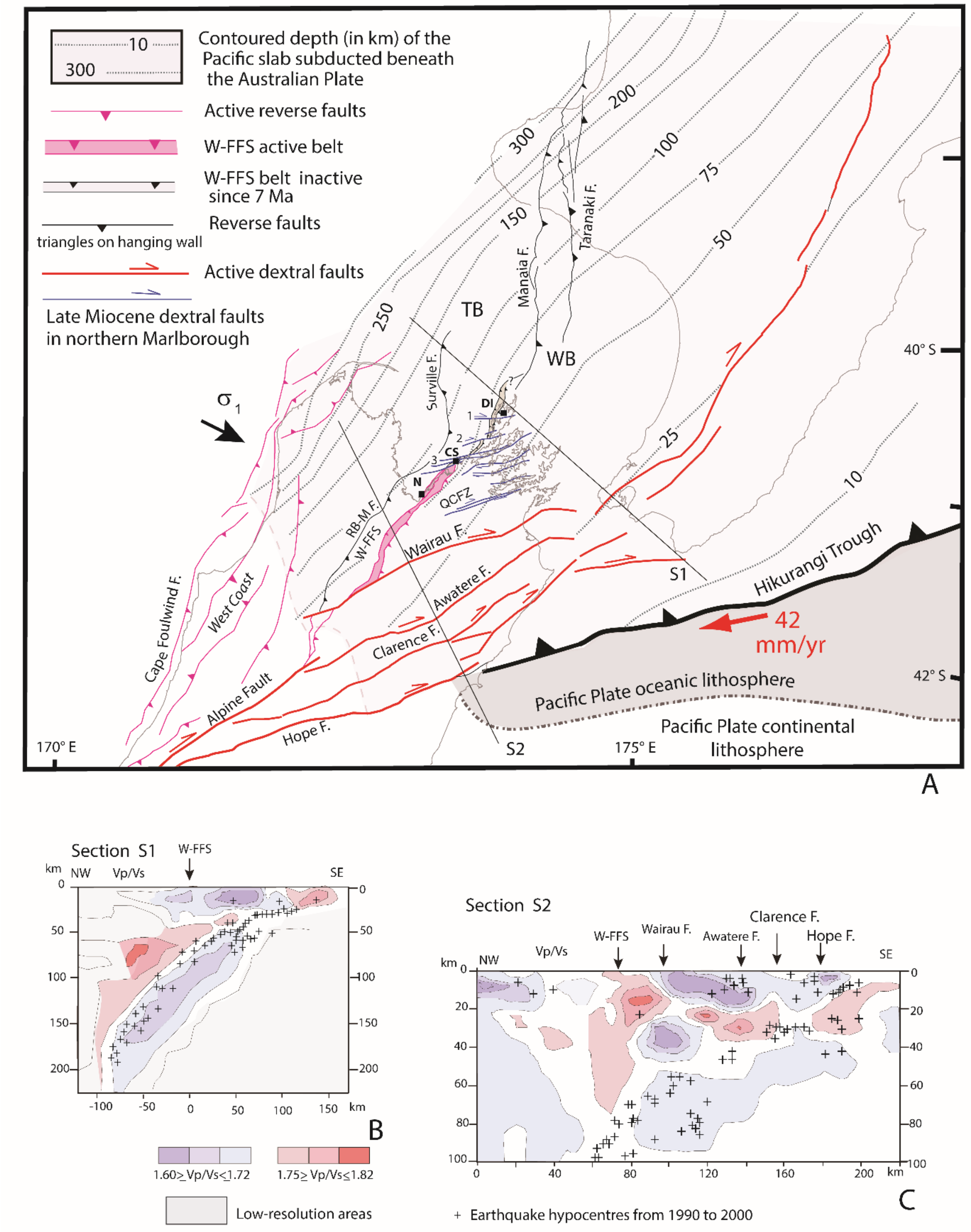

Figure 2. Interpretation of the along-strike variations of activity of the W-FFS within the transition zone from the West Coast-Nelson to the northern Marlborough tectonic domains in the framework of the collisional Australia-Pacific plate boundary. A. Regional setting of the W-FFS redrawn and modified from Ghisetti (2022). Contour depths of the subduction interface after Williams et al. (2013). The red arrow shows the relative motion vector and velocity between the Pacific and Australian plates (from

Wallace et al. 2012). Black arrows show the average direction of the axis of maximum horizontal compressional stress (σ1) from Townend et al. (2012). W-FFS: Waimea-Flaxmore Fault Zone; RB-M F.: Ruby Bay-Moutere Fault; QCFZ: Queen Charlotte Fault Zone. 1: D'Urville Fault; 2: Cross Point Fault; 3: Croisilles Fault Zone. TB: Taranaki Basin; WB: Wanganui Basin. The black squares show the position of Nelson (N), Cape Soucis (CS) and D'Urville Island (DI). **B**. Vp/Vs anomaly along transect S1 (trace in Figure 2A). The position of the inactive Waimea-Flaxmore Fault System is marked by the arrow labelled W-FFS. Redrawn and simplified from Figure 9a of Eberhart-Phillips and Bannister (2010). **C**. Vp/Vs anomaly along transect S2 (trace in Figure 2A). The position of the active Waimea-Flaxmore Fault System (W-FFS) and of the active dextral faults of the Marlborough Fault System are marked by the arrows. Redrawn and simplified from Figure 13B of Eberhart-Phillips and Bannister (2010). Note the different scale of sections S1 and S2.

References

Alder S, Smith SAF, Scott JM. 2016. Fault-zone structure and weakening processes in basin-scale reverse faults: the Moonlight Fault Zone, South Island, New Zealand. Journal of Structural Geology. 91:177-194.

Balfour NJ, Savage MK, Townend J. 2005. Stress and crustal anisotropy in Marlborough, New Zealand: evidence for low fault strength and structure-controlled anisotropy. Geophysical Journal International. 163:1073-1086.

Begg JG, Johnston MR (compilers). 2000. Geology of the Wellington area. Institute of Geological & Nuclear Sciences 1: 250 000 geological map 10. 1 sheet + 64 p. Lower Hutt, New Zealand, Institute of Geological and Nuclear Sciences.

Coleman RG. 1966. New Zealand serpentinites and associated metasomatic rocks (No. 76-77). Dept. of Scientific and Industrial Research, NZ Geological Survey.

Eberhart-Phillips D, Bannister S. 2010. 3D-imaging of Marlborough, New Zealand, subducted plate and strike-slip fault systems. Geophysical Journal International. 182:73-96.

Festa A, Ogata K, Pini GA. 2020. Polygenic mélanges: a glimpse on tectonic, sedimentary and diapiric recycling in convergent margins. Journal of the Geological Society. 177:551-561.

Fraser J, Nicol A, Pettinga J, Johnston M. 2006. Paleoearthquake investigation of the Waimea-Flaxmore Fault System, Nelson, New Zealand. Earthquakes and Urban Development, New Zealand Geotechnical Society 2006 Symposium; Nelson, New Zealand; February 2006. p 59-67.

Ghisetti FC. 2022. Map-view restorations of the South Island, New Zealand: a reappraisal of the last 10 Myr of evolution of the Alpine and Wairau faults. New Zealand Journal of Geology and Geophysics. 65:336-361.

Ghisetti F., Johnston M.R., Wopereis P., Sibson R.H. 2024. Structural evolution, segmentation and activity of the onshore-offshore Waimea-Flaxmore Fault System in south-eastern Tasman Bay, South Island, New Zealand. New Zealand Journal of Geology and Geophysics, https://doi.org/10.1080/00288306.2023.2260768.

Hatherton T. 1967. A geophysical study of Nelson-Cook Strait region, New Zealand. New Zealand Journal of Geology and Geophysics. 10:1330-1347.

Hirth G, Guilliot S. 2013. Rheology and tectonic significance of serpentinites. Elements. 9:107-113.

Hunt TM. 1978. Stokes magnetic anomaly system. New Zealand Journal of Geology and Geophysics. 21:595-606.

Hunt TM, Woodward DJ. 1971. Gravity and magnetic measurements in the South Taranaki Bight, New Zealand. New Zealand Journal of Geology and Geophysics. 14:46-55.

Johnston MR. 1979. Geology of the Nelson urban area 1:25,000. 1st ed. New Zealand Geological Survey. Urban Series Map 1, Map 1 sheet, notes 52 p., Wellington (NZ): Department of Scientific and Industrial Research.

Johnston MR. 1994. Geology of the Richmond Range. Scale 1:50,000. Institute of Geological & Nuclear Sciences geological map 12. 1 sheet + 32 p. Lower Hutt, New Zealand, Institute of Geological & Nuclear Sciences Ltd.

Johnston MR, Nicol A. 2013. Assessment of the location and paleoearthquake history of the Waimea-Flaxmore fault system in the Nelson-Richmond area with recommendation to mitigate the hazard arising from fault rupture of the ground surface. GNS Science Consultancy Report 2013/186; 28 p.

Johnston MR, Ghisetti FC, Wopereis P. 2024. Revised Geological Map of the Nelson-Richmond Urban Area and associated Cross Sections, v4. DOI: 10.6084/m9.figshare.26170315.

Okada T, Iio Y, Matsumoto S, Bannister S, Ohmi S, Horiuchi S, Sato T, Miura T, Pettinga J, Ghisetti F, Sibson RH. 2019. Comparative tomography of reverse-slip and strike-slip seismotectonic provinces in the northern South Islan, New Zealand. Tectonophysics. 765:172-186.

Pettinga JR, Wise DU. 1994. Paleostress adjacent to the Alpine Fault: broader implications from fault analysis near Nelson, South Island, New Zealand. Journal of Geophysical Research 99:2727-2736.

Rattenbury MS, Cooper RA, Johnston MR (compilers) 1998. Geology of the Nelson area. Institute of Geological & Nuclear Sciences 1: 250, 000 geological map 9. 1 sheet + 67 p. Lower Hutt, New Zealand, Institute of Geological and Nuclear Sciences.

Robertson AHF. 2019. Patuki and Croisilles melanges in South Island, New Zealand: genesis related to Permian subduction-accretion processes. In Robertson AHF (Editor) Paleozoic-Mesozoic Geology of South Island, New Zealand: Subduction-related Processes Adjacent to SE Gondwana. London: Geological Society London Memoirs. 49:119-156.

Sibson RH. 1985. A note on fault reactivation. Journal of Structural Geology. 7:751-754.

Sibson RH. 1995. Selective fault reactivation during basin inversion: potential for fluid redistribution through fault-valve action. Geological Society of London, Special Publication. 88:3-19.

Sibson RH. 1998. Dip range for intracontinental reverse fault ruptures: truth not stranger than friction? Bulletin of the Seismological Society of America. 88:1014-1022.

Sibson RH. 2012. Reverse fault rupturing: competition between non-optimal and optimal fault orientations. In Healy D, Butler RWH, Shipton ZK, Sibson RH (Editors). Faulting, Fracturing and Igneous Intrusion in the Earth's crust. Geological Society of London Special Publication. 367:39-50.

Smith SAF, Teser T, Scott JM, Collettini C. 2017. Reactivation of normal faults as high-angle reverse faults due to low frictional strength: experimental data from the Moonlight Fault Zone, New Zealand. Journal of Structural Geology. 105:34-43.

Tarling MS, Smith SAF, Scott JM, Rooney JS, Viti C, Gordon KC. 2019. The internal structure and composition of a plate-boundary-scale serpentinite shear zone: the Livingstone Fault, New Zealand. Solid Earth. 10:1025-1047.

Townend J, Sherburn S, Arnold R, Boese C, Wood L. 2012. Three-dimensional variations in present-day tectonic stress along the Australia-Pacific plate boundary in New Zealand. Earth and Planetary Science Letters. 353-354:47-59.

Vannucchi P, Morgan JP, Polonia A, Molli G. 2020. The life cycle of subcontinental peridotites: from rifted continental margins to mountains via subduction processes. Geology. 48:1154-1158.

Wallace LM, Barnes P, Beavan J, Van Dissen R, Litchfield N, Mountjoy J, Langridge G, Lamarche G, Pondard N. 2012. The kinematics of a transition from subduction to strike-slip:an example from the central New Zealand plate boundary. Journal of Geophysical Research. 117:B02405.doi: 10.1029/2011JB008640.

Waterhouse JB.1964. Permian stratigraphy and faunas of New Zealand. New Zealand Geological Survey Bulletin. 72.

Wellman HW. 1953. Data for the study of recent and late Pleistocene faulting in the South Island of New Zealand. New Zealand Journal of Science and Technology. 34:270-288.

Wellman HW. 1959. Geological interpretation of airborne magnetometer observations from Nelson to Waikato River, New Zealand. Geological Magazine. 96:118-124.

White SH, Bretan PG, Rutter EH. 1986. Fault-zone reactivation: kinematics and mechanisms. Philosophical Transactions of the Royal Society. 317:81-97.

Wiffin R. 2023. Active faulting and hazards of the Waimea-Flaxmore Fault System, Nelson, New Zealand. [Unpublished MSc. thesis]. University of Canterbury, New Zealand.

Williams CA. Eberhart-Phillips D, Bannister S, Barker DHN, Henrys S, Reyners M, Sutherland R. 2013. Revised interface geometry for the Hikurangi subduction zone, New Zealand. Seismological Research Letters. 84:1066-1073.