REVISED GEOLOGICAL MAP OF THE NELSON-RICHMOND URBAN AREA

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Principal faults of the Waimea-Flaxmore Fault System and associated structures

In the Nelson-Richmond urban area the principal faults of the Waimea-Flaxmore Fault System (W-FFS) have NE-SW strike and dip at moderate to steep angles to the SE. There are no seismic data that can be used to infer any change in fault dip with depth, and the cross sections associated with the "Revised Geological Map of the Nelson-Richmond Urban Area" tentatively depict steep to moderately-dipping faults in the basement down to depths of c. 5 km.

In the following we describe the principal structural features of individual faults of the W-FFS (from the structurally highest to the lowest) and associated folding.

Eighty-eight and Waimea faults and associated splays

The sub-parallel to obliquely intersecting Eighty-Eight and Waimea reverse faults (together with a number of unnamed splays in the footwall of the Waimea Fault) imbricate basement rocks and the oldest formations of the sedimentary succession (Bishopdale Conglomerate and Eocene Coal Measures) above the formations of the Tadmor Group in the Nelson-Richmond urban area. The faults strike NE-SW and are generally steeply dipping (c. 65°-70°) to the SE, though some fault splays dip at shallower angles (c. 30°-45°, Figures 7B-C). Reverse separation of the top basement unconformity along the Waimea Fault is c. 3 km in Nelson city, decreasing to 2 km c. 25 km southwest of the mapped area (Ghisetti et al. 2018). Reverse slip appears to be dominant, but dextral offset of Quaternary terrace risers of c. 40 m has been reported by Johnston (1983) for segments of the Waimea Fault c. 20 km SW of the mapped area (between the Motueka River and Quail Valley).

The Eighty-Eight Fault is the uppermost fault splay, superposing Maitai Group over Richmond Group. The Waimea Fault imbricates the Richmond Group over Marsden Coal Measures and, with its footwall splays, superposes basement rocks and Marsden Coal Measures above the Port Hills

and Moutere gravels (Figures 3 and 4). New exposures in the foothills of the Barnicoat Range have revealed a tectonic wedge of Bishopdale Conglomerate interposed between the Richmond Group and the Marsden Coal Measures in the footwall of the Waimea Fault.

To the NE of upper Jenkins Creek the Eighty-Eight and Waimea faults converge into one single strand which superposes the Maitai Group units over Marsden Coal Measures. The largest stratigraphic separation is documented along the foothills of the Barnicoat Range, where the Richmond Group overthrusts the Moutere Gravel or, in the north, the Port Hills Gravel.

An unusual tectonic setting is shown in the down-faulted wedge along the upper course of The Brook and at Tantragee Saddle, where Marsden Coal Measures are interposed between the normal Jenkins Fault to the NW and the reverse Waimea Fault to the SE. The two faults are sub-parallel and, at a maximum, only few hundred metres apart, but the Waimea Fault truncates the Jenkins Fault, with superposition of Maitai Group units above Brook Street Volcanics and the Marsden Coal Measures.

Holocene-active traces along preserved fault scarps of the Waimea Fault have been identified c. 6 km along-strike SE of the mapped area, in the Wairoa Gorge. A 1-2 m high late Quaternary scarp along the Eighty-Eight Fault has also been identified in the Barnicoat Range (Johnston and Nicol 2013), but the geomorphic escarpment indicates normal (up-slope down), rather than reverse slip displacement. Paleo-earthquake investigations (Fraser 2005; Johnston and Nicol 2013) have exposed ruptures to three major events in the last 20 kyrs, with cumulative fault scarp height of c. 3.5 m, and average slip rate of c. 0.2 mm/yr. The youngest rupture is dated c. 5 kyrs BP.

Flaxmore Fault

In Nelson city the Flaxmore Fault comprises a zone of imbrication with two major NE-striking SE-dipping fault splays between Jenkins Creek and The Brook. North of the Maitai River, the sub-parallel intra-basement Delaware Fault (with the associated shear zone of the Wakapuaka Phyllonite) is c. 1 km to the SE, and has been mapped to converge southwestwards to almost the Flaxmore Fault at the mouth of the Maitai valley. Multiple fault splays along the Flaxmore Fault are also recognised at the southern end of the Moutere Depression (Johnston 1990; Rattenbury et al. 2006), where distinct fault strands mapped 5-6 km west of the Waimea Fault converge into the Alpine Fault.

The Flaxmore Fault has the largest reverse separation north of the Maitai River, where Drumduan basement is thrust above the Port Hills Gravel. From north of the Maitai River to the intersection with the sub-orthogonal Grampian Fault the Flaxmore Fault superposes Drumduan or Brook Street basement rocks above Bishopdale Conglomerate. An abrupt along-strike change in separation occurs south of the Grampian Fault, with younger Port Hills Gravel in the hanging wall juxtaposed against older units (Bishopdale Conglomerate and Jenkins Group) in the footwall. The contact of younger over older along the SE-dipping fault is mapped from Jenkins Creek southward to Marsden Valley and Orphanage Creek, consistent with normal slip components along this strand of the Flaxmore Fault. However, net reverse separation is again apparent south of Orphanage Creek, with superposition of outcropping Port Hills Gravel onto Moutere Gravel and overlying Quaternary gravels. A distinct 1-2 m high escarpment several hundred metres in length can be traced across the Quaternary gravel by LiDAR imagery and is here interpreted as the southernmost trace of the Flaxmore Fault in the mapped area.

The major footwall splay of the Flaxmore Fault (West Flaxmore Fault) is mapped between the Maitai River and Jenkins Creek, where Bishopdale Conglomerate is thrust above vertical to overturned units of the Jenkins Group along the south limb of the Port Hills Syncline. The West Flaxmore Fault joins the main strand of the Flaxmore Fault south of Jenkins Creek.

Persistent activity of the Flaxmore Fault in the Quaternary is compatible with the prominent morphological scarp and aligned springs (Johnston 1979). Between Bishopdale and Jenkins Creek the fault dextrally offsets ridge crests by 25-30 m (Johnston 1981; 1983). Largely continuous Holocene-active strands are documented along the southernmost part of the W-FFS (Rattenbury et al. 2006), commencing about at the Wairoa River (3 km southwest of the mapped area). Paleoseismic trenches Bishopdale indicate a last surface-rupturing event dated at c. 5600 yrs BP, i.e. largely coeval with the youngest event identified for the Waimea Fault (Fraser 2005).

The wedge bounded by the Waimea and Flaxmore faults is intersected by two faults with E-W to WNW-ESE strikes (Bishopdale and Grampian faults). The Bishopdale Fault offsets the Port Hills Gravel with both dip-slip (south side down) and dextral strike-slip movements (c. 30 m of ridge crest separation) with paleoseismic evidence of Holocene activity (Bruce 1962; Fraser 2005; Johnston and

Nicol 2013). The Grampian Fault down-throws the Port Hills Gravel relative to the Brook Street Terrane. Neither fault appears to truncate the traces of the NE-SW Waimea and Flaxmore Faults.

Tahunanui Fault

The Tahunanui Fault is a newly named NE-SW-striking reverse fault of the W-FFS. The fault truncates and uplifts the north-western flank of the Port Hills Syncline, but is concealed beneath late Quaternary marine and terrestrial deposits at Tasman Bay and in the coastal plain between Tahunanui and Stoke.

The presence of the fault is required by the geometric superposition of steeply SE-dipping beds of the Magazine Point Formation above Moutere Gravel encountered beneath 20-40 m of late gravels by a number of boreholes (http://www.nzgd.org.nz). There is no evidence of a Quaternary surface escarpment, but the topographic erosional surface above the hanging wall units is c. 200 m higher than in the footwall.

The location of the available boreholes loosely constrains the fault trace projected to the surface, and its inferred convergence with the Flaxmore Fault south of Stoke is uncertain.

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Folds in the cover sequences

The units of the Jenkins Group, together with the overlying Port Hills Gravel and their basal unconformity are folded into the tight Port Hills Syncline, with a NE-SW axial trace. The north-western limb of the syncline dips at moderate to steep angle to the SE in the hanging wall of the Tahunanui Fault. The south-eastern limb dips steeply (55˚-75˚) to the NW, and is locally overturned (dipping c. 50˚-80˚ SE) beneath the West Flaxmore Fault.

Close to the mouth of the Maitai River the Port Hills Gravel and the axial trace of the Port Hills Syncline disappear beneath Quaternary alluvium, with possible truncation by a WNW-ESE fault, inferred from a topographic scarp. The Port Hills Gravel exposed north of the Maitai River dips gently to the SE, suggesting that the fold axial trace and SE limb are shifted to the NE and overthrust by Drumduan rocks along the Flaxmore Fault. The SW closure of the core of the Port Hills Syncline with exposure of the older beds of the Jenkins Group is compatible with northward plunge and truncation of the axial trace in the panel bounded by the Tahunanui and West Flaxmore faults.

South of the Grampian Fault, the Port Hills Gravel dips to the SE and is morphologically uplifted relative to the SE flank of the Port Hills Syncline in the hanging wall of the Flaxmore Fault. The gravel is overthrust by the Marsden Coal Measures and Richmond Group in the hanging wall of the Waimea Fault. In Johnston (1979) the Port Hills Gravel within this panel was mapped as folded within the symmetrical Marsden Syncline. However, the SE dip of beds shows that the outcropping Port Hills Gravel belong to a wide western flank of the syncline, whose axial trace lies further east, very close to - and truncated by - the Waimea Fault. Thus, the NW-dipping limb of the Marsden Syncline is almost entirely truncated and only exposed north of Jenkins Creek (as inferred from the basal contact of the Port Hills Gravel above the Brook Street Volcanics) and between Marsden Valley and Orphanage streams (as inferred from the change in bed dip to the NW).

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