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REVISED GEOLOGICAL MAP OF THE NELSON-RICMOND URBAN AREA

M.R. Johnston, F. Ghisetti, P. Wopereis 2021

This document describes the major units mapped in the Nelson-Richmond urban area. The reader is referred to Johnston (1979; 1981; 1982; 1984; 1990; Johnston et al. 1987; Rattenbury et al. 1998) for more detailed descriptions and comprehensive reference lists.

Basement rocks

The basement rocks in outcrop in the Nelson-Richmond area belong to a stack of thrust sheets that imbricate Eastern Province terranes onto the Median Batholith. The terranes were accreted at the Paleozoic-Early Cretaceous convergent margin of Gondwana prior to Late Cretaceous rifting (110-85 Ma), with opening of the Tasman Sea (Mortimer et al. 2017). The basement units and their boundaries dip steeply, a likely consequence of a long history of superposed deformation, from Late Cretaceous extensional rifting to Neogene-Quaternary rotation, shortening and uplift.

The sedimentary cover within the Moutere Depression and in the Nelson-Richmond area largely masks the contact between the Carboniferous-earliest Cretaceous intrusions of the Median Batholith and the Permian-Mesozoic Eastern Province terranes uplifted in the hanging wall of the Waimea-Flaxmore Fault System (W-FFS). Oil exploration wells in the Moutere Depression ((Tapawera-1, Ruby Bay-1) and its offshore extension (Surville-1, Tuatara-1, http://www.nzpam.govt.nz) have reached Late Jurassic-Early Cretaceous diorites (Rotoroa Complex) and Early Cretaceous granitoids (Separation Point Suite) belonging to the Median Batholith. Lat Triassic- volcano-sedimentary assemblages intruded by Early Cretaceous granodiorites of the Median Batholith (Tasman Intrusives) have been recognised within the Drumduan Terrane. This terrane is the structurally lowest unit of the Eastern Province outcropping in the mapped area. The tectonic contact with the structurally overlying units of the Brook Street Terrane (Permian volcanic arc rocks) is the Delaware Fault, a reverse fault within the Delaware-Speargrass Fault Zone (Johnston 1981). A belt of highly tectonised and foliated rocks and breccias exposed locally along the Delaware Fault (Wakapuaka Phyllonite, Late Jurassic-Early Cretaceous?) is interposed between the two accreted terranes.

The tectonic superposition of the Murihiku Terrane above the Brook Street Terrane is mapped throughout New Zealand (Edbrooke 2017).

In the Nelson-Richmond urban area, rock units of the Murihiku Terrane (Upper Triassic sandstones, siltstones and conglomerates of the Richmond Group, with andesitic dykes) are discontinuous and reduced to a narrow tectonic slice in outcrop in the south of the mapped area. At its base (between Richmond and Jenkins Creek) the slice is thrust above Paleogene-Neogene rocks along the Waimea Fault. At its top it is overthrust by the Dun Mountain-Maitai Terrane along the Eighty-Eight Fault. In upper Jenkins Creek, the Waimea and Eighty-Eight faults converge into one strand, with lateral closure of the Richmond Group and direct tectonic superposition of the Maitai Group above Brook Street Volcanics. Thus, in the mapped area there is no contact of the Richmond Group above the Brook Street Volcanics. However, sheared wedges of the Richmond Group between Brook Street and Maitai units are present to the northeast of the mapped area (Johnston 1981) and are inferred to lie beneath the Waimea Fault at depth (see cross sections). The Late Permian to Middle Triassic units of the Maitai Group uplifted in the hanging wall of the Eighty-Eight and Waimea faults belong to the highest imbricate sheet of basement rocks in the mapped area.

Late Mesozoic and Cenozoic sedimentary units

The following description employs international ages; the equivalent New Zealand chronology is provided in the stratigraphic column and used for the legend of the geological map.

The stratigraphy in the Nelson-Richmond urban area and its environs records: (1) deposition of terrestrial clastic units within fault-controlled basins during pulses of rifting in late Early Cretaceous (c.105-83 Ma) and Late Cretaceous-Paleocene (c. 80-55 Ma). (2) Unconformable deposition of post-rift Paleogene sequences transitioning from terrestrial coal measures (c. 37-35 Ma) to transgressive marine units (c. 35-25 Ma) within subsiding basins. (3) Dominant silicic-clastic sedimentation at c. 25-22 Ma, with likely tectonic control on the position of turbiditic depocentres relative to adjacent shelves. (4) Sedimentary hiatus at c. 20-10 Ma, coeval with convergent tectonism along the Pacific-Australian plate boundary. (5) Progressive shortening and uplift since the late Miocene, accommodated by reverse faulting and folding, with erosion of the sedimentary cover and subsidence in syn-compressional depocentres infilled with regressive terrestrial sequences. A variety of depositional environments with local and far-field source areas, ongoing tectonism and the strong climatic control during the latest

Pleistocene to late Quaternary glacial events are all factors controlling large variations in facies, particularly composition and clast size, of the late Neogene and Quaternary terrestrial

The basement units and the formations of the Jenkins and Tadmor groups are briefly described as follows.

Bishopdale Conglomerate (late Early Cretaceous ?)

The inferred oldest formation of the sedimentary cover sequence in the Nelson-Richmond urban area is the Bishopdale Conglomerate. It comprises sub-vertical, sheared conglomerate and breccia embedded in a rusty-red, shaly matrix. The clasts include diorites, volcaniclastic sandstones, mafic lavas, andesites and ignimbrite, all suggesting local provenance from the Median Batholith, Brook Street and Drumduan rocks.

Discontinuous outcrops of the Bishopdale Conglomerate (together with a dissimilar conglomerate that we now attribute to the Kawai Formation, see below), were originally mapped by Johnston (1979) as part of the Late Eocene-Early Oligocene Bishopdale Formation. The Bishopdale Conglomerate was subsequently shown (Johnston 1981) to be much more extensive. Johnston (1984) re-appraised the formation as being of likely late Early Cretaceous age and correlative of the Beebys Conglomerate (Johnston 1983; 1990). The Beebys Conglomerate comprises interbedded sandstone, siltstone and conglomerate with carbonaceous lenses. These deposits unconformably overlie Brook Street rocks in the hanging wall of the Flaxmore Fault at the southern end of the Moutere Depression. Plant fossils date the formation as late Early Cretaceous (c. 100-90 Ma, Johnston

Earthworks, particularly in the Bishopdale area (crossed by section line 3), have confirmed that the Bishopdale Conglomerate is continuous over a length of c. 5 km, but many outcrops have since been obliterated by ongoing urban development. In central Nelson the formation is largely concealed beneath alluvial deposits, but is exposed close to the Flaxmore Fault at the northern end of the Grampians, and has been intersected by a borehole at depth of 19 m on the NE side of the lower Maitai River. Similar deposits are also exposed on the south bank of Marsden Valley and Orphanage Creek, in Stoke. The formation is tectonically interposed between the sub-parallel strands of the West Flaxmore and

Flaxmore faults, with no preserved stratigraphic relations with the Brook Street rocks in the hanging wall and the Eocene-Paleogene formations in the footwall.

Outcrops of the Bishopdale Conglomerate have also been exposed in trenches (Wopereis 2011) recent excavations along the Waimea Fault near Richmond, where the unit is tectonically interposed between the Richmond Group and Eocene coal measures.

Eocene Marsden Coal Measures (basal terrestrial formation of the Jenkins Group)

The Eocene Marsden Coal Measures are the oldest formation of the Jenkins Group, consisting of terrestrial, poorly-bedded quartz-rich sandstones and mudstones with interlayered coal seams. The formation is tectonically bounded by the Waimea Fault and sub-parallel fault splays in its footwall, with sheared, steeply-dipping beds between basement (Richmond and Maitai groups) and Bishopdale Conglomerate in the hanging wall and Late Miocene-Pliocene Port Hills Gravel and Moutere Gravel in the footwall. Small outcrops of Marsden Coal Measures are also overthrust by Bishopdale Conglomerate along the West Flaxmore Fault in Bishopdale (north of section line 3).

There is no clear exposure of the base unconformity of the Marsden Coal Measures,. The contact with Brook Street terrane units occurs along sets of normal faults (Jenkins Fault and minor faults east of Marsden Valley and close to the trace of section 4). At the top, the stratigraphic contact with the overlying Braemar Formation was temporarily exposed south of Braemar Hospital during urbanisation (Johnston 1979).

To the NE of Jenkins Creek, along the upper course of The Brook, and at Tantragee Saddle (between the Brook and Maitai valleys), the Marsden Coal Measures are overthrust by Maitai Group along the Waimea Fault and downfaulted against Brook Street Volcanics along the steep, SE dipping Jenkins Fault.

Paleogene to early Neogene marine formations of the Jenkins

The marine formations of the Jenkins Group include (from base to top) the Braemar (late Eocene), Kawai (Late Eocene to Early Oligocene), Wakatu (late Oligocene) and Magazine Point (Late Oligocene to Early Miocene) formations. The newly named Kawai Formation introduced here comprises a conglomeratic unit that was previously included in the Bishopdale Formation (now Bishopdale Conglomerate). The Kawai Formation was well exposed in the 1970's adjacent to Kawai Street and in a temporary cutting in nearby Motueka Street. It is now poorly exposed in a single outcrop in the courtyard of Nelson Hospital.

The facies and chrono-stratigraphy of the Jenkins Group track the Eocene to Early Oligocene evolution of depositional environments (Johnston 1979) from lagoonal-deltaic and shallow marine to calcareous-rich shelf (Wakatu Formation). The onset of terrigenous input is recorded by the proximal siliciclastic turbidites and debris flows of the Magazine Point Formation. The flows contain fossiliferous, andesitic and intrusive clasts (e.g. at Arrow Rock). The substantial age overlap of the Wakatu and Magazine Point formations (Johnston 1979) can be interpreted in terms of a lateral facies transition between shelf and upper slope environments that persisted throughout the late Paleogene-early Neogene (Ghisetti et al. 2018). However, because of a lack of exposure, the relationship between Wakatu and Magazine Point formations is unconstrained.

The formations of the Jenkins Group are exposed mainly on the flanks of the Port Hills Syncline. Except for the Magazine Point Formation, all of the units are exposed in the vertical to overturned south flank of the syncline, in the footwall of the West Flaxmore Fault. On the opposite steeply SE-dipping only the Magazine Point Formation crops out. The formation is well exposed along the coastline and at Tahunanui. The basal contact of the Magazine Point Formation presumably underlies the Port Hills Gravel in the core of the syncline. The formations of the Jenkins Group exposed in Nelson are likely to extend westwards beneath the thick succession of late Miocene to Quaternary gravels within the Moutere Depression. The sedimentary succession is eroded in the hanging wall of the Flaxmore and Waimea faults, but a pocket of Wakatu Formation is preserved in the down-faulted wedge between the Waimea and Jenkins faults at Tantragee

Late Miocene and Plio-Quaternary terrestrial formations of the Tadmor

Following a c. 10 Myrs-long hiatus, the terrestrial Port Hills Gravel was deposited unconformably above the Jenkins Group and basement rocks in the late Miocene-earliest Pliocene.

In the mapped area, the Port Hills Gravel is exposed in the core of the Port Hills Syncline (in the footwall of the West Flaxmore Fault) and in a dominantly SE-dipping panel in the hanging wall of the Flaxmore Fault and footwall of the Waimea Fault. The Port Hills Gravel contains rounded clasts with dimensions ≤ 900 mm across. The gravel is matrix-supported, locally bedded and interlayered with claystone, mudstone and siltstone. Microflora within sparse carbonaceous lenses dates the formation to the Late Miocene-Early Pliocene (Johnston 1979). Locally the gravel is clast-supported and coarsely bedded, with poorly-sorted pebbles and boulders. These variations likely result from distinct depositional environments (braided rivers, fluvial channels, swamps, alluvial fans, debris flows).

The lower part of the formation is dominated by clasts sourced from the Median Batholith. Recently exposed outcrops at the southern end of the Port Hills Syncline, close to the base of the formation, contain relatively abundant granite and granodiorite boulders of likely derivation from the Separation Point and Rotoroa Complex, with rarer sandstones of the Richmond Group. While the igneous parent rocks are now only exposed west of the Moutere Depression, at the time of deposition the intra-Moutere structural high (Ghisetti et al. 2018) might also have been a source. Contributions from basement units now exposed in the hanging wall of the Flaxmore and Waimea faults (Richmond and Maitai sandstones and siltstones, Brook Street Volcanics and, rarely, Dun Mountain Ophiolite) increase in the upper part of the formation. In the immediate footwall of the Waimea Fault the exposed top of the formation contains pebbles dominantly derived from the Richmond and Maitai groups.

Following another hiatus, terrestrial sedimentation resumed with deposition of the predominantly greywacke-derived Moutere Gravel. The formation is exposed in narrow north-trending ridges eroded by the Holocene river network south-east of Richmond, where it is overthrust by the Waimea Fault. To the north, subsurface continuity of the Moutere Gravel beneath late Quaternary deposits is testified by several boreholes (http://www.nzgd.org.nz).

Within the Moutere Depression the formation consists of weathered clasts of Torlesse-derived sandstones (Rakaia Terrane) and rarer quartz and chert and, in the southwest, semi-schists, embedded in a yellow-brown silty-clay matrix. Coarser sandstone clasts of local provenance from the Maitai and Richmond groups are rare. Bedding is generally absent, though locally revealed by sandy interlayers. The Torlesse clasts point to a provenance from the Spenser Mountains, south of the Alpine Fault, with transport in alluvial fans. These deposits are only preserved within the Moutere Depression, but they probably covered a much larger area prior to the development of the depression (Ghisetti et al. 2018).

The base of the Moutere Gravel is not exposed in the Nelson-Richmond urban area, but in the adjacent Moutere Depression the formation conformably overlies the gravels of the Glenhope Formation (Johnston 1971; Ruby Bay-1, Tasman Petroleum Corporation Ltd 1966) of inferred Late Miocene (?)-Early Pliocene age. In the Moutere Depression the Glenhope Formation and Moutere Gravel unconformably overlie both basement and Cenozoic units. In the mapped area, the Moutere Gravel is either tectonically overlain by the Port Hills Gravel or buried beneath late Quaternary deposits. However, at the southern edge of the Moutere Depression the Moutere Gravel is unconformably overlain by glacial deposits of the Late Pliocene-Early Pleistocene (2.2-2.1 Ma) Porika Formation. Together with palynologic sampling (Mildenhall and Suggate 1981), these relationships indicate a probable Late Pliocene-Early Pleistocene age for the Moutere Gravel.

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