geological map 9

GEOLOGY OF THE NELSON AREA

M.S. RATTENBURY
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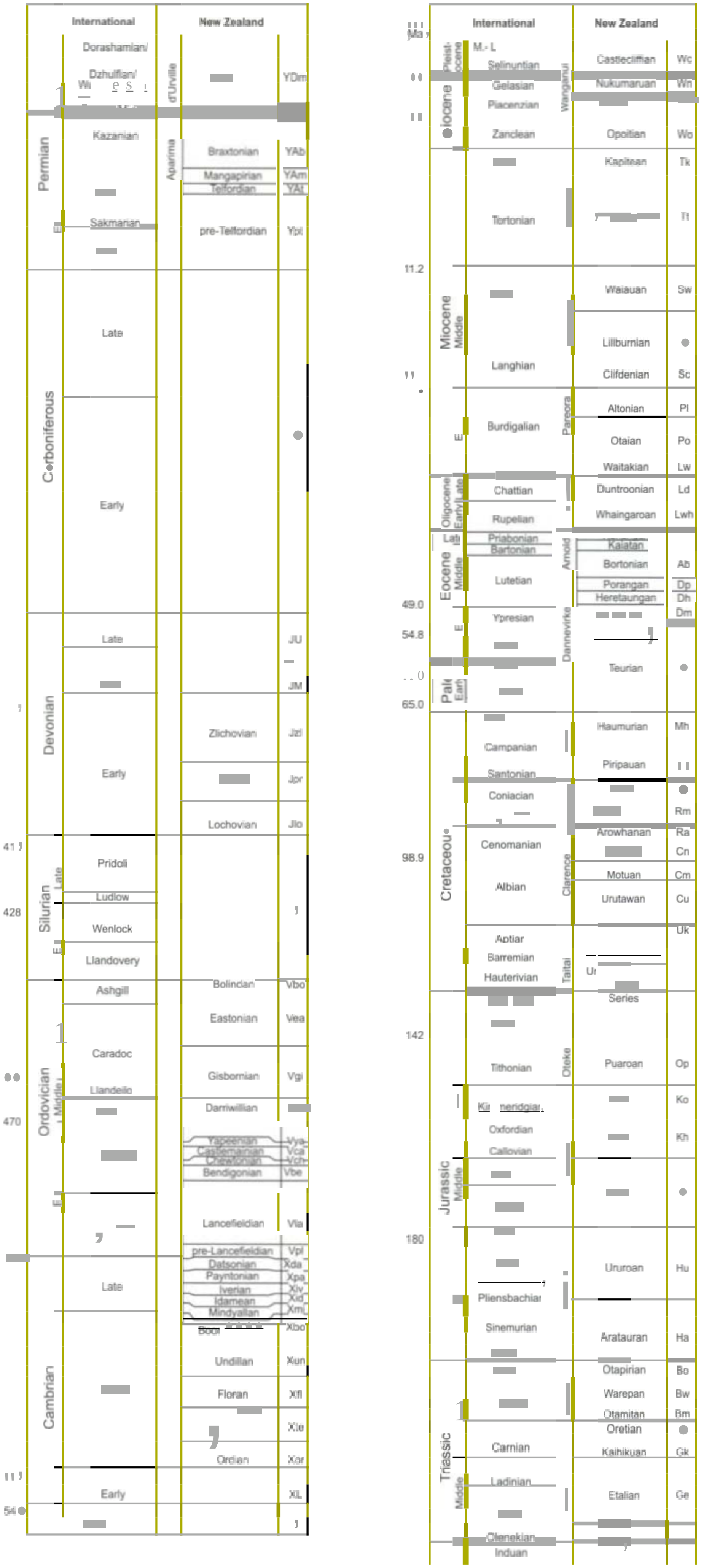
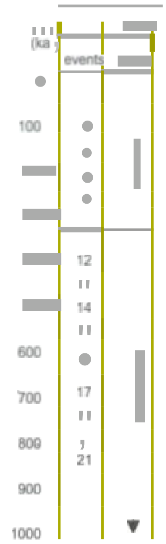
M.R.JOHNSTON
(COMPILERS)

Institute of GEOLOGICAL & NUCLEAR SCIENCES Limited





Interim New Zealand geological time scale from Crampton & others (1995), with geochronology after Gradstein & Ogg (1996) and Imbrie & others (1984).

GEOLOGY OF THE NELSON AREA

Scale 1:250 000

M.S. Rattenbury
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Institute of Geological & Nuclear Sciences 1:250000 geological map 9

Institute of Geological & Nuclear Sciences Limited
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FRONTCQVER

Nelson City lies in the foothills between the Permian to Cretaceous basement terranes of the Bryant Range (left) and the thick Pliocene 10 Quatemary sediments that have been down-faulted to form the Moulere Depression (right). The city area also contains remnants of a succession of Eocene to Miocene sedimentary rocks. Widespread Mesozoic and Cenozoic faulting, including presently active faults of the Waimca·Flaxmore Fault System. have disrupted the older rocks and locally influenced the deposition of younger sediments. The Boulder Bank (right) forms a natural barrier to Nelson Haven and is one of several prominent barrier spits within the Tasman Bay area.

Plloto CN32833: D.L HOllier

CONTENTS

ABSTRACT

The Nelson 1:250 000 geological map covers 11550 km² of the greater Nelson land area and part of Marlborough in the northwest of the South Island, New Zealand. The area comprises rugged, recently deglaciated Tasm3n Mountains in the west and the lower Richmond Range and other ranges in tbe east separated by the down-faulted low-lying Moutere Depression. In the southeast, the Wairau valley separates the Richmond Range from the southern Marlborough mountain ranges. The offshore part of the Nelson QMAP area is characterised by relatively shallow water depths.

The Paleozoic Buller and Takaka terranes, separated by the Amlloki Faull, and plutonic intrusive rocks form the geological basement in the western half of the map area. The Buller terrane contains Ordovician Greenland Group and Golden Bay Group metasedimentary turbidites. extensively intruded by the Late Devonian-Carboniferous Karamea Suite granitoids and to a lesser extent, the Early Cretaceous Separation Point Suite granitoids. To the east, the lower sequence of the Takaka terrane comprises a lower sequence of Cambrian volcanic and volcaniclastic arc·related sedimentary rocks (Devil River Volcanics Group and Haupiri Group). their metamorphosed equivalents (Waingaro Schist). and a prominent melange unit (Balloon Melange). The overlying upper sequence is a Late Cambrian to Early Devonian passive margin succession of clastic and carbonate sedimentary rocks (Mount Patriarch Group. Mount Arthur Group, Ellis Group, and Baton Group). The Takaka terrane has been intruded by the Late Devonian maficJultramafic Riwaka Complex and Separation Point Suite granitoids. The Takaka terrane is structurally complex, comprising a number of fault slices exhibiting varying amounts of layer-parallel thrust imbrication. subsequent folding. and strike-slip faulling. The Buller and Takaka terranes were amalgamated to form the Tuhua terrane in the Early-Middle Devonian.

The eastern basement comprises the Median Tectonic Zone and the Brook Street, Murihiku, Dun Mountain-Maitai, Caples. and Torlesse terranes. The Median Tectonic Zone. which underlies much of the Moutere Depression. is dominated by Jurassic to Cretaceous igneous suites including Ihe ROioroo Complex and the Tasman Intrusives Group, but contains a number of possible sedimentary and metamorphic terrane remnants as old as Carboniferous. The Brook Street terrane is a Pennian calc-alkaline, predominantly andesitic volcanic suite (Brook Street Volcanics Group). now in fault contact to the east with Middle-Late Triassic volcaniclastic rocks of the Richmond Group of the Murihiku terrane. Fanher east. also in fault contact, is the Dun Mountain-Maitai terrane containing an extensively faulted sequence of the Early Permian mafic/ultramafic igneous Dun Mountain Ultramafics Group, the Permian mafic igneous Livingstone Volcanics Group. and the clastic sedimentary and carbonate rocks of the Middle Permi3n to Early Triassic Maitai Group. The Patuki Melange marks the tectonic boundary between the Maitai Group and the Caples Group of the Caples terrane. The Caples Group is dominated by Permo-Triassic volcaniclastic sedimentary rock which becomes increasingly schistose to the southeast. The Marlborough Schist Zone incorporates the suture between the Caples terrane and the quanzofeldspathic schist of the Torlesse terrane. The schistose component of the Torlesse terrane in Marlborough is part of the ?Triassic Rakaia subterrane. separated by the Alpine Fault from the low grade Early Cretaceous Pahau subterrane sandstone and mudstone.

A regional unconformity separates Late Cretaceous and younger rocks from the indurated basement. Late Cretaceous to early Eocene sedimentary basins in which the thick Pakawau and Kapuni groups were deposited developed in the northwest in response to rifting along north-trending faults. The late Eocene saw widespread deposition of the generally thinner terrestrial Brunner Coal Measures and shallow water Kaiata Formation, followed by limestone and calcareous sediments of the Nile Group in the Oligocene. Renewed tectonism in the Miocene resulted in compressional reversal of Cretaceous faults and inversion of some of the older basins accompanied by widespread deposition of terrigenous muddy sediments of the Lower Blue BOllom Group. Much of the area was emergent during the late Miocene and Pliocene with deposition confined to localised basins. Rapid uplift of the Southern Alps and Spenser Mountains in the Plio-Pleistocene resulted in substantial volumes of gravels being deposited. including the voluminous Moutere Gravel now preserved in the Moutere Depression.

Numerous outwash gravels and marine incursions occurred between and during the Pleistocene glaciations followed by extensive postglacial alluvial and marine deposition in the Holocene. Continuing tectonism from the Pacific-Australia plate convergence has resulted in the mountainous topography. Active faults include the Alpine Fault in the Wairau valley, and the faults of the Waimea·Aaxmore Fault System along the eastern margin of the Moutere Depression.

Resources currently being extracted include aggregate. clay, limestone. dolomite, and building stone. Bituminous coal from the northern end of the Buller Coalfield has been mined near Millerton and Stockton and large working mines occur immediately south of Ihe Nelson QMAP area. Metallic minerals including copper, gold, chromium, molybdenum, iron. lead, zinc. nickel, silver,

and tungsten are present and have been evaluated or mined in the past, but only small alluvial gold operations are presently active. Hydrocarbon exploration has taken place offshore and onshore.

Natural hazards include slope instability in all groups of rocks, particularly those that are soft, very shattered and! or crushed, or are well foliated. SeisrnoteclOnic hazards include ground shaking from earthquakes and surface rupture on local faults, as well as earthquake-induced landsliding. Erosion, flooding, and tsunami constitute additional hazards, particularly in low-lying areas.

KEYWORDS

Nelson; 1:250 000 geological map; geographic information system; digital data; Buller terrane; Takaka terrane; Tuhua terrane; Brook Street terrane; Murihiku terrane; Dun Mountain-Maitai terrane; Caples terrane; Torlesse terrane; Rakaia subterrane; Pahau subterrane; Median Tectonic Zone; Dun Mountain Ophiolite Belt; Greenland Group; Golden Bay Group; Devil River Volcanics Group; Haupiri Group; Balloon Melange; Waingaro Schist Zone; Mount Patriarch Group; Mount Arthur Group; Ellis Group; Baton Group; Karamea Suite; Riwaka Complex; Parapara Group; Pepin Group; Rotoroa Complex; Tasman Intrusives Group; Drumduan Group; Brook Street Volcanics Group; Richmond Group; Dun Mountain Ultramafics Group; Livingstone Volcanics Group; Maitai Group; Caples Group; Patuki Melange; Croisilles Melange; Torlesse Supergroup; Separation Point Suite; Rahu Suite; Pakawau Group; Kapuni Group; Rapahoe Group; Jenkins Group; Nile Group; Lower Blue Bottom Group; Upper Blue Bottom Group; Old Man Group; Tadmor Group; Junction Formation; Brunner Coal Measures; Kaiata Formation; Greenland tectonic *event;* Cape Foulwind Fault Zone; Kongahu Fault Zone; Glasgow Fault; White Creek Fault; Wakamarama Fault; Fenella Fault Zone; Anatoki Fault; Haupiri Thrust; Cobb Thrust; Devil River Fault; Karamea Fault; Pikikiruna Fault; Surville Fault; Waimea-Flaxmore Fault System; Waimea Fault; Heslington Fault; Eighty Eight Fault; Bishopdale Fault; Flaxmore Fault; Whangamoa Fault; Delaware-Speargrass Fault Zone; Queen Charlotte Fault Zone; Northbank Fault; Alpine Fault; Boundary Syncline; Reding Syncline; Pakawau Basin; Murchison Basin; Taranaki Basin; Paparoa Trough; Buller Coalfield; Collingwood Coalfield; Takaka Coalfield; Nelson-Richmond Coalfield; resources; gold; chromite; copper; lead; zinc; nickel; platinum; silver; tungsten; coal; dolomite; marble; serpentine; hydrocarbons; groundwater; engineering geology; natural hazards; landslides; active faults; earthquakes; Murchison earthquake; Inangahua earthquake

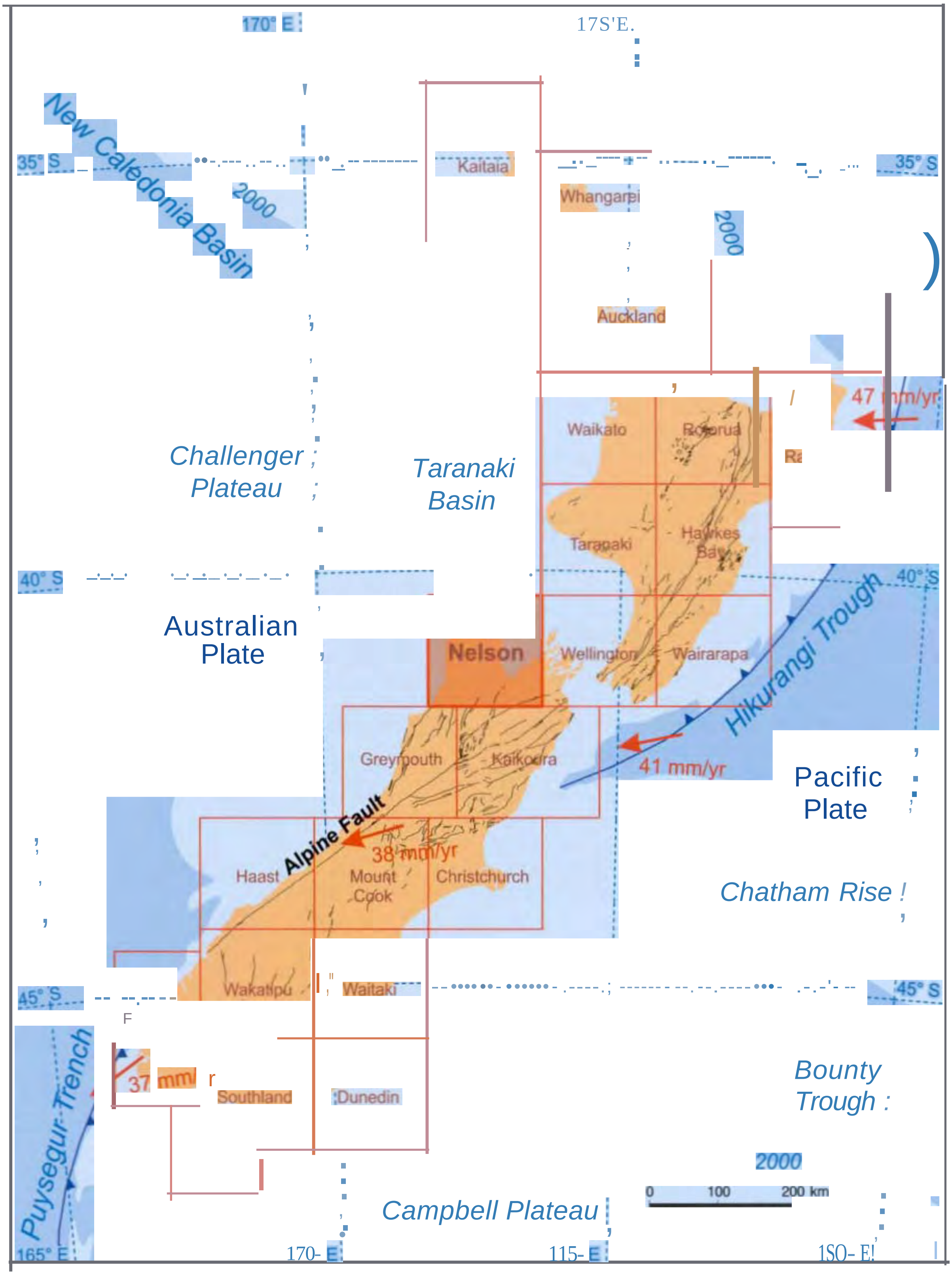


Figure 1 Regional setting 01New Zealand, showing the area 01the Nelson sheet and other QMAP sheets. Major active laults and bal hymetric features (as illustrated by the 2000 m isobath), are shown with arrows indicating the direction and rale 01convergence of the Pacific Plate relative to the Australian Plate. Adapted trom Anderson & Webb (1994).

INTRODUCTION

THE QMAP SERIES

This geological map of the Nelson area (Fig. I) is the third of the new national QMAP (Quarter-million map; Nathan 1993) series being produced by the Institute of Geological & Nuclear Sciences Ltd (ONS). QMAP supersedes the current Geological Map of New Zealand (GMNZ) 1:250 000 ("four miles to the inch") series. The four GMNZ sheets Golden Bay (Grindley 1961). Kaikoura (Lensen 1962), Buller (Bowen 1964), and Marlborough (Beck 1964) which overlap with the Nelson QMAP area were published between 1961 and 1964. Since then, concepts of plate tectonics, terranes and sequence stratigraphy have developed. and there has been considerable detailed geological and geophysical mapping by government, university, crown research institute, and industry geologists, both onshore and offshore. The requirement for geological information has also expanded as a result of the Resource Management Act, increasing demands on geological resources, a new educational syllabus, and greater awareness of natural hazards and their mitigation.

The geology of the Nelson QMAP area is in many places very complex and has necessitated considerable simplification to enable the geology to be legibly presented at 1:250000 scale. Rock units are mapped primarily in terms of their age of deposition, eruption. or intrusion. As a consequence, the colour of the units on the map face reflects their age. with overprints used to differentiate some lithologies. Leiter symbols (in upper case. with a lower case prefix to indicate early, middle or late if appropriate) indicate the predominant age of the rock unit. The last lowercase letter or lettcrs indicates a formally named lithostratigraphic unit and/or the predominant lithology. Mctamorphic rocks are mapped in terms of age of protolith (where known), with overprints indicating degree of metamorphism. Age subdivision is in terms of the international time scale. Correlation between international and local time scales and absolute ages in millions of years (Ma), revised as necessary for QMAP (Crampton & others 1995), is shown inside the front cover.

Theaccompanyingtext is generalised and is not intended to be an exhaustive description of the various rock units mapped. For more detailed information the reader is referred to refcrences cited throughout the text.

The QMAP geogr-aphic infor-mation system

The QMAP series uses computer methods to store, manipulate and present topographic and geological information. The maps are drawn from data stored in the QMAP geographic information system (GIS). a dalabasedeveloped and maintained by GNS. The primary software used is ARC/INFO·.

Digital topographic data were purchased from Land Information New Zealand and its predecessor the Department of Survey and Land Information. The QMAP database is complementary to. and can be used in conjunction with. other spatially referenced GNS digital data sets, e.g. gravity and magnetic surveys. mineral resources and localities, fossil localities, active faults. and petrological samples.

The QMAP series and database are based on detailed geological information ploltcd on 1:50 000 topographic base maps. These data record sheets are available for consultation at GNS offices in Lower Hult and Dunedin. The 1:50000 data have been simplified for digitising during a compilation stage, with the linework smoothed, and geological units amalgamated to a Slandard national system based on age and lithology. Point data (e.g. structural measurements) have not been simplified. All point data are stored in the GIS. but only selected representative structural observations are shown on the map. Procedures for map compilation, and dctails of data storage and manipulation techniques are given by Raltenbury & Heron (1997).

Data sources

The map and texi have been compiled from published maps and papers, unpublished university theses, GNS technical and map files. mining company reports, field trip guides, the New Zealand Fossil Record file in its digital form (FRED), and GNS geological resources (GERM) and petrological (PET) digital data bases (Fig. 2). Additional field mapping has been undertaken to ensure a minimum level of coverage over the map area. Landslides were mapped from aerial photos. with limited field checking. Offshore data have been compiled from published studies of Ihe West Coast region and the Taranaki Basin (Nathan & others 1986. King & Thrasher 1996). Data sources used in map compilation have been collated (Fig. 2), and are cited with other studies pertaining to the Nelson QMAP area in the References section.

Reliability

As a result of thecompilalion and simplification process. the accuracy with which geological contacts. faults, and folds are shown on the 1:250000 map has diminished, although point data are accurately located in terms of the NZMS 260 grid; the unpublished 1:50000 data record maps have a higher standard of detail and accuracy. The 1:250 000 map is of regional scale only, and should not be used alone for land use planning, planning or design

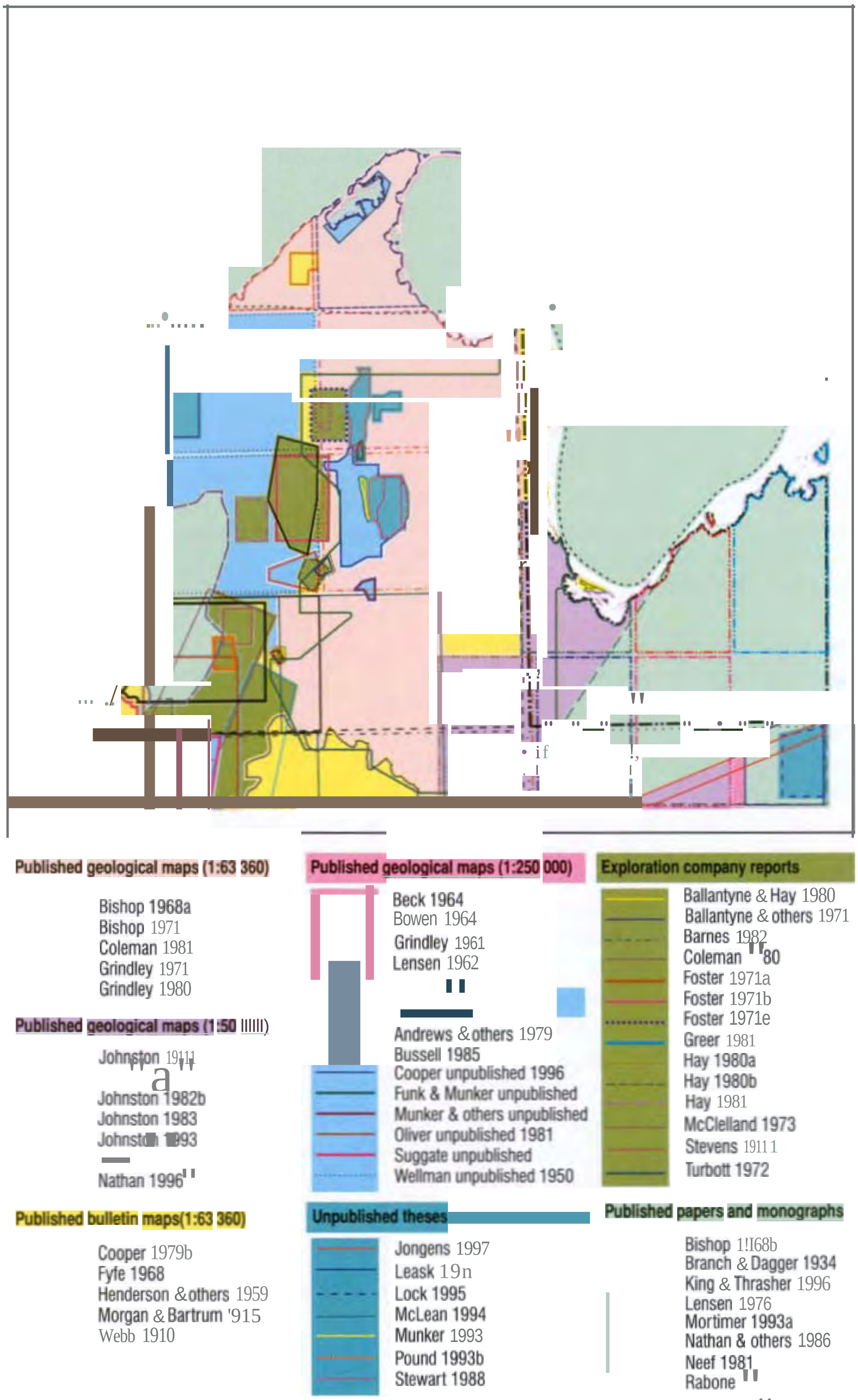


Figure 2 Sources of geological data used in compiling the Nelson map. Unpublished maps are held in the map archive of the Institute of Geological & Nuclear Sciences, Gracefield, Lower Hutt.

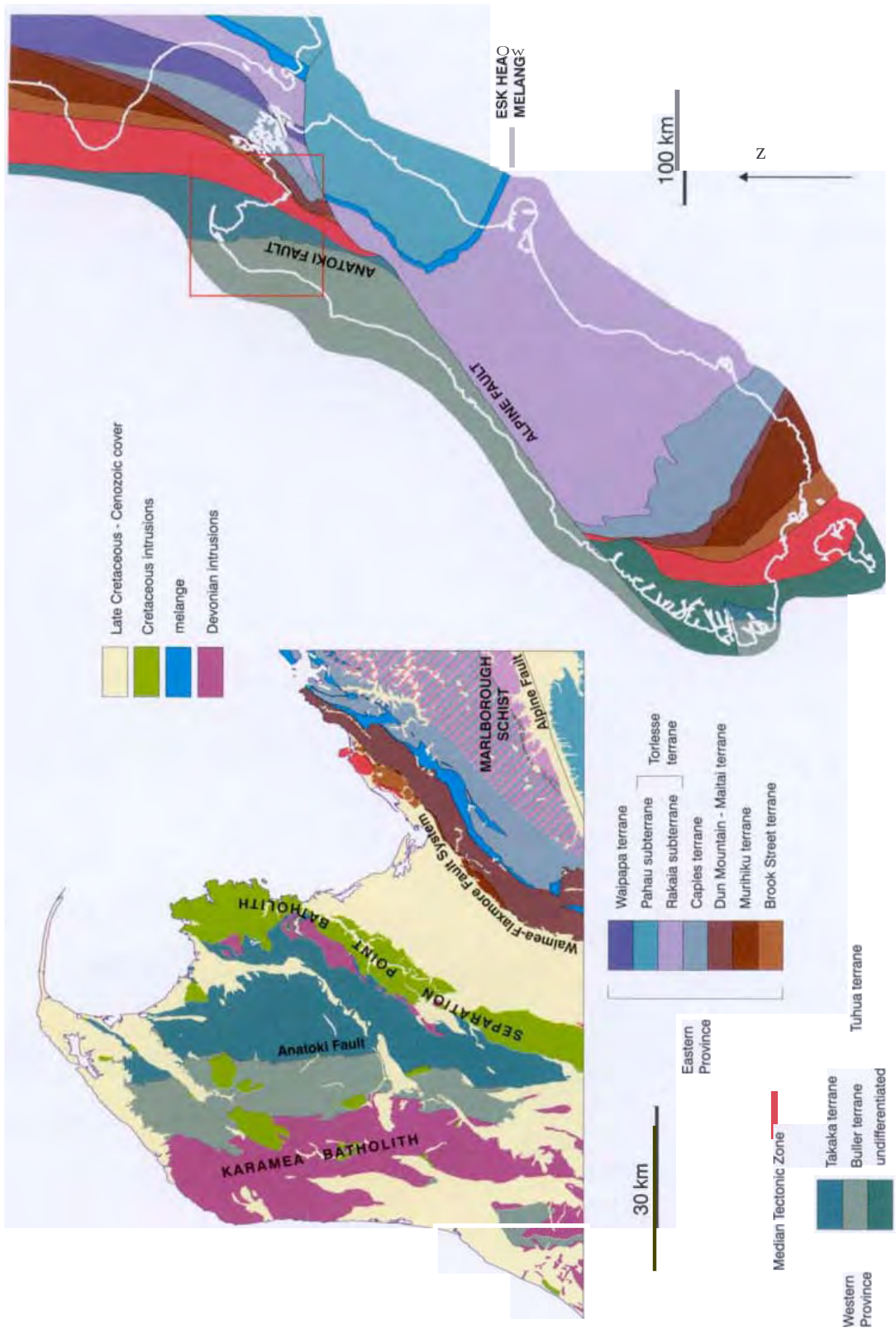


Figure 3 Basement rocks subdivided Into tectonostratigraphic terranes lor southern New Zealand and the Nelson area. Adapted lrom Cooper (1989), Mortimer (1993a, 1993bj, Mortimer & others (1997), Mortimer & Tulloch (1996).

of engineering projects, earthquake risk assessment, or other work for which detailed sile investigations arc necessary. Some data sets incorporated with lhe geological data (for example the geological resources map of New Zealand [GERM) dala) have been compiled from old or unchecked information of lesser reliability (see Christie 1989).

REGIONAL SEITING

The Nelson 1:250 000 geological map area covers 11 SSO km² of the northwest South Island including Nelson City and parts of the Buller. Tasman and Marlborough districts. Nelson City (pop. 40 000) is lhe largest urban centre in the area, and other principal towns include Richmond. Wakefield, Motueka and Takaka. Smaller seulements on the West Coast include Karamea and Granity. The major land uses are dairy, sheep, and cattle farming, horticulture, and exotic forestry. Coal mining is a large industry on the West Coast. Much of the map area is Crown Land administered by the Department of Conservation including Kahurangi and Abel Tasman national parks. and Mount Richmond Forest Park.

The Nelson QMAP area is adjacent to the active plate boundary (Fig. I) which passes through the West Coast of the South Island into Marlborough and the Hikurangi Trough off the East Coast of the North Island. Most of the Nelson QMAP area is part of the Australian Plate; the rocks southeast of the Alpine Fault lie within the Marlborough Faull System in the plate boundary woe with the Pacific Plate. The plate boundary is strike-slip through the Nelson QMAP area and lacks the effects of recent convergence seen in the western South Island and eastern North Island.

Geologically the basement rocks of New Zealand are divided into Western and Eastern provinces that are separated by the Carboniferous-Cretaceous Median Tectonic Zone *(MTI).* Both provinces are subdivided into fault-bounded, north-trending, tectonostratigraphic terranes (Fig. 3). In the Nelson QMAP area. the Western Province includes the Ordovician Buller terrane and the Cambrian-Devonian Takaka terrane. The Eastern Province terranes are. from west to east: the Permian Brook Street terrane. the Triassic Murihiku terrane, the Permian-Triassic Dun Mountain-Maitai terrane, the Permian-Triassic Caples terrane. and the Triassic-Cretaceous Torlesse terrane (including the Rakaia and Pahau subterranes). The largely Devonian Karamea Batholith intrudes the Buller terrane. and the Cretaceous Separation Point Batholith intrudes the Takaka terrane. The area is considered 10 have been a marginal part of the Gondwana supercontinent prior to rifting during the formation of the Tasman Sea which began in the Late Cretaceous. A number of sedimentary basins developed during the Late Cretaceous-Miocene, most of which were subsequently uplifted along a series of faults during the onset of convergence across the plate boundary in the Miocene.

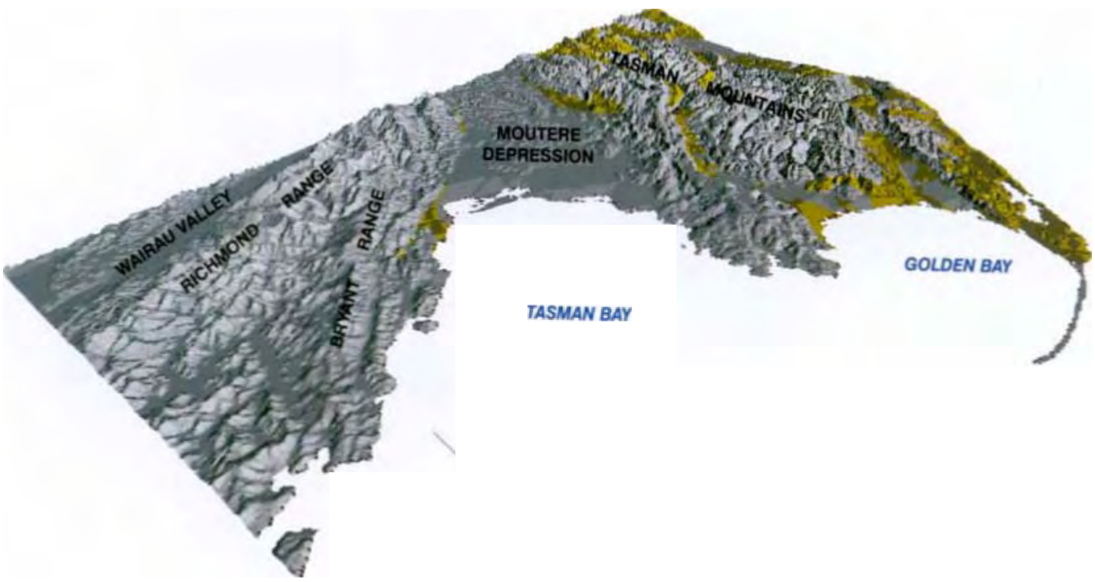


Figure 4 Hitl-shaded topographic relief model of the Nelson map area derived from digital contour data supplied by UNZ. The elevated and rugged Tasman Mountains (west) and the Richmond and other fanges (east) contrast with the intervening lower and subdued Moutere Depression, and the WaJrau Valley In the southeast. Remnants of the Lala Cretaceous to mid-Tertiary Bfosion surface and sedimentary sequences of this age are shown in a yellow overprint.

GEOMORPIIOLOGY

Moutere Depression

A 30 km-wide system of valleys between the Tasman Mountains and the ranges of east Nelson form the Moutere Depression (Fig. 4). The depression is fault-bounded to the east by the northeasHrending Waimea-Aaxffiore Fault System. Voluminous Plio-Pleistocene gravels preserved in the depression have been incised by the Motueka. Moutere. and Waimea rivers (Fig. 5). Geophysical interpretation of seismic dala and petroleum wells indicates the depression reaches depths of 2500 m (Lihou 1992). The depression formed in the Pliocene-Pleistocene during uplift of the Tasman Mountains and the east Nelson ranges.

Tasman Mountains

The Tasman Mountains of Northwest Nelson rise to approximately concordant summits between 1600 and 1875 m (Mt Owen) with the surface defined by these summits dipping gently to the west and less so to the north. The surface may be close to the early Tertiary erosion surface which probably levelled the pre-Tertiary rocks of the Northwest Nelson area (Nathan & others 1986). Exhumed remnants of the erosion surface occur at Gouland. Mackay. and Gunner downs (Fig. 6) as well as the southeastern slopes of the lower Aorere valley. and below Tertiary sequences such as in the Matiri Range area and the Ml Anhur Tableland (Fig. 4).

The Tasman Mountains were extensively glaciated during the Pleislocene and many of lhe larger valleys retain the classic glacial "U' shape with hanging valley tributaries and headwall (Fig. 7). The mountains are now incised by a complex drainage system dominated by the Karamea River catchment. The course of the upper Karamea River and its Leslie River tributary have been influenced by Late Cenozoic movement on the Karamea Fault. Recent movement on the Pikikiruna Fault and the Wakamarama Fault have similarly influenced Late Cenozoic sedimentation and geomorphology in the Takaka and Aorere valleys respectively. The numerous Paleozoic faults are commonly expressed as a series of low saddles on ridges due to erosion of weaker fault rocks formed either during Paleozoic deformation or Late Cenozoic fault reactivation.

Wairau valley

The ENE-trending Wairau valley separates the Richmond Range from the mountains of southern Marlborough. The linearity of the valley is influenced by the Alpine Fault whose active trace is mapped over much of the valley's length (Fig. 8).

Richmond Range

The Richmond. Bryant. and Gordon ranges form a triangular wedge of mountains bounded by the Moutere Depression and the active Waimea-Flaxmore Fault System to the west, to the south by the Alpine Fault. and to the northeast by the subsiding Marlborough Sounds. The ranges culminate in Red Hill (1790 m) and Mt Richmond (1756 m) which have relatively simple drainage patterns dominated by the Pelorus River catchment.

Farewell Spit

Farewell Spit is formed from dune sands and beach sands actively extending eastward in a 25 km-Iong arc from Cape Farewell (Fig. 9). Spectacular mobile dunes up to 22 m high are a feature of some parts of Ihe spit. The spit has formed as a result of northward transport of sediment along the West Coast. Farewell Spit is subject to frequent storm erosion from the northern, Tasman Sea side.

Boulder Bank

Another barrier spit of note is the 13.5 km-Iong Boulder Bank which encloses Nelson Haven. The bank is composed of granodiorite pebbles and boulders up to 0.8 m diameter. The boulders originate from Glencluan to the northeast and decrease in size and become more rounded towards the southwestern tip of the spit.

Lakes

Lakes are not a conspicuous feature of the Nelson map area although glacial tarns are widespread in the Tasman Mountains. The largest of these is the 67 ha Boulder Lake. The damming of the Cobb River for electricity generation has formed a 6.5 km long reservoir on the site of a former glacial lake. In the Richmond Range. a large landslide has fonned the 2 km-Iong Lake Chalice. and numerous small lakes in the Tasman Mountains formed as a result of slope failure damming rivers during the 1929 Murchison earthquake (Fig. 7).

Sea bed morphology

The offshore Nelson QMAP area eastward from Farewell Spit and across Tasman Bay is characterised by a relatively shallow (less than 70 m depth), gently undulating sea floor. The continental shelf off the western coast has a steeper gradient and deepens to 250 m within the map area. The Kahurangi Shoals up to 15 Ian offshore from Kahurangi Point are relatively shallow (30-50 m depth). The Challenger Plateau dominates the sea bed physiography further offshore beyond the Nelson QMAP area.

Figure 5 The Moutere valley, draining north towards Motueka. is part of the Moutere Depression which formed in the Plio-Pleistocene after the deposition of huge volumes of greywacke-derived Moulere Gravel predominantly "om the Southern Alps and Spenser Mountains. The linear valleys and ridges, with regularly spaced tributaries, ale 8 typical geomorphic expression of the Moutere Gravel. *Photo: CN25995 D.L. Homer*

FIgure 6 The Mackay Downs (foreground) and Gouland Downs (left background) are the exhumed remnants of the Late Cretaceous to mid-Tertiary erosion surface which probably covered much of the west Nelson area Including the Tasman Mountains shown in the far distance. The Mackay Downs and much of the Gouland Downs are underlain by Devonian Karamea Suite granlle. The granite Is CUI by numerous faulls and persistent regional joint sets have created a mesh-like topographic pallern. *Photo: CN25888 D.L. Homer*

Figure 7 Glacial features such as "U-shaped" and hanging valleys are *common* In the western Tasman Mountains, shown here from McNabb Creek, a tributary of the Ugly River. The valley and the Grindley Ridge (centre) are comprised of Karamea Suite granite which dominates the basement geology to the Karamea plains in the far distance. The small unnamed lake in the loreground lormed as a result 01 a landslide caused by the 1929 Murchison earthquake. *Photo: CN25648* D.L. *Homer*

FIgure 8 The Wairau valley in Marlborough Iollows the trace of the active Alpine Fault. Extensive alluvial gravels have formed from the glacial outwashes towards the head 01the valley. *Photo: CN26058 D.L. Homer*

Figure 9 The arcuate 25 km-long Farewell Spit Is the largest of many sand spits and tombolos which have formed in the Tasman Bay and Golden Bay due to longshore currents. Farewell Spit comprises fixed and mobile dunes with swamp deposits on the Golden Bay side. The early Tertiary Farewell Formation and overlying Nile Group are exposed in the loreground cliffs near the fold crest ol lhe Pakawau Anticline. *Photo: CN24252 D.L. Homer*

The rocks of the Nelson QMAP area are described in terms of four major time intervals:

- Cambrian 10 Devonian basement rocks of west Nelson
- Carboniferous to Early Cretaceous basement rocks largely in east Nelson
- Lale Cretaceous and Tertiary sedimentary rocks
- Quaternary sediments

The suatigraphic relationships between various sedimentary sequences and igneous suites are being increasingly constrained by radiometric dating. The dating techniques applied include K-Ar, U-Pb. $^{40}Ar/^{39}At$ and fission track analysis. There is currently someconfliet between ages derived from the two techniques usually used todclennine U-Pb ages of zircon. The conventional whole zircon technique (bulk or single crystal isotope dilution TIMS) offers more analytical precision whereas the ion microprobe method (SHRIMP) can be used for specific crystals or parts of crystals. In the early Paleozoic the SHRIMP dales are consistently younger than the isotope dilution (TIMS) dates on the same rocks (Tucker & McKerrow 19(5). In the Devonian-Carboniferous the SHRIMP dates are generally older than the rIMS dates. This text reports ages from both methods where applied to the same group of rocks.

CAMBRIAN TO DEVONIAN

Early Paleozoic rocks form two north-trending terranes - the Buller and Takaka terranes (Figs 3 & 10), separated by the Anatoki Fault (Bishop & others 1985, Cooper 1989). Rocks of the Buller terrane occur widely in the western part of the Nelson QMAP area and throughout Westland. The Takaka terrane is concealed under younger sedimentary rocks south of Mt Owen and re-emerges in a small area near Springs Junction. In Fiordland the two terranes have been recognised and mapped by Ward (1980.1984) in Dusky Sound. They are inferred toextend offshore to the north beneath the Challenger Plateau, and to the south beneath the Campbell Plateau (Cooper 1989, Beggs & others 1990. Mortimer & others 1991). Buller terrane rocks have been intersected in offshore wells: Haku-1 southwest of Karamea (Wodzicki 1974). and in Hoihoi and Kawau-IA on Campbell Plateau (Watters 1977, 1978). The terranes have boen most intensively studied in the Nelson map area, particularly in the area that includes the Cobb and upper Takaka rivers. They have boen described by Cooper (1989) and reviewed by Cooper & Tulloch (1992).

The Buller and Takaka terranes are the oldest structural units in New Zealand and can be regarded as constituting "proto-New Zealand" which, together with eastern Australia and Antarctica. fonned the southwest Pacific segment of Gondwanaland in the early Paleozoic. These terranes show strong affinities with terranes in eastern Australia and Antarctica (Cooper & Grindley 1982, Grindley & Davey 1982, Cooper & Tulloch 1992).

Buller terrane

All rocks older than Middle Devonian that lie to the west of the Anatoki Fault or its inferred extension comprise the Buller terrane (Fig. 3). In the Nelson map area. the great bulk of the sedimentary sequence is made up of basal Ordovician. continent-derived. quartz-rich turbidites of the Greenland Group which are also the oldest rocks of the terrane. Together with the overlying black shale. siltstone and quartz sandstone oflhe Golden Bay Group. they represent an almost unbroken sequence through the Early and Middle Ordovician with a composite thickness of at least 9000 m.

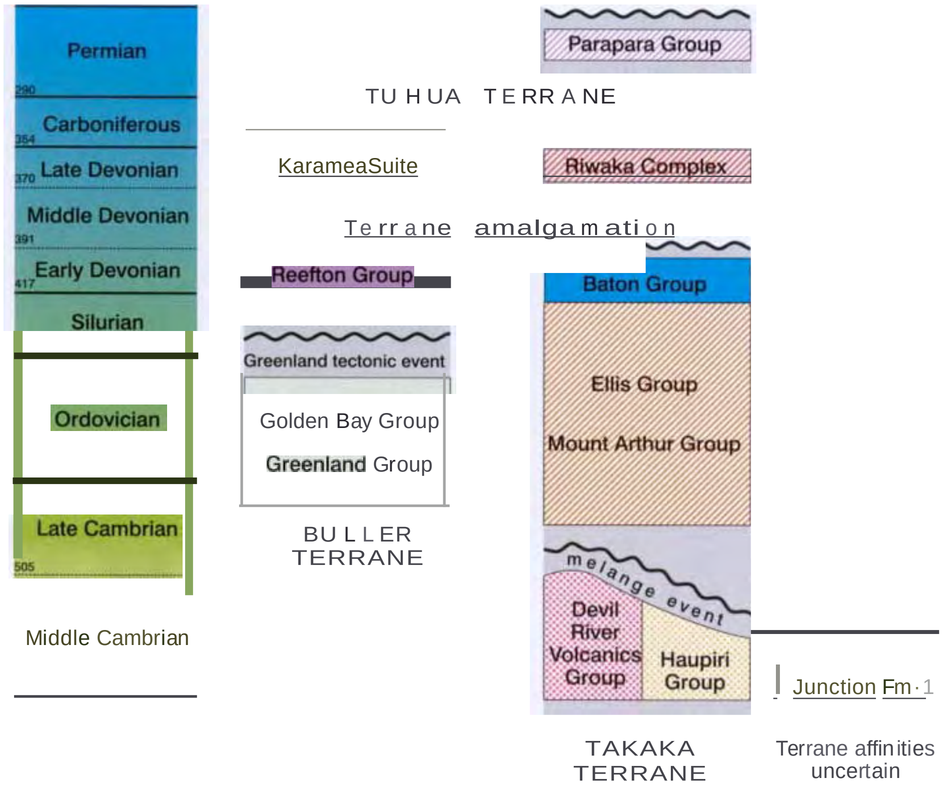
Late Cambrian to Early Ordovkian sedimentary rocks

To the west of the north-trending Karamea Batholith, undifferentiated Greenland Group (Ѳg) rocks comprise a thick (5000 m+) pile of indurated, well bedded, quartz-muscovite turbidites. The beds are dominated by graded sandstone, siltstone and mudstone and represent a submarine-fan depositional environment (Laird 1972). The rocks have characteristically low Na_2O/K_2O ratios (Laird 1972, Laird & Shelley 1974, Nathan 1977). Graptolites from a single locality near Reefton, 50 km to the south of the Nelson QMAP area, indicate a basal Ordovician (La2 Zone) age (Cooper 1974). A Rb-Sr whole rock isochron gives a similarageof495± 11 Ma (Adams & others 1975).

The group is subdivided east of the Karamea Batholith into the Roaring Lion and Webb formations (Ѳgr; Bishop 1968a, Grindley 1980) respectively south and north of the Wakamarama Fault (Figs 11 & 12).

Early to Late Ordovician sedimentary rocks

In the Wakamarama Range. Greenland Group passes conformably up into the Golden Bay Group. The base of the Golden Bay Group is composed mainly of quartzite, quartz sandstone and black siliceous shale ofthe Aorangi Mine Formation (Ѳba, Fig. 13). Theoverlying turbidite quartz sandstone. siltstone and black shale are mapped as Leslie and Slaty Creek formations (Bbl). Douglas and Peel fonnations (8be1: Grindley 1971. 1980) at the top of the Golden Bay Group are composed of rhythmically bedded, fine-grained sandstone and quartzite. The quartzite comroonly defines complex tight folds.



Agura 10 Major rock units of the Buller and Takaka terranes of west Nelson region showing various tectonic events which have affected the terranes. The Tuhua terrane formed by the amalgamation of the Buller and Takaka terranes, probably during the Early to Middle Devonian, followed by intrusion of the Karamea Suite and the Riwaka Complex.

Graptolites are present in black shale throughout the Golden Bay Group (Fig. 14) and range in age from early Early Ordovician (La 2 Zone) to early Late Ordovician (Gi1 Zone; Cooper 1979b). The pelagic Aorangi Mine Formation represents a starved basin depositional environment (Cooper 1979b) and contains abundant pyrite.

Between Mount Olympus and the Aorere Valley, the formations of the Golden Bay Group are metamorphosed to dark pelitic schist (Bay Schist ebb), containing quartz-muscovite-chlorite and quartz-biotite. Some large rafts of high grade, hornfelsed metasedimentary rock (8 a) within the Karamea Batholith have probably been detached from Buller terrane rocks during intrusion of the granite. The best known example of one of these rafts occurs at the north end of the Radiant Range where a large, Cu-Mo mineralised, gnessic enclave of metasedimenlary rock is surrounded by Karamea Suite granite.

Structure and metamorphism

The Ordovician rocks are folded throughout the terrane in Northwest Nelson with generally northwest to northeasl-trending, steeply dipping axial planes, a well developed cleavage and low grade (low greenschist facies) metamorphism (Fig. 13). The folding occurred during the Greenland tectonic event (Cooper 1989). An earlier phase of recumbent folding has been inferred at several localities (Bishop 1968b, Cooper 1979b). The Greenland tectonic event is poorly constrained in age; it pre-dates emplacement of the Karamea Batholith and appears to pre-date the Early Devonian Reefton Group. Cleavage formation is inferred, from KJAr whole rock dates of pelitic rocks, to have begun in the Late Ordovician or Silurian (Adams & others 1975). The Boundary Syncline is a tight fold that extends from Paturau River south at least as far as Leslie River, has an east dipping axial plane and an overturned eastern limb. The fold lies along the western boundary of the terrane and may be related to thrust movement on the Anatoki Fault.

The Fenella Fault Zone (Θff) is a major zone of folding and faulting that extends throughout the Buller terrane rocks of the Nelson QMAP area (Cooper 1989). It is generally structurally concordant with the regional strike and contains tight, steeply plunging folds in strongly sheared quartzite, sandstone, siltstone and limestone

Figure 11 Typical well bedded sandstone-dominated beds of the Roaring Uon Formation (Greenland Group) near lake Cobb. The steeply dipping. moderately well developed deavage formed during widespread open to tight folding of these beds.

FIgure 12 Sandstone beds of Roaring Uon Formation that have been deformed and contact metamorphosed by the nearby Separation Point Suite granodiorite pluton in the Spey River (M26I598236).

FIgure 13 Quartzite bands within the Aorangi Mine Formation folded into a gently north-plunging synformal structure on the southern edge of the Gouland Downs.

derived from the Aorangi Mine and Slaty Creek formations. In the north, in the Wakamarama Range, it is probably represented by the Conns Creek shear zone of Cooper (1979b). To the south, the Aorangi Mine and lower part of Slaty Creek formations become tectonically pinched out against the zone. South of Mount Olympus, these units are reduced to two or three tightly folded discontinuous bands and slivers of quartzite (Fig. 15) and rare slivers of graptolite-bearing black shale that can be traced to the Mount Patriarch area. Similarly folded and faulted quartzite, at a similar stratigraphic level and structural position, has been mapped at Dusky Sound in Fiordland (Ward 1980). The zone appears to mark a major zone of stratigraphic excision but its tectonic origin is obscure.

Figure 14 The age of the Aorangi Mine Formation is well coostrained by graptolite faunas ranging from Early to late Ordovician. The prominent graptolite is *Isograptus caduceus maximodivergens* with numerous other smaller didymograptids.

Takaka terrane

In contrast to the Buller terrane, the Takaka terrane (Fig. 3) contains a wide variety of rock types and is structurally complex. At least ıwo major depositional cycles are present and are inferred to represent volcanic arc-related (Cambrian) and passive margin-related (Cambrian 10 Devon;an) depositional environments respeclively (Mlinker & Cooper 1995. Roser & others 1996). The arc-related sequence is largely confined to the western part of the terrane, between the Anatoki Fault and Devil River Fault (the Central Sedimentary Belt of Cooper 1979a) and principally comprises the Haupiri Group and Devil River Volcanics Group. The passive margin sequence is composed of the Mount Patriarch. Mount Arthur and Ellis groups (Fig. 10) and is best developed in the eastern part of the terrane (Eastern Sedimentary Belt of Cooper 1979a). Near Springs Junction, to the south of the Nelson QMAP area. the passive margin sequence overlies the volcanic arc sequence with structural concordance but it separated from it by a detachment fault (R.A. Cooper unpublished data).

The Takaka terrane has been extensively disrupted by faulting. It is now preserved in a series of generally north-trending fault-bounded slices (Fig. 16), each of which has a distinct stratigraphy. In the western part of the terrane, 11 fault slices are recognised. Facies conlrasts between rocks of the different faull slices. particularly those of the Cambrian arc-related part of the sequence, suggest stratigraphic complexities with lateral facies changes and intertonguing of volcanic and sedimentary rocks (Fig. 17). In the eastern part of the Takaka terrane. fewer fault slices are present but lateral facies changes in Ordovician and Silurian Slrata are apparent. The fault slices therefore appear to have juxtaposed parts of the sequence, that were originally some distance apart, by imbricate thrust stacking and/or by transcurrent displacement.

Figure 15 Quartzite bandS on the Peel Range which form pari of the Fenella Fault Zone separating leslie Formation to the east (left) from the older Roaring Uon Formation to the west (right). *Photo: CN25717 D.L. Homer*

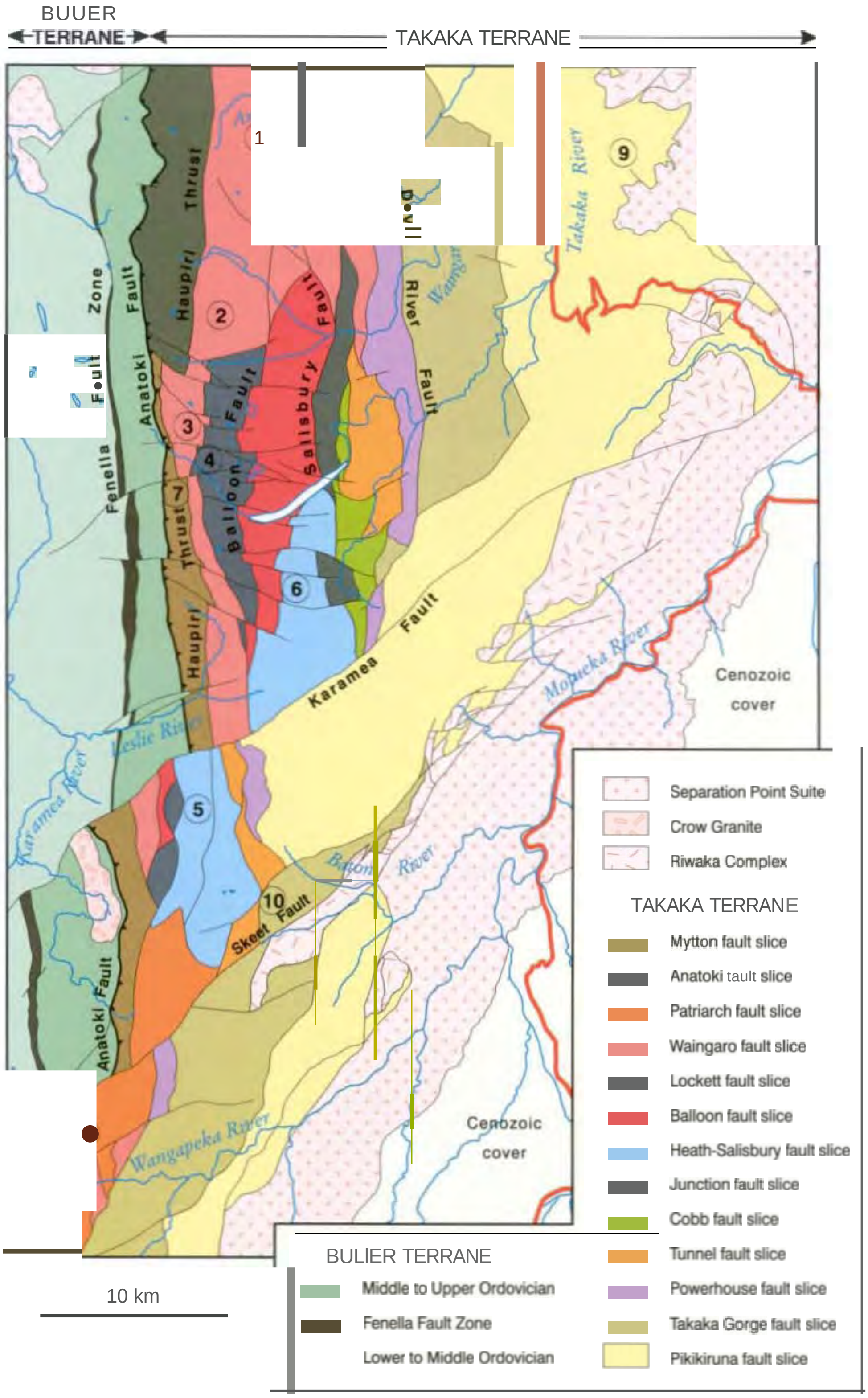


Figure 16 Structural slices 01 the Takaka terrane between the Anatoki and Wangapeka rivers (cenozoic cover removed). The structural slices are fault-bounded and separate related yet distinct strallgraphlc sequences and lacies changes. Figures in circles refer to local stratigraphic sequences shown In Fig. 17 stratigraphy.

Figure 17 Cambrian stratigraphic correlations across the Takaka terrane, showing inferred facies relationships between and within the Devil River Volcanics Group and the Haupiri Group. The location of the sequences is shown in Fig. 16. The rock units have been coded to match the unit labels on the main map except for some further subdivision as indicated in Appendix 1. Based largely on unpublished work by Münker & Cooper.

displacement.

Middle to LaIeCambrian sedimentary and igneous rocks

Turbiditic feldspathic and lithic sandstone. siltstone and debris flow conglomerate of the Junction Formation (**Єgj**, Fig. 18) occur within the Junction and Anatoki fault slices (Fig. 16). Highly strained trilobites from a single locality indicate a probable Middle Cambrian age (RA Cooper unpublished data). The formation is inferred to pre-date adjacent rocks of the Haupiri Group in which it is thought to be represented as detritus (Pound 1993a).

The oldest rocks dated by fossils in the Takaka terrane, and in New Zealand, are found within the Haupiri Group (€b), which is here restricted to the sedimentary part of the volcano-sedimentary Haupiri Group of Grindley (1971, 1980; Appendix). The rocks are calcareous siltstone and conglomerate known informally as the Heath Creek beds. which contain trilobites of probable Floran (early Middle Cambrian) age. They are confined to a small area in the Heath-Salisbury fault slice (Fig. 17) where they are interlayered with Benson Volcanics.

The clearest and fullest development of the Haupiri Group is in the Lockett fault slice (Fig. 17). Laminated siliceous siltstone and fine-grained sandstone with lenses of limestone and debris-now conglomerate form the **Tasman Formation** (€ ht)(Figs 19& 20). Trilobite and inarticulate brachiopod faunas at several horizons indicate an Undillan (Middle Cambrian) age for the lower part. and a Boomerangian (late Middle Cambrian) age for the upper part. Allochthonous olistolithic limestone lenses contain rich trilobite (Cooper 197930). brachiopod (Henderson & MacKinnon 1981) and mollusc (MacKinnon 1982. 1983) faunas. Theoverlying Lockelt Conglomerate (€hl) is a polymict granule to boulder conglomerate (fig. 21) up to 500 m thick containing clasts of volcanic and ultramafic rocks. gabbro, granitoid. quartzite. limestone and sandstone including sandstone derived from Junction Formation. Abundant detrital chromite was probably derived from Cobb Igneous Complex (Hunter 1m. Pound 1993b). The conglomerate is inferred to have been deposited in a fan-delta environment (Pound 1993a). Inarticulate brachiopods are known from a single locality and indicate a Mindyallan (early Late Cambrian) age. The contact with the Tasman Formation is concordant, although locally erosional (Pound 1993b).

Rocks previously mapped as Lockett Conglomerate (Grindley 1971. 1980) are now thought to represent several other units. From the Anatoki River to the Waingaro River. in what is most probably Waingaro fault slice, a thick polymict matrix-rich conglomerate is here mapped as **Christmas** Conglomerate (**Єhc**, following McLean 1994) containingdasts of chert. sandstone and volcanic rock. The conglomerate is considered to occupy a stratigraphic position near the middle or lower part of the Tasman Formation. In the Heath-Salisbury fault slice. polymict matrix-rich volcaniclastic conglomerate, sandstone and siltstone of Undillan (late Middle Cambrian) age is mapped as Salisbury Conglomerate (€hs. following Pound 1993a). Clasts include chert, sandstone, some igneous rocks derived from Matalc.i Volcanics. and rare gabbro.

In the Waingaro fault slice. the Haupiri Group is represented mainly by graded and channelled sandstone. at least 800 m thick. of the **Mount Benson** Sandstone (€ hl). The Mount Benson Sandstone is interpreted as a proximal equivalent of the Tasman Formation (MUnker & Cooper 1995). Boomerangian to Mindyallan (latest Middle Cambrian) brachiopods (MacKinnon 1983) date the youngest beds. Fine-grained sandstone and siltstone. at least 360 m thick, of the **Peel** Formation (€ht) is interpreted to be a lateral equivalent of the Lockett Conglomerate.

In the Anatoki fault slice unfossiliferous turbidite granule conglomerate, sandstoneand siltstone. previously mapped as Anatoki Formation (Grindley 1971, 1980), are here mapped as undifferentiated Haupiri Group. To the north of Aorere River these rocks have been metamorphosed toquartz-albite±hornblende±biotitet muscovite ±Chloritdgarnet schist. amphibolite and metasandstone of the Wakamarama Schist (€ pw).

The Devil Rivel' **Volcanics** Group (€d) includes all volcanic and plutonic rocks of Cambrian to early Ordovician age, previously included by Grindley (1971, 1980) in the Haupiri Group. Volcanic rocks are interbedded with. and intertongue with, sediments of the Haupiri Group, particularly in the Waingaro fault slice where the Mount Benson Sandstone and Peel Formations interdigitate with volcanic breccias. tuffs and sandstones, and in the Heath-Salisbury fault slice where basaltic flows and breccias interdigitate with Salisbury Conglomerate. Four volcanogenic formations are recognised (MOnker & Cooper 1997). The first. **Benson Volcanics** (€ db). is the most extensive and comprises a thick pile of volcaniclastic breccia conglomerate and sandstone. tuffs and nows representing a minimum of seven volcanic suites (MUnker & Cooper 1995) composed of, in general upward stratigraphic succession. from low-K to high-K calc-alkaline basalt and basaltic andesite with some andesite. dacite and rhyolite. One of the more highly differentiated suites, Heath Volcanics (€ dh), is distinguished on the map and contains andesite with primary amphibole. plagioclase and magnetite. From their geochemistry, the rocks are inferred to represent deposits formed on and adjacent to a volcanic island arc

Figure 18 Disrupted packets of thin-bedded laminated siltstone of the Junction Formation (probable Middle Cambrian age) from Sylvester Road near Cobb Reservoir. Junction Formation is inferred to be the oldest recognised stratigraphic unit in New Zealand

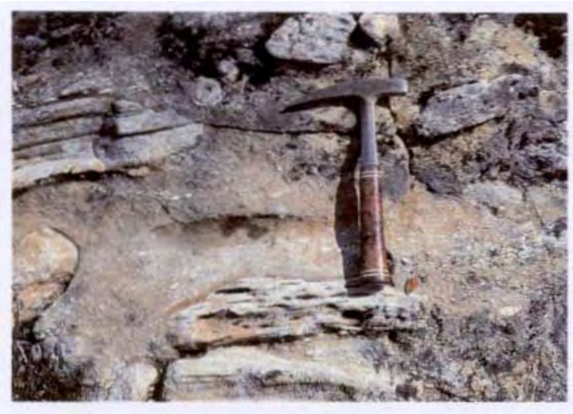


Figure 20 Debris flow conglomerate within Tasman Formation (Haupiri Group) near Trilobite Rock, Cobb Valley.

Figure 22 Basaltic andesite flow breccia of the Mataki Volcanics (Devil River Volcanics Group) from Deep Creek, upper Takaka River.

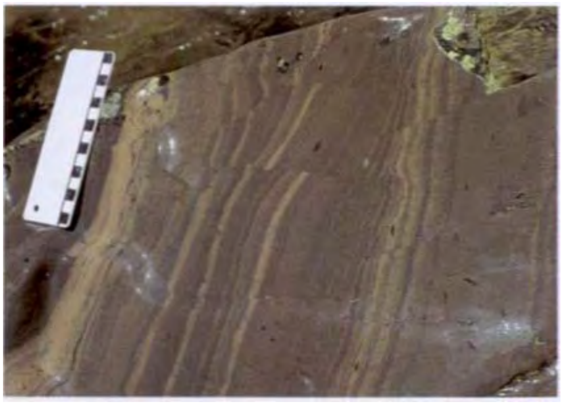


Figure 19 Thin- to very thin-bedded laminated sandstone and siltstone ol the Tasman Formation (Haupiri Group) from Cobb Valley.

Agure 21 Well rounded dasts in the Lockett Conglomerate (Haupiri Group) at Lake Sylvester. The clasts have been derived from most 01 the older Haupiri Group and Devil River Volcanics Group units.

Mataki Volcanics (€dm; Fig. 22), is dominated by basaltic flows, volcaniclastic breccia, conglomerate and sandstone with some shallow intrusive gabbro intrusions. The basalt has a geochemical affinity with back arc basin tholeiites (Stewart 1988. Milnker & Cooper 1997). The fourth unit, Cobb Igneous **Complex (€dc),** intrudes Mataki Volcanics and contains gabbro and ultramafic rocks. now largely serpentinised, interpreted as layered shallow level intrusions of boninitic andesites (Hunter 1977, MUnker & Cooper 1997). Numerous mafic and felsic dikes intrude the gabbro and ultramafic rocks.

From their relationship with fossiliferous rocks of the Haupiri Group. the Benson Volcanics effusive rocks are inferred to range from Undillan to Mindyallan (late Middle to earliest Late Cambrian) in age (Miinker & Cooper 1997). Late stage felsic intrusives give SHRIMP U-Ph zircon dates of 494 ± II Ma and 485 ± 8 Ma (latest Cambrian to earliest Ordovician; Milnker. Weaver & Ireland unpublished). The Cobb Igneous Complex intrudes Mataki Volcanics and has given a SHRIMP U-Ph zircon ageof515 ± 7 Ma. (Munker 1997) and the age of the Cobb Intrusive Complex is taken as Undillan (late Middle Cambrian). The Mataki Volcanics is inferred to be of Floran to Undillan (early Middle Cambrian) age.

Late Cambrian melange and metamorphic rocks

Diamictite, broken formation and melange (after Raymond 1984. Fig. 23) are developed in the Balloon, Anatoki and Tunnel fault slices (Cooper & Tulloch 1992. Pound 1993a. Jongens 1997) and are here mapped as Balloon Melange (€b.€bj.€bl,€bh). The bulk of the melange is derived from the Junction Formation by primarily tectonic processes (Stewart 1988. Cooper 1997).11 includes exotic blocks, generally a few metres but up to a few kilometres in length, of chert, limestone, conglomerate. siliceous siltstone, volcanic sandstone, andesite. basalt and mafic intrusives. Parts of the melange are dominated by blocks derived from Lockett Conglomerate (€bl). Junction Formation (€bj), Heath Volcanics (€bh), as well as Cobb Igneous Complex and Tasman Formation. Blocks fanned of the Ordovician to Devonian passive margin sequence rocks are absent and the melange is therefore inferred to have formed in the Late Cambrian (Cooper & Tulloch 1992. Cooper 1997).

An elongate. north-trending zone of ductile shear, up to 1.5 km wide adjacent to and mostly west of the Devil River Fault, is mapped as Waingaro Schist Zone (€wb.€wh.€wd,€w; Grindley 1971. 1980). The zone is dominated by fine grained volcanic-derived greenschist containing quartz-albite-muscovite-chlorite-calcite-

Figure 23 Balloon Melange rocks from the Cobb Reservoir area. The Balloon Melange records a late Cambrian deformation event which formed a tectonic unit comprising angular clasts of various parentage. with varying degrees 01 foliation. The clasts are locally dominated by particular rock units of the Haupiri and Devit River Volcanics groups.

containing quartz-albite-muscovite-chlorite-calcite-titanite-epidote with some schistose sandstone and conglomerate. Mylonitic fabrics are common and a steeply east-plunging stretching lineation is present (powell 1985). Parent rocks include Haupiri Group (€wh), Devil River Volcanics Group (€wd), Balloon Melange (€wb) and Wangapeka Formation (powell 1985).

Latest Cambrian to Devonian sedimentary rocks

The Late Cambrian to Silurian sequence forms a "covering" succession of carbonates and siliciclastics that have geochemical affinities with passive margin sequences (Roser & others 1996). Although the general sequence is similar throughout the Takaka terrane, there are variations between areas (Fig. 24) and within the various faul! slices, especially in Ihe late Cambrian to earliest Ordovician Mount Patriarch Group. The oldest unit in the group is the Anatoki Formation (€pa) which consists of finely bedded and laminated quartz-mica siltstone, volcaniclastic graded sandstone and granule conglomerate (Coleman 1981). They pass gradationally up into Patriarch Formation (€pp) calcareous siltstone, carbonaceous limestone and carbonaceous shale in Wangapeka Valley (Fig. 25). Trilobites and conodonts indicate that the Patriarch Formation ranges in age from lalest Cambrian to early Ordovician (Cooper & Druce 1975, Wright & others 1994). A calcareous facies of the Anatoki Formation in Cobb Valley (the "Myllon Beds" of Cooper 1989) contains Late Cambrian conodonts. At Mount Owen, limestone and calcareous sandstone and siltstone grading upward into more quartzose sandstone and siltstone comprise the Owen Formation (€pp).

The onset of carbonate deposition in the Late Cambrian to Early Ordovician marks a major change in depositional regime at the base of the Mount Arthur Group. The limestone, extensively altered to marble, with calcareous mudstone and sandstone, and some dolomite bands (Θms, Coleman 1981) is mapped as Summit Limestone in the western part of the Takaka terrane and Arthur Marble 1 in the east (Figs 26 & 27). At Springs Junction, to the south of the Nelson QMAP area, it is mapped as Sluice Box Formation (Farmer 1967). The lower part of the Summit Limestone is generally composed of carbonaceous and calcareous mudstone, and the upper part of all three units of skeletal to intraclastic limestone. Siliceous bands and nodules are present in some areas. Macrofossils are rare but conodonts have been recovered thoughout the Summit Limestone at Mount Mytton in the Peel Range. Whereas the base of the limestone ranges in age from Late Cambrian (*P. muelleri Zone*, Cooper 1989) to Early Ordovician (Arenigian; Cooper & Druce 1975), the lOp everywhere appears to be Middle Ordovician (Llanvirnian). Overlying the limestone is lhin-bedded, siliceous siltstone, quartz sandstone, calcareous siltstone and locally, carbonaceous shale and limestone (6mw, called Baldy Formation in the western part of the terrane and \Vangapeka Formation in the east, Coleman 1981). Graptolites indicate an Eastonian to early Bolindian age (Cooper 1979a, 1989). In the Pikikiruna fault slice the upper part of the Wangapeka Formation is replaced by black limestone and calcareous mudstone of Arthur Marble 2 (6ma) containing sparse Late Ordovician corals and crinoids.

Overlying the Mount Arthur Group is the Ellis Group comprising thin- to thick-bedded quartz sandstone, quartzite and siliceous siltstone (Seh, Hailes Quartzite and Fowler For-mation, Coleman 1981) with brachiopods in the upper part, indicating a Middle to Late Silurian age (Cooper & Wright 1972), and a mixed brachiopod-coral fauna indicating a Pridolian (Late Silurian) age (Wright 1967). The group appears to span the Silurian Period.

In the Pikikiruna Range amphibolite grade quartz±oligoclase±K-feldspar-biotite-muscovite gamel±clinozoisite±Staurolite schist with quartzite bands comprise Pikikiruna Schist (amp) which is thought to represent metamorphosed Mount Arthur Group rocks (Ghent 1968, Cooper 197901) or Ellis Group (Shelley 1981) rocks. Siliceous quartZ±albiteloligoclase-biotite-muscovite schist wilh thick bedded quartzite, calc-silicate lenses and metavolcanic bands are mapped as Onekaka Schist (9mo) which concordantly overlie Arthur Marble 2 and are stratigraphically equivalent to the Hailes Quartzite and, possibly, upper Wangapeka Formation. Rocks mapped as Onekaka Schist near Onekaka are of uncertain stratigraphic affinity.

Mudstone and fine-grained sandstone, with minor limestone and conglomerate form the Baton Formation (Db), which is confined to the eastern part of the terrane. Brachiopods, bivalves, corals and trilobites (Shirley 1938) which fonn shellbeds at several horizons indicate a late Lochkovian to early Pragian (Early Devonian) age and conodonts from near the base indicate an early Lochkovian (basal Devonian) age (J.E. Simes pers. comm.). The basal contact has been interpreted as an unconformity (Willis 1965, Coleman 1981) but it may be conformable and gradational into quartzose sandstone and siltstone of the Ellis Group (Bradshaw 1997).

Structure and metamorphism

The earliest deformational event (01) recognised in the Cambrian-Devonian sequence was probably that associated with melange formation in the Late Cambrian.

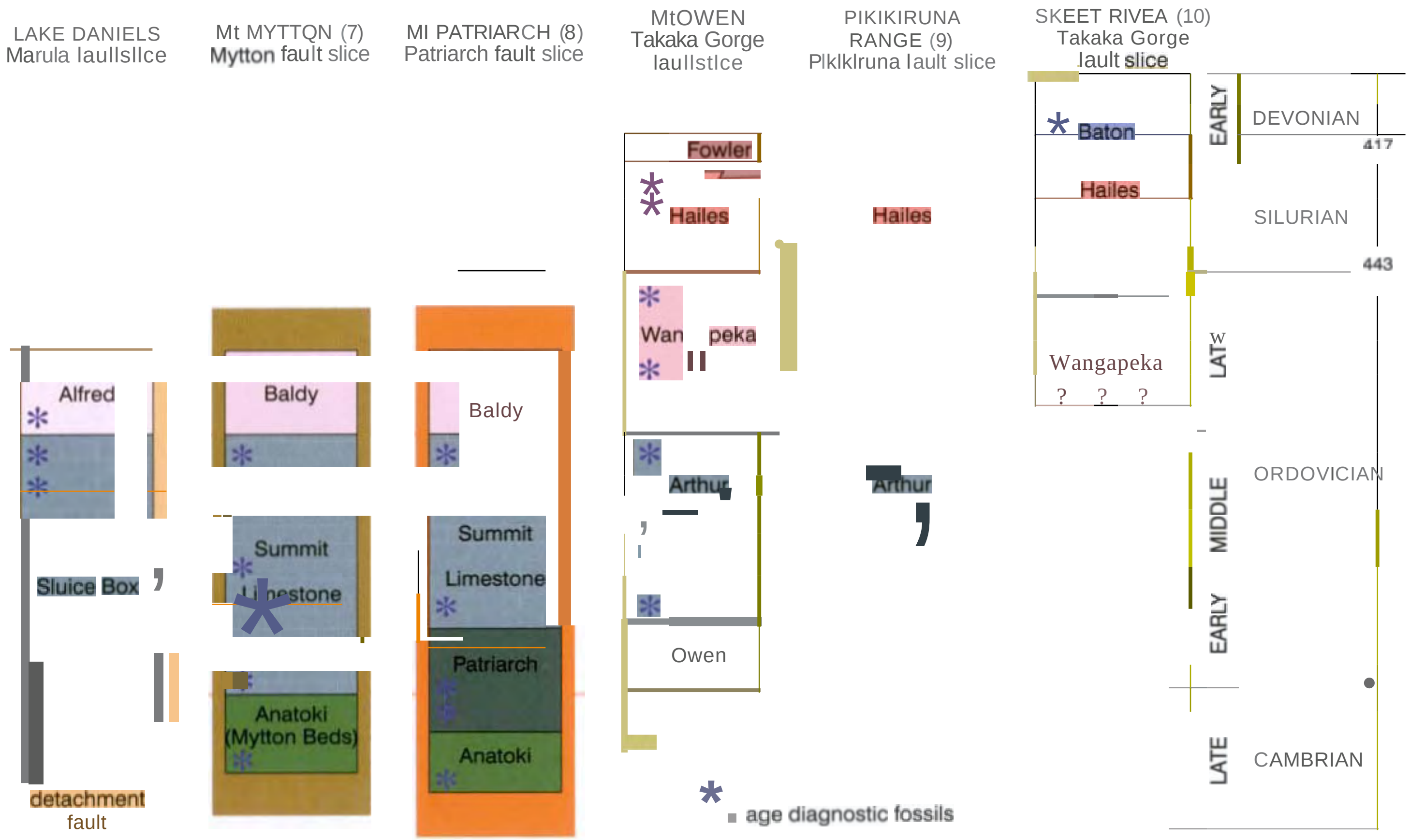


Figure 24 Correlation of Late Cambrian to Devonian formations of the Takaka Terrane. Equivalent rocks at Lake Daniels near Springs Junction, south of the Nelson sheet area, are shown for completeness. Coloured frames match fault slices depicted on Fig. 16 and the locations of the numbered columns are also shown on Fig. 16.

Figure 25 Mount Patriarch comprises a cap of Ordovician Summit Umestone overlying Late cambrian Patriarch Formation The sequence has been disrupted by a number of recumbent folds and low angle faults (Coleman 1977). *Photo: CN4124* D.L. *Homer*

Figure 26 Recumbent folds within Arthur Marble 2 from Takaka Hill, west of Riwaka, Folding of Mount Arthur Group rocks reflects widespread Middle Devonian deformation.

It is not clear how much of the observed deformation occurred at this time but it is likely to have included some of the folds and faults in Cambrian rocks.

Most of the deformation seen in the Takaka terrane is ascribed to a second (02) tectonic event. The Devil River Fault divides the Takaka terrane into western and eastern parts. The western part is dissected by numerous. generally north-trending faults including those which define the fault slices (Fig. 16). Where dip and sense of movement can be determined, they are east-dipping thrusts (e.g. Cobb Thrust). Folds are tight to isoclinal (Fig. 28), have similar northerly trend. moderate to gentle plunge and, commonly. overturned eastern limbs

Figure 27 Well bedded Summit Umeslone (Mount Arthur Group) near Mt Mytton, Peet Range.

Figure 28 The Lindsay Syncline, here defined by bedding in Tasman Formation on the Anatoki Range, is one 01 many north-trending folds with overturned limbs. These folds are associated with large scale thrusting, and resulted from a major period of deformation in the Middle Deyonian related to accretion 01 the Takaka and Buller terranes. *Photo: CN25665 D.L. Homer*

indicating a westerly vergence (Coleman 1977 & 1981. Grindley 1980). The eastern part of the terrane has fewer north-trending faults. An early phase of recumbent folding (FI of Grindley 1980) with westerly vergence inyolYes Arthur Marble 1 and Wangapeka Formation at Mount Owen and near Mount Arthur (Coleman 1981. Johnston 1974). It is most probably responsible for tectonic thickening of the Arthur Marble at Mount Owen and Mount Arthur and Summit Limestone in the Peel Range at Mount Mynon. A later phase (F2) of open, gently plunging, north trending folds is pervasive (Coleman 1981, Grindley 1971 & 1980).

Grindley (1961, 1971, 1980) proposed the early recumbent folds and thrusts were formed as a result of northward thrusting of the Cambrian sequence over the Ordovician sequence. Geometrical and stratigraphic problems with Grindley's model (Bradshaw 1982, Cooper 1989, see also Grindley 1982) resulted in an alternative model involving largely east-directed thrusting and recumbent folding (Cooper 1989, Cooper & Tulloch 1992). The Devil River Fault and Waingaro Schist Zone are thought to have fonned during east-directed thrusting and ductile shear (Powell 1983, Jongens 1997). Recumbent folds with easterly vergence have been inferred by Shelley (1984) in the upper Takaka valley and may represent the same deformational event. Their relationship with the east-dipping faults and folds is unknown.

The timing of 02 folding and thrusting pre-dates the cross-cutting Late Devonian Riwaka Complex intrusive rocks (Grindley 1978). The Permian rocks at Parapara Peak (see below) are also folded into a syncline(Grindley 1971), presumably representing a third (03) deformation.

Two discrete phases of pre-Middle Devonian metamorphism recognised in volcanogenic rocks of the Takaka terrane by Powell (l986b). The first produced incipient recrystallisation under prehnite-pumpellyite to greenschist facies conditions with quartz-albite-clinozoisite-chlorite-titanite±actinolite±carbonate±pumpellyite±prehnite±hematite assemblages. The second phase, synchronous with folding, thrusting and foliation development, took place under lower to middle greenschist facies conditions and produced ankerite-quartz-albite-chlorite-rutile-muscovite assemblages which replace the pre-exisitng assemblages in many rocks. Secondary ankerite is widespread in pre-Devonian rocks and is a most distinctive character of the terrane.

The Pikikiruna Schist. metamorphosed to amphibolite facies (Ghent 1968), was thought to pre-date the Middle Devonian Riwaka Igneous Complex by Shelley (1981). The schist, however. is adjacent to Separation Point Suite granite (Early Cretaceous) and may have formed during granite emplacement as did similar grade schist in the Golden Bay area (Wodzicki 1972. Powell 1986a, L. Hoke pers. comm.).

The Anatoki Fault separating the Buller and Takaka terranes is the most significant fault in west Nelson basement rocks (Fig. 3). The fault is generally marked by a conspicuous but narrow zone of breccia. mylonite and cataclasite. and slivers of Ordovician limestone are commonly incorporated along the fault zone (Fig. 29). In the Boulder Lake area it dips gently to the east but elsewhere its dip is steeply east to vertical.

There is almost no mixing of the two terranes along the entire length of the Anatoki Fault. The fault has had a long and complex history with several periods of reactivation. and the sense of movement along the fault has almost certainly varied with time (Jongens 1996. 1997). Earlier fault structures and fabrics have been largely obliterated by later reactivation. Powell (1985) inferred uplift of Takaka terrane over Buller terrane rocks. consistent with westward thrusting, but the age of movement is unknown. Jongens recognised considerable ductile dextral strike-slip movement at Mount Olympus and dextral normal movement at Crow River; at both localities the movement post-dates emplacement of Early Cretaceous Separation Point Suite and Crow granites.

Jongens (1997) suggested that terrane amalgamation was brought about by transcurrent movement along the Anatoki Fault followed by thrusting in the Early Devonian, prior to emplacement of the Karamea Batholith. The major movement along the fault may therefore have been transcurrent, and for this reason the original name of Anatoki Thrust is here changed to Anatoki Fault.

Tectonic history

Buller terrane rocks were deposited in Ordovician time adjacent to a continental landmass inferred to be the Australo-Antarctic segment of Gondwanaland (Cooper 1989). Cambrian rocks of the Takaka terrane formed on. and adjacent to. a volcanic island arc (Mtinker & Cooper 1995, Roser & others 1996). The histories and tectonic settings of the two terranes suggests that they were originally a considerable distance apart. perhaps hundreds of kilometres (Cooper 1989). It is possible that the chert bodies in the Balloon Melange and the Junction Formation represent one or more distinct terranes, and that the Takaka terrane is a composite of two or more terranes (Cooper 1997). The Late Cambrian to Devonian passive margin part of the sequence is previously thought to have been deposited conformably on the arc-related part (Grindley 1971 & 1980, Coleman 1981, Cooper 1989) but the recognition of the widespread Balloon Melange event in the Late Cambrian may indicate a significant tectonic contact. Although they are here retained as parts of the one terrane it is possible that the passive margin part of the sequence is allochthonous (Cooper 1997).

Amalgamation of the two terranes post-dates deposition of the Silurian Hailes Quartzite and possibly of the Early Devonian Baton Formation (Cooper 1989. Bradshaw 1997). Amalgamation pre-dates emplacement of the Middle Devonian Karamea Granite and Riwaka Complex diorites (Muir & others 1997a) and is therefore taken as

Figure 29 A tectonic sliver 01 sheared Summit Limestone occurs within the Anatoki Fault zone where it crosses the Lockett Range northwest of Mt Benson. The Anatokl Fault separates the Cambrian-Devonian Takaka terrane to the east (left) from the Ordovician Buller terrane to the west. *Photo: CN25949 D.L. Homer*

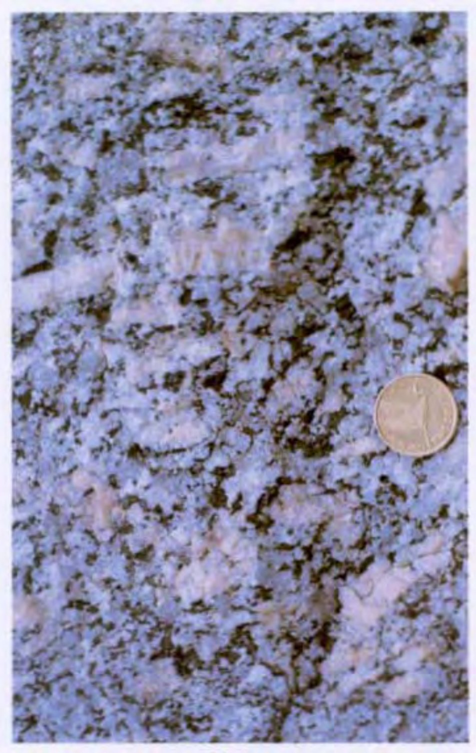
Early to Middle Devonian. An early phase of transcurrent movemem was followed by fonnation of the east dipping thrust faults and fault slices in the Takaka terrane (Jongens 1997). the Anatoki Fault. and the Boundary Syncline in the Buller terrane. The west verging folds in the Takaka temne are likely 10 have formed at the same time.

Late Devonian intrusive rocks

Voluminous potassic biotite granitic rocks form the bulk of the Karamea Batholith which intrudes the Buller terrane metasedimentary rocks in the west of the Nelson QMAP area (Tulloch 1988). The batholith is dominated by a distinctive pink, white and black. medium-to coarse· grained Karamea Suite granite (Dk; Fig. 30) containing prismatic megacrysts of K-feldspar (Dkp) in a groundmass of quanz-plagioclase-biotite±muscovite. The K·feldspar megacrysts. typically microcJine. are commonly pink or white. The eastern margin of the batholith has a north- to northeast-trending igneous flow banding defined by aligned K-feldspar megacrysts and elongate metasedimentary xenoliths. The central portion of the batholith is intruded by a fine-IO medium-grained. equigranular biotite·muscovite granite and granodiorite (Dke; Fig. 30). Biotite diorite (Dkd) occurs in a series of gently dipping sheets which are intruded by the megacrystic granite (Fig. 30). The diorite is the oldest intrusive phase recognised. Leucocratic muscovitetbiotite

Figure 30 The Karamea Suite granite is dominated by a coarse-grained biotite granite with distinctive pink euhedral K-leldspar megacrysts (A, S I271 392993, Karamea area). Locally the megacrystic granite intrudes biotite diorite (C, M27/537836, Kakapo River) and is intruded by finer grained equigranular biotite granite in a number ol areas (0, L27/462027, Oparara River).

A



B

C

D

granite (Dkm) with white labular K-feldspar phenocrysts occurs in the southwest in Ihe Glasgow Range. F1uorite-bearing biotite granite with A-type chemical affinities occurs at Whakapoai Poinl and from the base of the Toropuihi-1 exploralion well 14 km offshore (Cooper & Tulloch 1992).

The Karamea Suite has been dated by two U-Pb zircon methods which indicate a Middle Devonian to Early Carboniferous crystallisation age of 358-388 Ma (Muir & olhers 1996a. D.L. Kimbrough & AJ. Tulloch unpublished dala). The range of ages is in part due to differences in the results of the two V-Pb zircon dating methods. The granite from the Toropuihi exploration well has been U-Pb zircon dated at 312 ± 7 Ma (Mortimer & others 1997). Large amounts of inherited zircon clustering around ages of 500. 600 and 1000 Ma suggest the suite has been derived from old continental basement or has incorporated subslantial sediment into the magma (Muir & others 1996a). Despite these sedimentary components in the granite, the Karamea Suite is ambiguous with respect to 1-5 type granite classification. The diorite. and to a lesser extent the porphyritic biotite granite. has closer I-type affinities (Muir & others 1996b).

Mafic and ultramafic igneous rocks of the layered Riwaka Complex (Dr) intrude the Silurian-Devonian Onekaka Schist. Baton Formation, Arthur Marble, and Wangapeka Formation. The Brooklyn Diorite (Drb) forms the massive upper part of the layered intrusion and consists of two-pyroxene-biotite diorite, hornblende-quartz diorite, and amphibolite in a semi-concordant pluton. The diorite represents the most fractionated and felsic part of the primary magma (Grindley 1980). The diorite grades laterally into layered clinopyroxene gabbro. hornblende gabbro. norite. pyroxenite. and amphibolite of the Campbell Gabbro (Drg). The southern part of the Riwaka Complex comprises olivine c1inopyroxenite with minor hornblende pyroxenite. pyroxene peridotite. olivine-spinel peridotite and dunite of the Pokororo Pyroxenite (Drp).

The Riwaka Complex has yielded Lale Devonian 362-383 Ma V-Pb zircon and ^{40}Ar/^{39}Ar ages (Harrison & McDougall 1980, Muir & 0lhers 1994. D.L. Kimbrough & A.J. Tulloch unpublished data) which are similar to Ihose of the Karamea Suite and their age range also renects differences between the daling methods. Geochemical similarities between the Riwaka Complex and the diorites of the Karamea Suite suggest a common source (Muir & others 1996b) and may constrain docking of the Buller and Takaka terranes to pre-date Middle Devonian (Muir & others 1997a).

CARBONIFEROUS TO EARLY CRETACEOUS

The Carboniferous 10 Early Cretaceous rocks of the east Nelson area have been subdivided into a number of tectonostratigraphic lerranes (Figs 3 & 31; Coombs & others 1976. Bishop & others 1985): Brook Streel, Murihiku, Dun Mounlain-Maitai, Caples. and Torlesse (incorporating the Rakaia and Pahau subterranes). In addition, the Median Tectonic Zone has variously been interpreted as a zone of small terranes, terrane shards and stitching plutons (Bradshaw 1993). or as an igneous suite (Mortimer & Tulloch 1996). The east Nelson terranes were emplaced over a long period culminating in the Early Cretaceous. Intrusive rocks, including the Tasman Intrusives. Separation Point Suite and Rotoroa Complex. dominate the central part of the Nelson QMAP area between the Takaka terranes and the east Nelson terranes. An isolated occurrence of Permian sedimentary rocks outcrops in west Nelson at Parapara Peak.

Late Permian to Early Triassic sedimentary rocks

Late Permian to Early Triassic rocks occur in an isolated fault-bounded outlier al Parapara Peak (Fig. 32) amidst the early Paleozoic rocks of weSI Nelson. The Parapara Group (Ypp) includes a basal unil of pelitic schisl and graphitic slale, overlain by metaconglomerate and fossiliferous pebbly sandSlone of the Flowers Formation, which in lurn is overlain by thin- to thick-bedded quartzites and quanz sandstone of the Walker Quartzite (Walerhouse & Vella 1965). The basal pelitic schist and graphitic slate have previously been assigned 10 the Ordovician Bay Schist bUI are now considered to be Permian (Campbell & others in press). The rocks are folded into a syncline with a sleep western limb which has been truncated by the Parapara Fault. Delrital zircon ages from the Parapara Group are similar to those of the Permian-Early Cretaceous Torlesse terrane, suggesting a common source area, and contrast with detrital zircon ages from adjacent Paleozoic strata (Wysoczanski & others 1997).

Late Jurassic to Early Cretaceous intrusive rocks

An isolated pluton of hornblende-biOlile granite (Crow Granite, Kc) with porphyritic K-feldspar occurs in the Crow River. The granite superficially resembles nearby Karamea Suite granite but has yielded an Early Cretaceous SHRIMP V-Pb zircon age of 137±3Ma(Muir & others 1997b). The granite has calc-alkaline I-type affinities more typical of the Jurassic-Early Cretaceous Median Teclonic Zone than of the Late Devonian Karamea Suite.

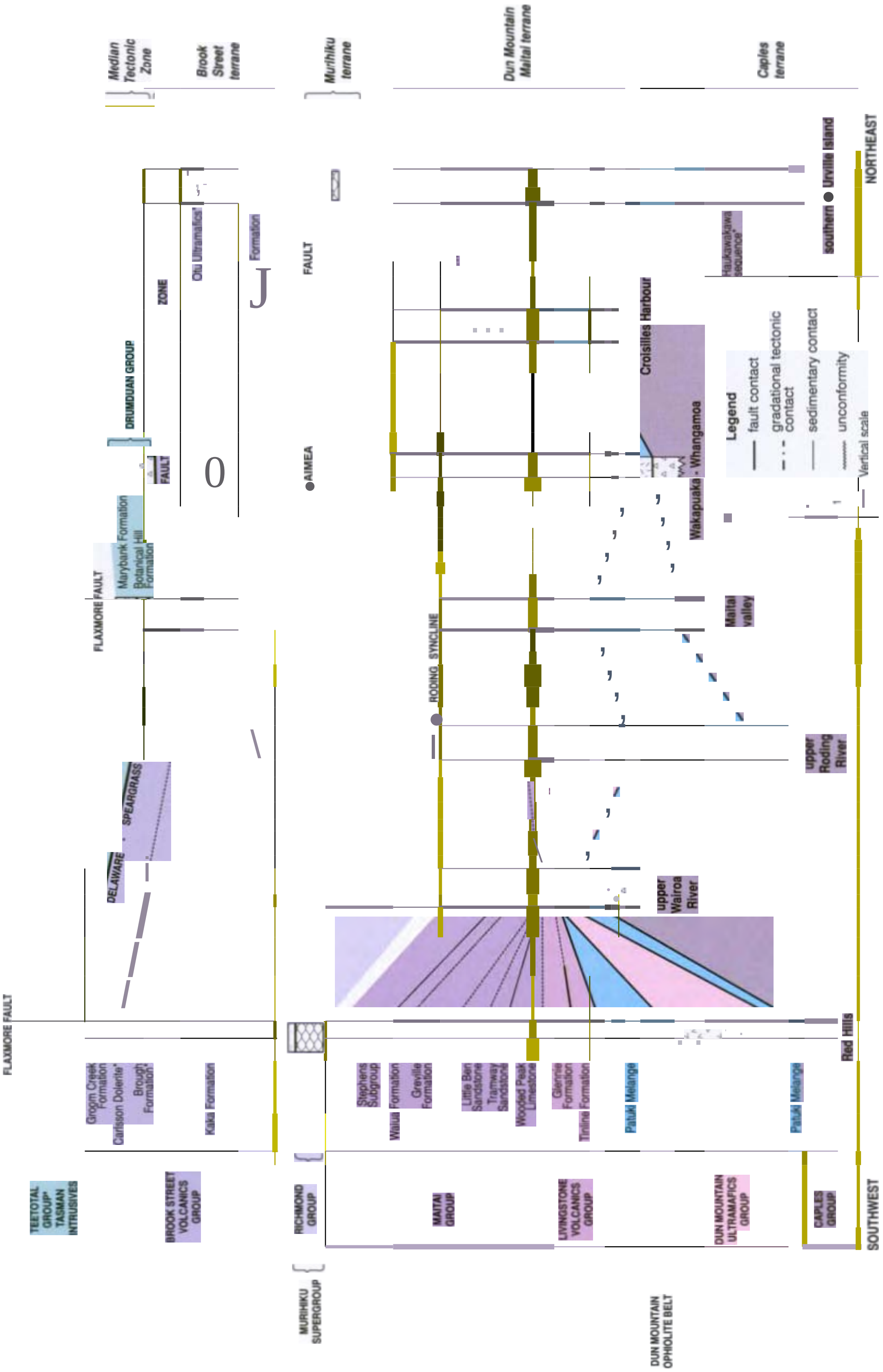


Figure 31 The late Paleozoic-Mesozoic basement rocks 01 east Nelson comprise four terranes and the Median Tectonic Zone, all 01 which show local variations In straUgraphlc thickness, complicated by excision or imbrication by faulling , The southern D'Urville Island column Is for a locality 15 km northeast af the Nelson QMAP area, and the Red Hills column Includes some rocks 10 the south altha ares. Stratigraphic names nol described In the text Of map are marked with an asterisk.

Figure 32 Permian age rocks In west Nelson occur In an IsoIaled fault-bounded outlier at Parapara Peak, west of Takaka. Whether the Parapara Group is an erosional remnant of a previously widespread cover sequence on the pre-Devonian Takaka terrane rocks or has been tectonically emplaced over a substantial distance has not been resolved. *Photo: CN25789 D.L. Homer*

The Separation Point Suite (Ks) occurs principally within a major batholith of composite granite and granodiorite pillions (Tulloch 1988) which intrudes the early Paleozoic Takaka terrane rocks. the Late Devonian Riwaka Intrusives. and the Late Jurassic Rotoroa Complex. The batholith is dominated by equigranular biotite granite (Ksg. Fig. 33). with minor amounts of leucocratic biotite-muscovite gllrnet granite. Biotite-hornblende granodiorite and diorite (Ksd. Fig. 34) occur in a number of large plutons through the batholith. Relatively leucocratic biotite quartz monzonite (Ksm) as well as granite, granodiorite and quartz porphyry occur as isolated plutons intruding Paleozoic Buller terrane rocks and Late Devonian Karamea Suite. Some of the granodiorite plutons contain molybdenum. copper, lead and zinc mineralisation (Tulloch & Rabone 1993).

The Separation Poim Suite batholith and ouLlying plutons have been dated between 109 and 121 Ma by two U-Pb zircon methods (Kimbrough & others 1994, Muir & others 1994. 1997). The I-type Separation Point Suite is characterised by primitive Sr and Nd isotopic ratios and limited inherited zircon suggests the granite was derived from the melting of mafic lithosphere (Muir & others 1995).

Dark grey biotite quartz diorite in the southwestern part of the map area near Granity has Rahu Suite (Krd) affinities (Tulloch 1983). Early Cretaceous Rahu Suite granitoids are widespread immediately south of the map area around the Buller River and the Paparoa Range. The I/S-type Rahu Suite shows more crustal involvement than Separation Point Suite.

Median Tectonic Zoue

The Medilln Tectonic Zone of New Zealand incorporates several units which lie west of the convergent margin rocks of the Eastern Province (Brook Street, Murihiku. Dun Mountain-Maitai. Caples. and Torlesse terranes) and east of the Paleozoic Western Province (Buller and Takaka terranes). The Median Tectonic Zone has evolved as a concept from a line (the Median Tectonic Line) signifying the boundary of paired metamorphic belts (Miyashiro 1961).1100 the boundary between the Western and Eastern provinces (Landis & Coombs 1967). to a zone between 10 and 35 kIn wide consisting of mainly Mesozoic subduction-related caJc·alkaline plutons. predominantly diorite (Bradshaw 1993. Kimbrough & others 1993).

In Nelson the Median Tectonic Zone is about 15-20 kIn wide but is largely obscured by Cenozoic rocks in the Moutere Depression. Only near Nelson City and near Glenhope are Median Tectonic Zone rocks exposed. although more extensive outcrop occurs immediately south or the Nelson QMAP area. Medinn Tectonic Zone

Figure 33 The Early Cretaceous Separation Point Suite is dominated by equlgranular, medium-grained biotite granite. The granite is typically weathered with feldspar minerals breaking down into days as at Ugar Bay (N25I 024436). *Photo:* CN45200 *D.L. Homer*

Figure 34 Raft of hornblende quartz diorite within Separation Point Suite granite at Ugar Bay (N25/024436). *Photo: CN45201 D.L. Homer*

rocks have also been identified in the base of the Ruby Bay-1 drillhole (Mortimer & others 1997). The Median Tectonic Zone is separated from the Brook Street terrane of the Eastern Province by the Delaware-Speargrass Fault Zone. In the west the zone is sutured to the Takaka terrane of the Western Province by the Separation Point Batholith.

Carboniferous to Early Cretaceous intrusive and sedimentary rocks

The Rotoroa Complex (Jr) crops out at the southern edge of the map area at Glenhope and consists of sheared and altered biotite granite and granodiorite, and amphibolitic hornblende-biotite diorite (Coleman 1981). The Rotoroa Complex occurs more extensively to the south of the map area (Challis & olhers 1994) and has been dated at 155 ± I Ma (Kimbrough & others 1994). The Rotoroa Complex is associated with slrong magnetic anomalies and is inferred to underlie the Late Miocene-PlioceneGlenhope Formation and Moutere Gravel in the Moutere Depression (Wellman 1973, Lihou 1992).

Weakly deformed, altered, coarse-grained biotite±hornblende granodiorite (Echinus Granite, Cae) dated at 310 ± 5 Ma (V-Pb zircon, Kimbrough & others 1993) intrudes the strongly foliated and lineated biotite and/or hornblende quartzofeldspathic granite mylonite and orthogneiss (Platform Gneiss, Cap) at Pepin Island (Fig. 35; Lauder 1964, Beresford & others 1996). Hornfelsed and silicified quartzofeldspathic sandstone with interbedded siltstone, mudstone and pebble conglomerate (Fall Formation/Pepin Group, YpO occurs adjacent to the Platform Gneiss. The base and top of the Pepin Group are not exposed and the relationship to the Platform Gneiss is unclear. The Pepin Group is only constrained in age by the intruding Early Jurassic Tasman Intrusives Group.

The Tasman Intrusives Group consists of plugs and dikes of porphyritic hornblende andesite and quartz-biotite andesite of the Palisade Andesite (Jap), and a series of widely metasomatised small intrusive stocks of hornblende granodiorite, tonalite, quartz diorite, and syenite comprising the Cable Granodiorite (Jac). The

Figure 35 The ?Carboniferous Platform Gneiss OII Pepin Island is a strongly loliated and lineated, segregated granite mylonite and orthogneiss. The gneiss is one of many rock types within the Median Tectonic Zone.

Palisade Andesite dated at 132-176 M0 (K-Ar hornblende) is no younger than Late Jurassic (Johnston 1981). The Cable Granodiorite has been dated at 143 ± 3 MOl (zircon U-Pb. Kimbrough & others 1993. 1994).

The Drumduan Croup (Jd) consists of fine-grained. altered green tuffs and purplish-red tuff breccia of the Botanical Hill Formation (Jdb). and poorly bedded grey mudstone, siltstone. and fine-grained sandstone with thick beds of grey breccia of the Marybank Formation (Jdm). The Marybank Fonnation contains Late Triassic to Early Cretaceous (probably Jurassic) plant macrofossils. The presence of metamorphic lawsonite indicates high pressure-lOW temperature metamorphism of the Drumduan Group (Johnston & others 1981). Fine-grained altered green tuffs and purplish-red tuff breccia of the Botanical Hill Fonnation have been bracketed with Marybank Formation as part of the Drumduan Group (Johnston 1987).

Highly tectonised. brecciated and schistose sedimentary rocks and mafic and intermediate volcanic rocks occurring between the Drumduan and Brook Street Volcanics groups are mapped as Wakapuaka PhyUon.ite (Kw). Some of the rocks are derived from Marybank. Formation and a Late Jurassic to Early Cretaceous age is inferred (Johnston 1981). The foliation is typically steeply east-dipping. The phyllonite has been imerpreted as the zone of thrusting of the Brook Street Volcanics Group westward over the Drumduan Group (Johnston & others 1987) in the Early Cretaceous.

Brook Street terrane

The Brook Street terrane contains the remnants of a Permian calc-alkaline volcanic arc that is exposed in Southland and east Nelson. Within the Nelson QMAP area the terrane fonns a 5 km-wide fault-bounded strip from Delaware Bay to Nelson City. To the southeast the terrane is obscured by Cenozoic sediments although it reappears several kilometres south of the map area boundary.

Permian volcanic and sedimentary rocks

The Brook Street terrane in the Nelson QMAP area comains volcanogenic sedimentary and minor igneous rocks of the Brook Street Volcanics Croup. The basal Crampian Formation (Ybr) contains bedded grey calcareous mudstone. siltstone. and sandstone. with some tuffaceous material (Fig. 36) and rare lenses of black impure limestone. Conformably overlying are andesitic augite tuff and breccia (Fig. 37) with rare basalt flows of the Kaka Formation (Ypk). which in turn is overlain by generally poorly bedded andesitic tuffs and volcanogenic sandstone of the Croom Creek Formation (Ybg; Bruce 1962. Johnston 1981). The rocks are typically altered with widespread albite, chlorile, epidote. sericite. pumpellyite. actinolite and prehnite. reflecting prehnite-pumpellyite to pumpellyite-actinolite facies metamorphic grade.

Atomodesmatinid fragments scattered through the Grampian Formation and the gastropod ***Peruvispira*** (Bruce 1962) indicate a Pennian age; fossils immediately south of the Nelson QMAP area are of late Early Permian age. The sequence dips steeply. and youngs to the southeast.

Figure 36 Well bedded tulfaceous sandstone and siltstone near the gradational contact between Kaka and Grampian formations of the Brook Street Volcanics Group in the Maitai valley (027/ 360926). *Photo: CN45178 D.L.* Homer

Figure 37 Augitetuff of the Kaka Formation, Brook Street Volcanics Group at its type locality at Brook Street Quarry in Nelson City (027/346906). The coarse crystal size, and accompanying breccia fragments, indicate a proximal source of the volcanism. PhoIO: *CN45180* D.L. *Homer*

Murihiku ***terrane***

The Murihiku terrane consists of Triassic-Jurassic, calc-alkaline, volcanogenic sedimentary rocks which occur as thick sequences in the Southland, Nelson. and Waikato areas.

Triassic sedimentary rocks

In the Nelson QMAP area the terrane is represented by the Richmond Group (Tr) of the Murihiku Supergroup, which is present over a strike length of more than SOkm in a belt nowhere more than 2 km wide. The western contact is faulted against or obscured by Tertiary and Quaternary sediments but at depth is faulted against the Brook Street Volcanics Group (Johnston 1982a,b). The Eighty-eight Faull separates Richmond Group and the Maitai Group to the east. The Richmond Group is characterised by indurated and weakly metamorphosed (zeolite facies) sedimentary rocks comprising poorly to mcxlerately well bedded sandstone, siltstone, mudstone. conglomerate, tuffs. and sparse andesitic sills. Most of the group is fossiliferous. including some shellbeds, and ranges in age from Middle to Late Triassic. The conglomerates typically contain igneous (including large well rounded felsic plutonic rocks) and sedimentary clasts

Figure 38 Conglomerate containing abundant igneous and sedimentary clasts within a succession of medium bedded volcanogenic sandstone and mudstone of the Triassic Richmond Group (Murihiku terrane) aI Wairoa Gorge (N28/211786). *Photo: CN45183 aL. Homer*

(Fig. 38). The Richmond Group typically dips moderately to the southeast. The beds are folded into the Heslington Syncline. although the eastern limb is locally overturned and elsewhere largely faulted out.

Dun Mountain·MaiJai terrane

The Dun Mountain-Maitai terrane is a distinctive feature of South Island geology. occurring in south Otago. northern Southland. and northwest Otago where the terrane terminates against the Alpine Fault. The terrane reappears in east Nelson at the Red Hills on the northwest side of the Alpine Fault. The 480 km of apparent dextral strike-slip along the Alpine Fault was recognised by linking these rocks with their counterparts in northwest Otago.

The Dun Mounlain-Maitai terrane in Northwest Nelson comprises the Dun Mountain Ultramafics and Livingstone Volcanics groups. constituting the Dun Mountain Ophiolite Belt (Coombs & others 1976. Davis & others 1980). overlain by the Maitai Group. The Maitai Group ranges in age from Late Permian 10 Middle Triassic (Owen 1991) in Nelson. The Dun Mountain Ultramafics Group and Livingstone Volcanics Group are of Early Permian age whereas the Maitai Group ranges from Late Permian to Middle Triassic.

Permian ultramafic and mafic igneous rocks

The ultramafic rocks of the Early Pennian Dun Mountain Ultramafics Group have a semi-continuous strike length of 70 km within the Nelson QMAP area. The ultramafic rocks of east Nelson rarely exceed I km in width except in the vicinity of Red Hills where the rocks are about 9 km wide. The rocks weather to a distinctive red-brown (dun) colour and lend to be sparsely vegetated (Figs 39. 40). Beech forest (*Nothofagus*) is typically stunted or absent on these ultramafic rocks in sharp contrast to the mature tall stands on adjacent rock types. The lack of vegetation has been attributed to the higher and more toxic levels of extractable nickel and/or magnesium in the ultramafic rocks (Robinson & others 1996). The Red Hills consist largely of unserpentinised. massive or locally layered protoclastic harzburgite (Ydp) or harzburgite. with minor dunite (Ydm), and minor wehrlite. gabbro. and rare plagiogranite (Fig. 39. Walcott 1969). Harzburgite. pyroxene and hornblende gabbro and other cumulate rocks occur as fault slivers along the western margin of the ultramafic rocks.

North of the Red Hills Fault. the ultramafic rocks are of cumulate origin and consist largely of serpentinised layered harzburgite. with minor dunite, pyroxenite, and gabbro (Ydc:). Unserpentinised dunite occurs locally at Dun Mountain. its type locality (Hochsteller 1864). Rodingile (after the type locality at Roding River) dikes are common and irregular layers of chromite up to 30 mm thick are widespread. Podiform chromite deposits with localised copper mineralisation are present close to the western boundary. Primary layering is typically steeply dipping and youngs to the west. The ultramafic rocks are variably IeCtonised from coherent sequences through to strongly sheared tectonic melanges on the eastern margin of the terrane and as fault slivers on either side of the Red Hills.

Figure 39 Vertical igneous layering in cumulate ultramafic rocks of the Dun Mountain Ultramafics Group on Porter Ridge In the Red Hills (N28/ *107522). Photo: CN7071* D.L. *Homer*

Figure 40 The red-brown coloration and lack 01 vegetation typifies outcrop 01 the Dun Mountain Ultramafics Group, seen here on the Bryant Range looking northeast to Dun Mountain (centre distance). To the southwest (right), the lorested Patuki Melange is in fautl contact with the ultramafics. To the northeast, the forested hills comprise Livingstone Volcanics Group and basal Maitai Group. *Photo: CN13554* D.L. *Homer*

The Patuki Melange forms a struclural boundary zone between the Dun Mountain Ultramafics Group and the Caples Group. Conventional zircon U-Pb dating of samples from the Red Hills and correlative ultramafic rocks in Southland gives ages spanning 275-285 Ma (Early Permian. Kimbrough & others 1992).

The igneous rocks of the Livingstone Volcanics Group. formerly mapped in Nelson as the Lee River Group. comprises two formations; the Tinline Formation (VII) is overlain by the Glennie Fonnation (Y1g). The Tinline Formation consislS of massive 10 foliated. tholeiitic. plagioclase-augite-magnelile gabbro grading from coarse-grained at the base through a sheeted dike complex 10 miCTOgabbro at the top. Alteration 10 amphibole-albite-chlorile-epidote-sericite is widespread. The Glennie Formation consislS of sheets and flows of fine-grained spilitic basalt with minor microgabbro at the base and basaltic breccia lenses. up to 8 m thick. near the top.

The group is mineralogically and chemically similar to ocean floor basalts with very low $^{87}Sr/^{86}Sr$ and depleled large-ion Iilhophile elemenlS (Davis & others 1980). Zircon U-Ph dating indicates an Early Permian age both in Nelson and Southland (Kimbrough & others 1992). The Livingslone Volcanics Group is unconformably overlain by Ihe Late Pennian Maitai Group.

Early Permian to Triassic sedimentary rocks

The Maitai Group comprises well bedded and relalively weakly metamorphosed sedimentary rocks folded into the Reding Syncline. The basal formations of Ihe group are only exposed on the southeast limb of the fold. The Upukerora Formation (Ynm) occurs as a narrow discontinuous band unconformably overlying Livingstone Volcanics Group in the Bryant Range. The Upukerora Formalion is characterised by breccia clasls of fine-grained volcanic rocks in a hematised matrix. Farther northeast. there are isolated occurrences of dark grey siltstone and sandstone. The Wooded Peak Limestone (Ymw) rests unconfonnably upon Upukerora Formation. and consists of bedded fine-grained grey limestone (Fig. 41). and calcareous sandSlone and sillStone with locally abundant atomodesmatinid shell debris. The limestone is up 10 I km thick and occurs throughout except where excised by faulting. The conformably overlying Tramway Sandstone (Ymt) auaios a thickness of I km along the Bryant Range and consislS of well bedded grey sandstone and sillStone, impure limeslone with minor interbedded dark grey mudstone and numerous atomodesmatinid fossils (Johnston 1981. 1993). The sandstone contains abundant volcanic debris dominaled by andesite as well as sedimentary rock and locally minor serpentinite. The Little Ben Sandstone (T0Il) conformably overlies Tramway Sandstone. reaching thicknesses of 600 m. but is more laterally restricted and in some areas is absent from the local Maitai Group stratigraphy. The Liule Ben Sandstone is dominated by hard green fine- to coarse-grained volcanogenic sandstone and minor sillStone. The Greville Formation (Tmg) is one of the more areally extensive Mailai Group formations and. taking into accoumthe imernal folding and faulting. is estimated to be belween 1000 and 1500 m thick. The Greville Formalion conforrnably overlies the Little Ben Sandstone, and locally Tramway Sandstone. and consists of laminated 10 thin-bedded grey sandstone and mudslone (Fig. 42) with locally interbedded thicker green sandslone and sparse ammonites. The Waiua Formation (Tmw) is between 500 and 700 m thick and differs primarily from the conformably underlying Greville Formation in the red or reddish-purple colour of the finer grained beds. caused by the presence of finely divided hematite (Fig. 43). Thicker sandslone unilS. with beds of conglomerate containing andesitic and sandslone c1aslS occur in some areas. The Stephens Subgroup (Tms) is also areally eXlensive and is estimated to be aboul2000 01 thick. The unil may be locally unconfonnable with the underlying Waiua Fonnation and is more lithologically variable than the other units within the Maitai Group. Slephens Subgroup consislS largely of poorly 10 well bedded grey or green sandstone with minor mudstone (Fig. 44). Massive green or red sandstone, red mudstone, light grey luff and lenses of conglomerate and fossiliferous limestone occur sporadically through the sequence. Serpentinitic breccia containing c1aSIS of serpentinite, gabbro, dolerite, and ultramafic rock (Tmm) occurs in fault-bounded lenses within basal Maitai Group at Croisilles Harbour. The origin of the tcctonised breccias is unclear and they may be olistotromes (Landis & Blake 1987), intrusions. or diapirs (Johnston 1993).

The Maitai Group has been folded into the regional Reding Syncline. the axis of which has largely been faulted OUI by the Whangamoa Fault. The eastern limb comprising the basal formations of the Maitai Group generally dips sleeply west or northwesl and is relatively planar. The weslern limb comprising the upper unilS of the group has generally shallower dips and numerous ENE- to NNE-trending folds. The group is internally dissected by numerous faullS. and an axial planar cleavage is well developed within some lithologies. The age of the Maitai Group is constrained by Late Permian fossils such as *Maitaia* from the Tramway Sandstone and Early Triassic ammonoids in the Greville Formalion (Waterhouse 1964. 1993). The Stephens subgroup contains blocks oflimeslone. with reworked Late Permian fossils. The Permian-Triassic boundary is probably at the top of the Tramway Sandstone (Owen 1991).

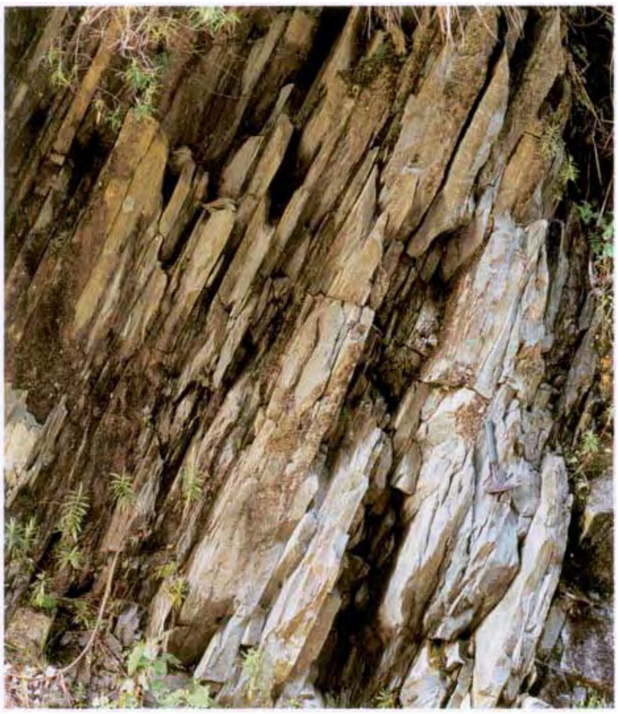


FIgure 41 Thin-bedded, fine-grained Wooded Peak Umestone Is the oldest Maital Grouplormation exposed on the Maungatapu Track in the Maltal Valley (027{424892). *Photo: CN45 146 D.L. Homer*

FIgure 42 Steeply northwest-dipping, thin-bedded Greville Formation with a weak steeply east-dipping cleavage on a roadcut near Whangamoa Saddle (027/477988). *Photo; CN45173 D.L. Homer*

FIgure 43 Charact8fistic red and green laminated siltstone 01 the Waiua Formation at Lee River. The red coloration is caused by fine disseminated hematite (N28/230756). *Photo: CN45186 D.L. Homer*

After deposition of the basal Upukerora Formation in local fault basins, the bulk of the Maitai Group was probably deposited in a large elongate basin. The Wooded Peak Limestone was derived from redeposited shell material and mafic/ultramafic clastic material from topographic paleohighs of LivingslOne Volcanics Group and Dun Mountain Ultramafics Group (Johnston 1996). The Tramway Sandstone contains more quartz and generally lacks a significant mafic rock contribution. in contrast to the more volcanogenic Little Ben Sandstone. The Greville and Waiua formations are fine-grained, thin-bedded rocks which were probably deposited in deep water far from land. The Stephens Subgroup is also attributed to deep-water turbidite fan deposition although the variability of the formation may reflect shallowing of the sea.

Metamorphism of the Maitai Group largely falls within the prehnite-pumpellyite facies but sparse lawsonite within the basal formations and in the vicinity of the axis of the Roding Syncline indicates local metamorphism to lawsonite-albite-chlorite facies (Landis & Blake 1987).

Figure 44 Well developed ripple marks on a bedding surface 01 Stephens Subgroup al Federal quarry, Reding River (N28I 230795). *Photo: CN40935 D.L. Homer*

Caples terrane

The Caples terrane is areally extensive and forms much of south and west Otago, the Marlborough Sounds and western North Island geological basement. The Caples terrane ranges from weakly metamorphosed sandstone and siltstone to high-grade schist near its suture with the Torlesse terrane in Otago and Marlborough. In the Nelson QMAP area the Caples terrane is represented by the Caples Group, which forms the bulk of the mountains between the Bryant and Richmond ranges.

Permian toTriassic sedimentary rocks

Non-schistose Caples Group (Ye), previously mapped in the Nelson/Marlborough area as Pelorus Group, consists of grey generally well bedded indurated sandstone and siltstone (Fig. 45) with thick sequences of coarse sandstone and minor conglomerate (Ward **Formation** Yea). These rocks enclose alternating red and green sandstone and siltstone interbedded with massive green sandstone and sparse conglomerate of the Wether Formation (Yew), and conformably overlie predominantly massive to poorly bedded green sandstone of the Star Formation (Yes; Walcott 1969). The Caples Group generally dips southeast but sedimentary younging directions indicate widespread overturning. In the upper Pelorus valley, a major east-closing inverted anticline is inferred from minor fold vergence (Johnston 1977) although the eastern upper limb of the fold has not been recognised. The Caples Group lacks good diagnostic fossils and is poorly constrained in age to between Late Permian and Middle Triassic.

Permian to Triassic schistose rocks

The Caples Group becomes increasingly schistose southeast towards the Wairau Valley. The schistose Caples Group rocks have been divided according to the textural zone nomenclature applied to the Otago Schist by Bishop (1972). These textural zones range from I.z. IlA where incipient cleavage exists in sandstone units through t.z. 1m where the foliation becomes penetrative and bedding becomes increasingly transposed and dismembered until eventually obliterated. Incipient segregation laminae of quartz-feldspar 1-10 mm long mark t.z. IlIA, and I.z. um has laminae>10 mm long and up to 2 mm wide. The formations described from the non-schistose Caples Group become difficult to map with increasing cleavage development and their schistose equivalents have generally not been differentiated. Weakly metamorphosed, undifferentiated Caples Group rocks grade into t.z. lIA semischists (Fig. 46), with widespread transposition of bedding into parallelism with foliation and grade further into t.z. IlIA segregated schists (Fig. 47). A distinctive band of well foliated quartzite and minor foliated greenschist occurs with t.Z. HB schistose sandstone and siltstone in the Wakamarina valley (Wakamarina Quartzite, Ycq). Fine-grained mylonitic rocks below the quartzite have been variously interpreted as a pre-metamorphic thrust (Johnston 1993) or a major extensional shear zone (Skinner 1996). North- to northeast-trending narrow wnes of ductile shear are also present within the schistose rocks.

Figure 45 Thin- to very thin-bedded indurated sandstone and siltstone with light-coloured carbonate lenses of I.z. I caples Group In the Pelorus River (027/492871). *Photo: CN4513B D.L. Homer*

Figure 46 Transposed sandstone and siltstone beds in t.z. IIA Caples Group semischist in the Wakamarina River (027{628835). *Photo: CN45161 D.L. Homer*

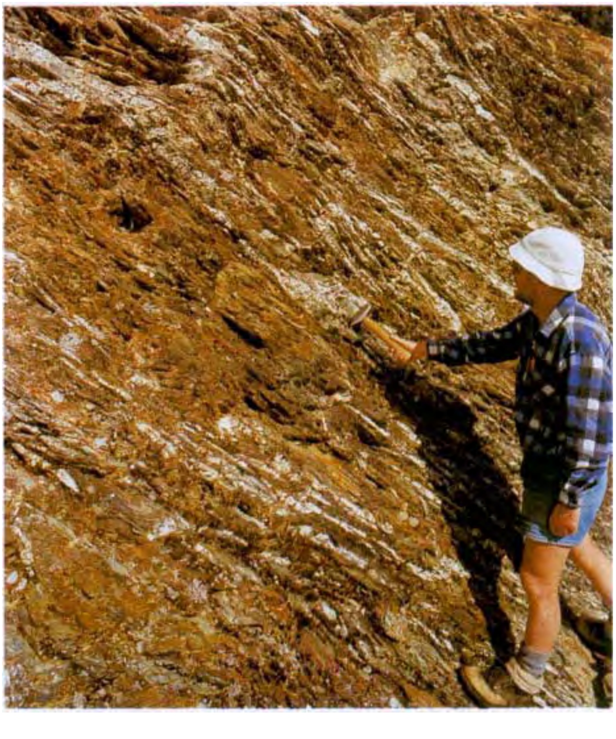


Figure 47 Foliated t.z. IIIA caples Group-derived schist with incipient quartz segregation laminae on the Lake Chalice Road (028f394604). Numerous foliation-parallel quartz veins have accentuated the schistose appearance 01 the rock. *Photo: CN25709 D.L. Homer*

The dominant foliation throughout the schistose Caples Group is northeast-trending and shallow-dipping. The foliation is regionally and openly folded into the Goulter Synform (Monimer & Johnston 1990. Johnston 1993. 1994). Textural metamorphic grade increases from t.z. I in the northwest to t.z. lllA in the southeast across the axial trace of the Gauller Synform. The lack of textural zone symmetry across the synfonn suggests the fold is not post-metamorphic despite the fold being defined by deviations in metamorphic foliation. The origin of the structure remains enigmatic. Cenozoic faulting. such as the Queen Charlotte Fault Zone. has resulted in local displacement of textural zones.

The metamorphic grade of the Caples Group ranges from prehnite-pumpellyite facies in the northwest through pumpellyite-actinolite facies to greenschist facies in the southeast.

?Triassic melange

Tectonic melanges occur between the Dun Mountain Ultramafics Group and the Caples Group (Patuki Melange, Tmp), and within the Caples Group (Croisilles Melange. Tmc). They consist of blocks of variable size comprising basalt, gabbro. ultramafic rock, siltstone. and sandstone in a sheared serpentinitic matrix (Fig. 48). The variation in rock type and their differing susceptibilities to erosion has resulted in a characteristic hummocky topography (Fig. 49). The largely continuous Patuki Melange. up to 4.5 km wide. is interpreted as the suture zone between the Dun Mountain-Maitai and the Caples terranes. The melanges cut Caples Group rocks and are probably younger than Triassic. The Croisilles Melange consisting of sheared serpenlinite is discontinuous and in many places is only weakly developed. At Croisilles Harbour the melange encloses a sandslone block containing a Late Permian fauna (Dickins & others 1986).

Torlesse terrane

The Torlesse terrane has the largest onland area of any terrane in New Zealand and extends through Otago. Canterbury. and Marlborough into the axial ranges of the North Island to East Cape. The terrane and a number of sublemnes comprise the Torlesse Supergroup which ranges from Pennian to Early Cretaceous in age and consists predominantly of quanzofeldspathic sandstone (loosely termed greywacke) and argillite. The Esk Head Melange. the largest of a number of melange units which cut the Torlesse Supergroup. separates the Rakaia and Pahau subterranes. In the Nelson QMAP area, the Rakaia subterrane rocks are strongly metamorphosed and the Pahau subtemne rocks have undergone only low grade metamorphism.

Figure 48 The Patuki Melange contains tectonic lenses 01 rodingite and other igneous rocks In a strongly foliated serpentinitic matrix at Collins Valley quarry, Whangamoa River *(027/551055) Photos: CN45129.CN45133 D.L. Homer*

Figure 49 The contrast in hardness between the tectonic clasts and the softer matrb(of the Patukl Melange commonly results in a hummocky topography which is otten accentuated by the scrubbier vegetation on the serpentinite, as on the Bryant Range southeast of Mt Duppa. *Photo: CN26423 D.L. Homer*

Triassic schistose rocks

The rocks of the Rakaia sublerrane (Tt) are dominated by pelitic schist with textural metamorphism ranging from t.Z. lIlA 10 t.Z. lIm-IV. Schists at t.Z. IV are s!fongly foliated and segregated with quartz-feldspar segregation laminae>2 mm thick (Bishop 1972). The rocks are grey, well foliated and segregated with widespread veining parallel to foliation (Fig. 50). The source rocks were probably well bedded alternating quartzofeldspathic sandstone and mudstone. and sandstone dominated sequences. The schists are metamorphosed to greenschist facies and have been multiply folded and sheared. The age of the Rakaia subterrane schist is not known but is probably Triassic although a Permian age cannot be discounted.

The boundary between the Torlesse and Caples terranes is a tectonically mixed and metamorphosed transition zone (Tel) up to 1.5 km wide (Johnston 1994). The transition zone has been partly excised by Cenozoic movement on the Northbank Fault Zone. The transition zone consists of fine-grained schist derived from Caples Group and Torlesse Supergroup. with lenses of greenschist and talcose schist derived from mafic and ultramafic igneous rocks respectively (Johnston 1994).

FIgure 50 Segregated t.z.IIIB Marlborough Schist derived from metamorphosed Trlassic-Jurassic Torlesse Supergroup of the Rakaia subterrane, north bank, WaJrau River. (028/616650). *Photo: CN45160 D.L. Homer*

Figure 51 Foliated, veined, and segregated greenschist band within Marlborough Schist, north bank Wairau River. Greenschist bands such as these are usually derived from tuffaceous horizons (O28/691671). *Photo: CN45159 D.L. Homer*

Figure 52 Medium- to thin-bedded, unfoliated sandstone and mudstone of the Cretaceous Pahau subterrane, Torlesse Supergroup, at Two Cottage Stream, Wairau Valley (028/405504). The beds dip and young to the southeast. *Photo: CN45149 D.L. Homer*

The zone has similar rock types to the Aspiring lithological association in northwest Otago (Craw 1984) which occurs at the Caples and Torlesse terrane boundary (Norris & Craw 1987, Cox 1991). Mortimer (1993b) on geochemical grounds incorporated the Aspiring lithological association into the Torlesse terrane, although recognised there may be some structural complexities at the Torlesse/Caples boundary. Greenschist and schist on the north bank of the Wairau River (Fig. 51) may be part of a down-faulted block of Caples terrane.

Late Jurassic to Early Cretaceous sedimenlary 'ocks

The Torlesse Supergroup rocks of the Pahau subtemnc are dominated by weakly-metamorphosed, grey. well-bedded alternating sandstone and mudstone (Fig. 52) with poorly bedded or thick-bedded sandslone (Jtp. Ktp). The rocks are metamorphosed to zeolite facies. Plant fragments are locally abundant are not age-specific. Fossils from the Leatham River area to the sooth of the Nelson QMAP area boundary are of Late Jurassic age (Johnston 1990). A Jurassic to Early Cretaceous age is inferred for Pahau rocks in the Nelson QMAP area. The rocks strike northeast and generally young to the southeast although folding occurs in some areas. Two melange zones with disrupted sandstone and/or mudstone-dominated sequences, containing blocks of chert and basalt (Ktm). occur within Pahau subterrane rocks of the map area. The westernmost melange zone is up to 4 km wide and extends south into the Waiohopai valley. The melange is arbitrarily shown as the boundary between Pahau subterrane rocks of Late Jurassic and Early CretacCQus age. The melanges are distinct from the Esk Head Melange which truncates against the AlpinelWairau Fault on the southern edge of the map area beneath Quaternary alluvial gravels. The Esk Head Melange south of the Alpine Fault comprises a 20 kln-wide zone of deformed Torlesse rocks that mark the tectonic contact between the Pahau and Rakaia subterranes (Johnston 1990).

LATE CRETACEOUS TO EARLY PLEISTOCENE

Northwest of the Waimea Fault. Late Cretaceous Ioearly Pleistocene sediments record the formation and deformation of localised fault-bounded sedimentary basins in response to changing tectonic stresses across the developing boundary between the Australian and Pacific plates. Most time intervals of the Late Cretaceous and Cenozoic are represented, and the sedimentary succession commonly shows marked lateral facies and thickness changes, as well as relatively abrupt relocation of depositional areas and changing paleohighs. The Murchison Basin in the southern part of the QMAP

Nelson map area is one of these localised fault-bounded basins which has an unusually thick Late Oligocene-Miocene sedimentary sequence.

Late Cretaceous to Paleocene sediments

In the northwest of the Nelson QMAP area, Late Cretaceous sedimentary deposits are present in narrow, northeast-trending, fault-bounded basins which are well defined from offshore seismic surveys and drillholes (King& Thrasher 1996, their map 8). Part of one of these basins is now partly exposed onshore around Whanganui Inlet as the Pakawau Group. The group is divided into two major units; the predominantly terrestrial Rakopi Formation, resting on basement rocks, and the shallow marine North Cape Formation. King & Thrasher (1996), from consideration of Taranaki Basin stratigraphy offshore, placed the boundary between the Pakawau Group and the Farewell Formation of the Kapuni Group near the Cretaceous-Tertiary boundary.

The Rakopi Fonnation (Kpr) consists of terrestrial coal measures, predominantly sandstone cyclically interbedded with carbonaceous mudstone and thin coal seams. An abundance of thin coal seams is typical of this unit For example, a drillholenear Rakopi in Whanganui Inlet (M25n39656) penetrated 433 m of coal measures with 75 cool seams, none more than 0.5 m thick. The Otimalaura Conglomerate Member (Kpo) is locally exposed at the base of the Rakopi Formation at the southern edge of its outcrop area (Bishop 1971). and consists of cobble-size clasts of Paleozoic lithologies in a sandy matrix. Lithofacies in the Rakopi Formation suggest swamp and overbank deposition on a fluviatile floodplain.

Figure 53 Cross-bedded sandstone and **pebbly** sandstone 01 the late Cretaceous North Cape Formation, Pakawau Group, at Pecks Point, Whanganui Inlet (M24/784707). *Photo: CN40468 D.L. Home'*

Figure 54 **Carbonaceous** laminae In cross-bedded sandstone 01 the Late Cretaceous North Cape Formation, Pakawau Group, on the southern head of Whanganui Inlet (M24/705693). *Photo: CN40792 D.L.* ***Homer***

In contrast, theoverlying North Cape Formation (Kpn) consists mainly of shallow-marine sandstone interbedded with siltslone (Fig. 53; Wizevich & others 1992). locally containing dinoflagcllates. and minor conglomerate with Iittle carbonaceous material or coal seams (Fig. 54). The formation is inferred to have been deposited in a variety of paralic and nearshore terrestrial environments as the sea flooded a coastal floodplain and coastal valleys 10 form an interconnected system of tidal embaymenlS (King & Thrasher 1996). Ncar Whanganui Inlet. interbedded coal measures and tidally influenced sandstones (Bal & Lewis 1994) have been mapped as the Puponga Member (Kpp).

A faull·bounded sliver of crushed. red-stained conglomerate (Kh). containing generally well rounded c1aslS that include felsic intrusive and mafic volcanic rocks, occurs wesl of the Aaxmore Faull in Nelson City. A Late Cretaceous age has been inferred (Johnston 1984).

Paleocene to Eocene sediments

The Farewell Formation (PkO of the Kapuni Group (Pk) consists of fluvial quartzofeldspathic sandstone (Fig. 55) and pebbly conglomerate (Fig. 56) between Cape Farewell and Kahurangi Point. and is inferred to have formed on a braided floodplain or heavily ladcn meandering river system. Although Bal (1994) and Bal & Lewis (1994) describe an unconformity between the North Cape and Farewell formations. there is no evidence for a significant erosion or a time break onshore. The contact is interpreted as the progradation of fluvial sediments over a coastal plain. Deposition of the Farewell Formation occurred throughout the Paleocene and earliest Eocene into the widening transgressive basin which hosts the Pakawau and Kapuni groups. The uppermost part of the Farewell Formation. exposed around Abel Head. is significantly more quartzose and may reflect a slowing down of tectonic activity. with greater chemical weathering in the source area.

Much of the Nelson area was above sea level from Late Cretaceous to early Tertiary time. and the landmass was a source area for terrigenous sediments of the Pakawau Group and Farewell Formation. A widespread unconformity separates Farewell Formation from the overlying Brunner Coal Measures. This break in the stratigraphic record. at least from 55 to 40 Ma (Early Eocene). is the culmination of a period of tectonic quiescence and subsequent erosion that affected much of New Zealand for varying periods between the latest Cretaceous and earliest Oligocene. Generally the rocks beneath the erosion surface arc deeply leached. with the less resistant minerals such as feldspar and biotite completely decomposed.

Eocene sedimentation commenced with the deposition of non-marinc quartz sandstone. conglomerate. carbonaceous shale and coal seams of the Brunner Coal Measures (Eb, Figs 57 & 58). Being largely derived from deeply weathered. mainly granitoid basement rocks. the unit is characteristically highly quanzosc. The coal measures are widely preserved in three main geological settings: as plateaux such as the BullerCoalfield. synclinal structures such as the Heaphy and Takaka coalfields, or along major faults such as the Nelson-Richmond Coalfield. In the Takaka area, the BrunnerCoal Measures are up to 350 m thick immediately west of the Pikikuruna Fault. The coal measures consist mainly of fining-upwards sequences of cross-bedded sandstone passing up into carbonaceous mudstone with scattered coal seams up to 2.5 m thick (Leask 1993). In the southwest of the

Figure 55 Cross-bedded Farewell FormatiOll sandstone at the mouth 01 Whanganui Inlet (M25/705693). *Photo: CN4079S D.L. Homer*

Figure 56 Conglomerate with interbedded sand lenses in Paleocene Farewell Formation (lowermost Kapuni Group) near cape Farewell *(M24/B12777). Photo: CN40719 D.L. Homer*

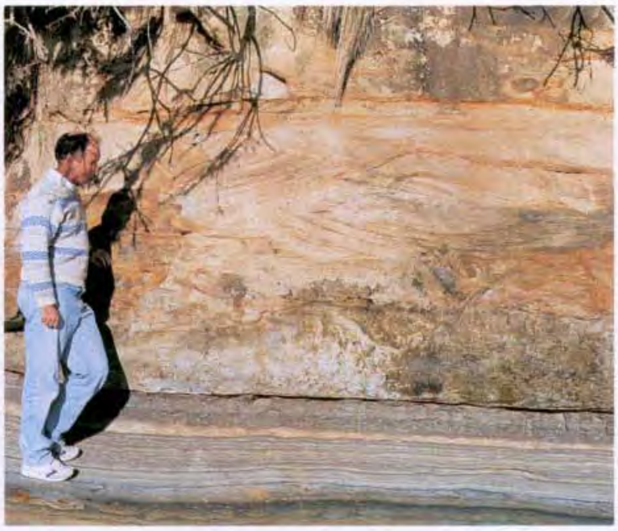


Figure 57 Cross-bedded and laminated sandstone. with carbonaceous layers In Brunner Coal Measures at Rangihaeata Head, N25/924440). *Photo: CN40868 D.L. Homer*

Nelson QMAP area. the coal measures of the northern end of the Buller Coalfield are dominated by quartz sandstone with subordinate conglomerate, mudstone and coal seams up to 17 m thick (Nathan 1996).

The coal measures are conformably (and in most places gradationally) overlain by shallow-water marine sediments. In the southwest these marine sediments are massive carbonaceous mudstone with minor muddy sandstone of the Kaiata Formation (Erk) whereas in Golden Bay and at Tadmor they are poorly cemented beach sands. Mudstone, commonly containing a high proportion of thick-bedded quartzofeldspathic sandstone, with minor conglomerate and thin coal seams, occurs in the Murchison area as Maruia Formation (Em) (Fig. 58). In the vicinity of Nelson City, steeply dipping and extensively faulted well-bedded sandstone, siltstone, conglomerate, and thin coal seams collectively form the lower part of Jenkins Group (Ej; Bruce 1962, Johnston 1979).

Tectonic activity recommenced at about 38 Ma (late Middle Eocene), with regional extension leading to the formation of small, local basins, many of them fault-bounded, separated by areas of low-lying land. Ongoing subsidence, from the Middle Eocene into the Late Oligocene, led to progressive drowning of the land area. At the end of the Eocene much of the present land area was still emergent, with a low-lying area (Karamea Peninsula) surrounded by shallow seas (Nathan & others 1986, their map 13 and fig. 3.11).

Oligocene 10 earliesl Miocene sediments

Continued marine transgression from late Eocene into the Oligocene led to the gradual drowning of the low-lying land, and by the end of the Oligocene virtually the whole map area was submerged. The supply of terrigenous sediment dwindled. and as a consequence Oligocene sediments are typically calcareous, and limestone is widespread. Although Oligocene sediments covered the whole area, their present limited distribution is due to subsequem uplift and erosion (and, to a lesser extent, burial by younger sediments). Nathan (1974) included all the calcareous sediments in the Nile Group (On), and Nathan & others (1986) divided Nile Group lithologies into two major groupings:

(a) Platform facies (usually <100 m thick), consisting of shallow-water bioclastic limestone and muddy micaceous limestone, formed on a stable shelf; and
(b) Basinal facies (usually >100 m thick), predominantly muddy limestone, massive calcareous mudstone and interbedded calcareous sandstone and mudstone, formed in rapidly subsiding basins.

The platform facies is found as erosional remnants over much of Northwest Nelson. mainly as bluff-forming shelly, locally algal, limestone (Fig. 59 & 60) that includes the Takaka Limestone of Golden Bay. The basinal facies occurs in the south (Figs 61 & 62) in the Murchison Basin and the Mokihinui catchment, where it is mapped as Matiri Formation (Om). In Nelson city, calcareous siltstone with minor barnacle plate limestone of Oligocene to early Miocene age are included within the upper Jenkins Group (Ej).

Figure 58 Remnants of the Brunner Coal Measures on a granite basement ridge above Silvermine Creek. In the distance, the coal measures are overlain by the Eocene Maruia Formation mudstone and interbedded sandstone at Pyramid on the Garabaldi Ridge. *Photo: CHI2151 D.L. Homer*

Early to Middle Miocene sediments

A major change in the pattern of sedimentation, related to the initiation of oblique compression between the Pacific and Australian plates, took place in early Miocene time (late Wailakian to Altonian stages). Renewed tectonic activity is reflected in a regional change from carbonate-rich to terrigenous muddy sediments, locally called 'papa' and collectively included in the Lower Blue Bottom Group, which are typical of Neogene sediments on the western side of the South Island.

Sedimentation ceased in several early Tertiary basins, and there is an unconfonnity beneath early Miocene sediments in many places. In particular, the Otaian Stage (earliest Miocene) is missing over much of the onshore area except in the northwest and in the Murchison Basin in the south (Nathan & others 1986, their fig. 3.24).

Early to Middle Miocene sediments are preserved in several isolated depressions, separated by uplifted ranges of pre-Tertiary rocks. Because of this isolation, several nomenclatural schemes have been devised for different areas (summarised by Nathan & others 1986, their fig. 3.23) for what are very similar sediments. Apart from the Murchison Basin, the dominant lithology is light grey-brown calcareous mudstone or muddy sandstone, collectively mapped as Lower Blue Bottom Group (Mb, after Neef 1981).

In the Takaka area, there is a marked shallowing in the Middle Miocene (Clifdenian to Lillbumian stages) from shelf mudstone upwards into marginal marine sandstone (Grindley 1971; Fig. 63). This represents the start of regional uplift. and much of Northwest Nelson has remained emergent since that time. In the Murchison Basin, the gradational contact between the Oligocene Matiri Formation and the overlying Mangles Formation (Mm) is marked by the incoming of quartz-mica sandstone beds within the calcareous interbedded sandstone and mudstone at the top of the Matiri Fonnaiion. The lower pan of the Mangles Formation, exposed within the Nelson QMAP area, consists of an allernating sandstone and mudstone turbidite sequence, which passes upwards into more massive, locally glauconitic, shallow-water sandstone. In Nelson city, the upper part of the Jenkins Group (Ej) contains Miocene graded sandstone-siltstone lenses, and massive blue-grey siltstone with minor conglomerate and breccia.

Figure 59 Oligocene Nile Group limestone nonconlormably overlying Karamea Granite under Ihe Oparara Arch, Oparara Valley (L27/418066).

Figure 60 Solution seams in Oligocene Nile Group limestone at Te Hapu, near Whanganui Inlel (M25/654657).

Figure 61 Nile Group calcareous Interbedded sandstone and mudstone (calcflysch) with a large granitic boulder at Uttle Wanganui Head (l28/308789). The boulders may have eroded off the Kongahu Faull scarp which lay to west (ollshore) prior to Miocene inversion. *Photo: CN25619 D.L. Homer*

Figure 62 Well bedded, calcareous mudstone and sandstone of the Matiri Formation, viewed looking south along the Matiri Range to The Haystack.

Late Miocene 10 Pliocene sediments

Much of Nonhwest Nelson was emergent during the late Miocene-Pliocene, and marine sediments (mapped as Upper Blue Bottom Group, **ℙb)** are preserved only on the southwest side of the map area near Karamea and further south near the mouth of the Mohikinui River. At both places the lithology is similar. consisting of blue-grey muddy fine sandstone containing shallow-water fossils. There is a change at about the Miocene-Pliocene boundary to massive fine-grained sandstone. often weathered rusty brown in outcrop.

At Karamea, the late Miocene-Pliocene sediments are part of a continuous Neogene sequence (Neef 1981). South of the Mohikinui River the Upper Blue Bottom Group sediments rest unconformably on early Tertiary sediments (Saul 1994), and the unconformity is a regional feature that extends funher south (Nathan & others 1986, their fig 3.28).

Non-marine conglomerate and gravel of the Tadmor Group, resting unconformably on older rocks, are exposed further east. The Glcnhopc Formation (1PIg), exposed in the southwest of the Moutere Depression, consists of locally derived conglomerate. sandstone, and lignite seams of latest Miocene-Pliocene age (Coleman 1981). In Nelson City, the Port Hills Gravel **(ℙtp),** up to 500 m thick, consists of granitic conglomerate grading upwards into conglomerate composed of clasts of volcaniclastic Permianrrriassic rocks largely derived from the east of the Waimea Fault (Johnston 1979).

Late Pliocene to early Pleistocene sediments

Rapid uplift of the Southern Alps in the Late Pliocene is reflected by a flood of Torlesse-derived gravel that extended west and northwest. and is infened to have covered much of the present land area (Nathan & others 1986. their map 30). An extensive area of uniform yellow-brown. clay-bound gravel, with deeply weathered clasts almost entirely of Torlesse-derived sandstone and semi-schist (Moutere Gravel, **ℙtm),** is preserved in the Moutere Depression (Figs 5 & 64). A similar weathered conglomerate, but also containing schist, granite and other igneous and sedimentary clasts. as well as a higher proportion of interbedded sandstone is exposed in the Karamea area where it is mapped as Old Man Group

Figure 63 Well bedded mudstone and siltstone of the Lower Blue Bottom Group at the Tarakohe quarry, Golden Bay (N25/013419).

Figure 64 Slighlly weathered, well rounded quartzofeldspathic sandstone clasts in a brown weathered muddy sand matrix comprise the bulk of the Moutere Gravel, shown here al Moutere Bluff, Tasman Bay (N27/171995). *Photo: CN45206 D.L. Homer*

(Fo). The Late Pliocene Hillersden Gravel (Fh), composed of c1ay·bound Torlesse·derived quartzofeldspathic sandstone clasts, is preserved to the south of the Alpine Fault in the Wairau Valley.

Climatic cooling at about 2 Ma resulted in glaciers extending northward from the Spenser Mountains. Torlesse-derived moraine deposits with large glacial erratics. local lake sediment deposits. and well·sorted gravels comprise the Porika Formation (eQp). The fonnation was deposited immediately above the Moutere Gravel at the southern edge of the Nelson QMAP area (Johnsoon 1990).

Structure

The early Eocene erosion surface were first buried by younger Cenozoic sediments, and subsequently exhumed in many parts of Norlhwest Nelson (Figs 4, 6). The erosion surface forms a useful datum for assessing Cenozoic defonnation (Suggate &. others 1978, their fig. 6.2). Identification of sedimentary depocentres and basin reconstruction (Nathan &. others 1986, King &. Thrasher 1996) have highlighted significant spatial and temporal changes in the sedimentary basins of the Nelson QMAP area. These changes were strongly influenced by fault movement and fault reactivation. For instance, the Cretaceous-Paleocene Pakawau Basin fonned as a half graben during wesl-side-down. normal movement on the Wakamarama Fault during a period of extensional tectonics. Tectonic conuaction in the Miocene resulted in reverse reactivation of the Wakamarama Fault and shifted the focus of deposition to the east side of the fault. Farther south, the Eocene-Oligocene sediments deposited against the east-dipping normal Kongahu Fault were inverted in the Early Miocene with reverse reactivation of the fault (Nathan & others 1986, Kamp & others 1996; Fig. 65).

The north.uending Paleozoic structures of west Nelson. particularly in the western part of the Takaka terrane, have been offset by numerous, WNW- to ENE-trending faults. with horizontal displacements of up to 1 km. The faults are thought to pre-date the late Cenozoic structures.

In the east. much of the uplift has occurred on thedextral-reverse faults of the Waimea-Aaxmore Fault System. Many of the faults are reactivated older faults that separate the terranes of east Nelson. The Moutere Depression. is a faull-angle depression or half-graben that developed in the Early Pleistocene along the Waimea·Flaxmore Fault System. displacing the Moutere Gravels and older rocks. Only in the Moutere Depression and to a lesser extent near Karamea and in the Wairau valley. are the formerly extensive Late Pliocene-Early Pleistocene terrestrial gravels now preserved.

QUATERNARY

Alluvial terrace and flood plain deposits

Alluvial gravels (Q1a, Q2a. Q6a, Q8a. uQa. eQa) are widespread and well preserved in the nood plains and aggradation surfaces of major river valleys and alluvial fans within the Nelson QMAP area (Fig. 66). Some of these gravels have been differentiated and formally named on the basis of relative age and clast composition (e.g. Suggate 1965. Johnston 1983). The ages inferred

Figure 65 l.ate Tertiary deformation in Northwest Neisoo has resulted in a series of monoclinal flexures over basement faults. At Kohaihai Bluff, Brunner Coal Measures and Nile Group dip steeply towards the east-dipping Kongahu Fault Zone, the surface trace of which lies immediately offshore. Offset of these units, which dip near horizontally within 3 krn of the faull both inland and offshore, indicates a vertical separation of about 3 krn. *Photo: CN25773 D.L. Homer* for the respective terrace deposits are largely based on absolute and relative heights of correlated outwash aggradation terrace surfaces, the degree of clast weathering, the presence of loess, and the proportion of clay content.

Alluvial fan deposils

Large alluvial fans, screes and colluvial deposits (Q1a, Q2a, uQa) are prominent at the foot of steep streams draining hills and ranges. The fans comprise poorly sorted, angular, silt- to boulder-sized clasts and lack clear stratification. Extensive low-gradient fans near Nelson City are the result of erosion of uplifted basement rocks southeast of the Waimea Fault. Many smaller fans are included with the mapped alJuvialterrace and flood plain deposits.

Marine deposils

Marine and beach deposits consisting of gravel, sand and mud (Q1b, Q5b, Q7b, uQb) are preserved on terraces along the West Coast (Fig. 67) and in places around Golden Bay. A gently sloping surface cut into Moutere Gravel between Mapua and the Moutere Inlet may also be a marine bench cut in the early 10 mid-Pleistocene. Marine deposits such as boulder banks, storm ridge beaches. and sand bars occur near sea level around Tasman Bay. Marine gravel and sandy gravel resulting from longshore drift form beach ridges adjacent to Tasman Bay. The 13.5 km-Iong Boulder Bank barrier spit at Nelson City formed by longshore drift of boulders derived from the Cretaceous Cable Granodiorite at Drumduan.

Sand dunes and marine sand deposils

Beach ridges and dunes (Q1d) occur along the western coast, parlicularly in the lee of coastal promontories such as the Karamea area and northwest of Kahurangi Point (Fig. 68). The arcuate sweep of Farewell Spit, with both fixed and mobile dunes (Fig. 9), has formed from the northward longshore drift of sand along the West Coast. The spit is prone to sea erosion from the north and is in a continual state of depletion and replenishment. Sand dunes have formed along much of the coast of Golden Bay and Tasman Bay, as at Tahunanui Beach. Many of these dunes overlie marine beach ridges composed of sand.

Peat and swamp deposils

Swamp deposits (Q1a) consisting of poorly consolidated sand, mud and peat are mapped in flat, generally low-lying areas close to the coast, commonly on the landward side of beach dunes near river mouths. Smaller swamps have developed immediately upriver of recent landslides.

Figure 66 Modern nood plains, comprising alluvial gravels (a1a) deposited by the Waimea River, are extensively used fOf horticulture and are an important source of aggregate. *Photo: CN17836 D.L. Homer*

Landslide deposits

Landslides (QII. uQI) are a common feature of the steeper country throughout the map area. The larger landslides have involved several square kilomelres of source area and resulted in often devastating downslope movement of millions of tonnes of rock. The landslides vary in composition from very large masses of largely coherent but very shattered rock to unsorted fragments of rock in a silty clay matrix. Earthflow deposits. consisting of a chaotic mixture of blocks up to 10 m across in a silly. locally serpentinitic matrix. fill valleys downslope of areas of crushed rocks such as those of the Patuki and Croisilles melanges in east Nelson.

Many of the landslides have been triggered by seismicity. The 1929 Murchison earthquake caused widespread landsliding in parts of Northwest Nelson (Fig. 7). Some of these landslides have dammed rivers to form lakes (such as Lake Stanley and Lake Elmer. Fig. 69). Lake Chalice in the Richmond Range resulted from one of several landslides that occurred about 2100 years ago that may have been triggered by earthquake.

The Marlborough Schist commonly fails along foliation planes and joint surfaces. The Triassic Richmond Group rocks have been involved in a number of relatively large landslides. These landslides have largely stabilised and may possibly be the result of earthquake ruptwe on the adjacent Eighty-eight Fuult (see beluw). Tertiary rocks are typically low strength and many are prone to failure.

Deposits of human origin

Significant land reclamation has occurred in the Nelson City area around Nelson Haven using hard fill. hydraulic fiJl. and domestic rubbish. Minor reclamation has also occurred around Waimea Inlet.

Structure

Demonstrably active faults. such as those displacing young «125 000 yr DP) surfaces in the Nelson QMAP area are the Alpine Fault. and the Waimea. Heslington. Eighty-eight. Whangamoa and Dishopdale faults within the Waimea-Aaxmore Faull System. The White Creek. Lyell and Glasgow faults show evidence of post-125 000 yr DP activity south of the Nelson QMAP area but their activity further north has not been demonstrated. In general. fault activity decreases away from the Alpine Fault although some northern faults. such as the Whangamoa Fault. Eighty-eight and Bishopdale faults. contain sections with significant surface rupture (Johnston & others 1993). Other faults. such as the Karamea Fault. have a significant level of mid-crustal seismic activity (Coote & Downes 1995).

Figure 67 Older marine terraces cleared for grazing above the modern Holocene marine sands, gravels, and dune sands immediately south of the Mokihinui River mouth. *Photo: CN313S2 D.L. Homer*

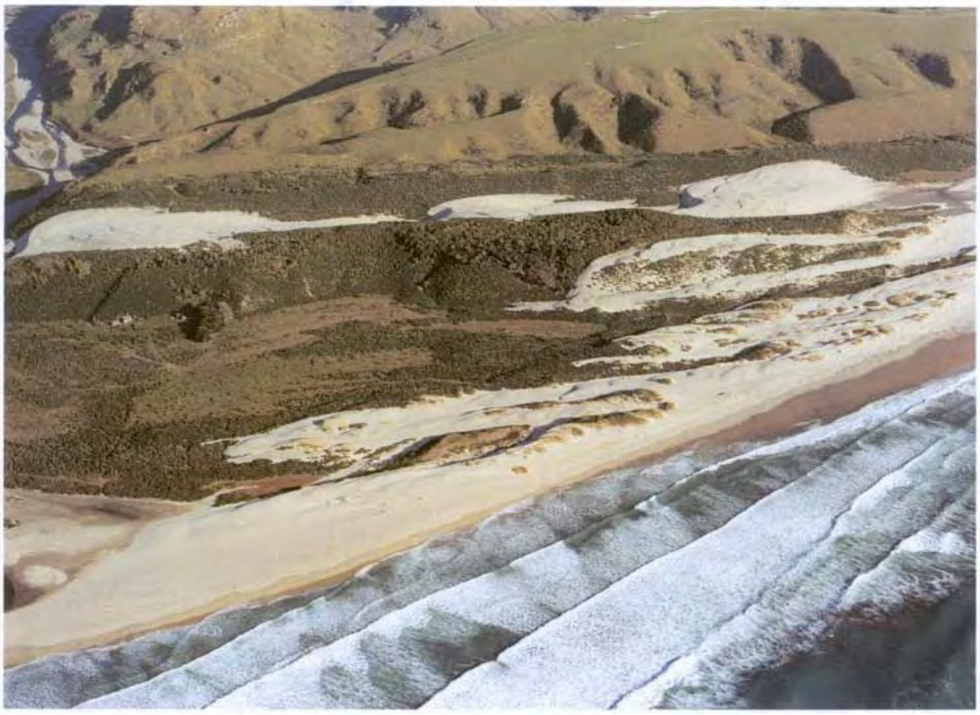


Figure 68 Longitudinal dunes formed by the prevailing coastal winds at the mouth of the Turimawiwi River. *Photo: CN4149 D.L.* Homer

Figure 69 The 1929 Murchison earthquake resulted in many large landslides in Northwest Nelson. A landslide deposit which dammed the Ugly River has formed Lake Elmer. *Photo: CN25705 D.L. Homer*

OrFSlIORE GEOLOGY

A major sedimentary basin. the Late Cretaceous-Recent Taranaki Basin. lies to the north and west of the Nelson coastline. The offshore geology of the Taranaki Basin has been described in detail by King & Thrasher (1996) and is only summarised here for the area pertaining 10 the Nelson QMAP area. The offshore area has been extensively explored by seismic reflection surveys and deep exploration wells. The northern coastal geology of the Nelson QMAP area provides the only exposures of much of the southern Taranaki Basin stratigraphy, particularly the Late Cretaceous Pakawau Group, the Paleocene-Eocene Kapuni Group. and the Oligocene-early Miocene Ngatoro Group (similar to the Nile Group). Major sub-basins developed along faults throughout the Cretaceous-Tertiary. The Pakawau Sub-basin developed as half grabens west afthe Wakamarama Fault and east of the Kahurangi Fault in the Cretaceous-Paleocene and attained local sedimentary thicknesses in excessor2000 m. The Eocene was a period or relatively unirorm deposition and limited rault control on basin development. Major subsidence in the Oligocene-Miocene and post-Middle Miocene by reverse inversion of major normal faults such as the Wakamarama, Kahurangi and Surville faults resulted in deep half-graben basins.

The offshore basement geology or the Nelson QMAP area has been summarised by Mortimer & others (1997). mainly from oil exploration well core from the Taranaki and Wanganui basins. Paleozoic and Cretaceous granite basement horsts extend north into the Taranaki Basin. Biotite granite samples from the exploration wells Kongahu-J. Toropuihi-I and MOlueka-1 are chemically similar to Karamea Suite granite. The Motueka-l granite has been dated as Late Devonian-Early Carboniferous (SHRIMP U-Pb zircon) and Toropuihi-l granite as Carboniferous in age. The Survitle-I well. 23 km almost due south of the Motueka-l well. bonomed in biotite granite of Separation Point Suite affinities. Further south, on the shore of Tasman Bay. the Ruby Bay-I well penetrated diorite with chemical and petrographic similarities with the Rotoroa Igneous Complex of the Median Tectonic Zone.

Figure 70 The east side of the lower Aorere Valley yielded significant alluvial gold last century Irom the colluvium, days and conglomerate on the Late Cretaceous to mid-Tertiary erosion surface and In Slate River. Alluvial workings are visible In the foreground, and the rich, hard-rock Johnstons United Mine is Just left 01 the photo centre. *Photo: CN25680* D.L. *Homer*

The Nelson QMAP area contains a diverse range of mineral commodities hosted in a wide range of rock types. The geological resources of the Nelson QMAP area have been described in detail by Williams (1974) and Roser & others (1994) and the following is a summary of the latter publication. The diversity Or mineral commodities has resulted in a number of periods of concentrated exploration beginning with the working of altered sedimentary blocks in the melanges of east Nelson by pre-European Maori for Slone implements. European mining followed with the discovery of gold in Northwest Nelson in 1842 with the first gold rush. to the Collingwood area, occurring in 1857. Gold has continued to be mined and explored for throughout the Nelson QMAP area although interest has been relatively subdued since 1917. Chromite and copper prospecting was al times intensively undertaken between 1850 and 1900, and scheelite was mined around World War I. Curtailment of imparls during World War II sparked interest in serpentinite, talc-magnesite, iron, and asbestos. Regional copper, molybdenum. and nickel surveys were undertaken in the late 1960s and 1970$, followed by further gold exploration in the 1980s. Non-metallic mineral deposits such as aggregate, clay, dolomite, and serpentine have been the basis for a number of successful local industries.

Gold

The Nelson QMAP area has been a significant past producer of gold. Detrital gold has been won from many riverbeds and terraces throughout the area. Early workings were concentrated in the Anatoki, Takaka, Aorere and Parapara valleys of Golden Bay, the Wangapeka and Baton valleys of west Nelson and the Wakamarina valley of Marlborough. The largest detrital gold operations centred around the east side of the lower Aorere valley including Slate River (Fig. 70). Much of this gold, and that from other areas such as the Tablelands near Mt Arthur. was concemrated in colluvium. clay and gravel lying on the Waipoonamu erosion surface. The Wakamarina River in east Nelson became a focus of mining activity in 1864 for a few years. and several tributaries of the Wairau River were prospected but with limited success. Although exploration has continued, no large-scale mining has occurred since last century. Small-scale alluvial gold mining continues in many areas.

The largest of the hard-rock goldfields was in the Aorangi Mine (Golden Blocks) area. The Golden Ridge and Anthill mines produced 172.3 kg of gold from 10 784 t of ore between 1897 and 1904. The Aorangi (Golden Blocks) Mine produced 870.2 kg from 23 994 t of ore between 1897 and 1913. Most of the gold occurred in quartz veins within a carbonaceous shale horizon of the Ordovician Aorangi Mine Formation. Secondary enrichment of gold occurred near the surface. The Owen River Goldfield was prospected and mined between 1881 and 1890 but only 2.2 kg of gold was extracted from 732 t of quartz. The gold occurred in discontinuous quartz-carbonate veins in the Owen Formation. Several hard-rock mines developed after the decline in the alluvial operations. Johnston's United (formerly Perservance) Mine was the richest producer yielding 583 kg of gold from 62 240 t of ore although it was rarely profitable. The nearby Ophir, Phoenix and Red Hill mines produced liule. The deposits occur near a thrust contact between schistose metavolcanic Haupiri Group rocks and underlying Wangapeka Formation schistose metasediments. Exploration in the 19805 identified the Sams Creek prospect, west of the upper Takaka River, with a potential resource of 3.5 Mt at 2 gjt Au. The gold occurs with arsenopyrite and pyrite in quartz vein stockworks within a Late Triassic(?) peralkaline granite porphyry emplaced into the Ordovician Wangapeka Formation and the Silurian Ellis Group.

The Caples-derived semi-schists of the Wakamarina area host a number of quartz lodes of which the Golden Bar reef yielded significant amounts of gold. The reef was traced over 1800 m at up to 3 m wide and yielded in excess of 518 kg of gold and 442 t of scheelite. The gold occurred in vuggy quartz with scheelite. pyrite, and calcite. Of the several reefs in the Wairau valley only the Jubilee or Big Reef and the Sylvia or Small Reef are noteworthy and yielded 37 kg of gold from 3673 t of quartz.

Other metallic minerals

Chromium from chromite has been produced from the ultramafic rocks of both east and west Nelson. The most important deposits were in the Dun Mountain Ophiolite Belt rocks near Dun Mountain. Mineralisation typically occurs as lenticular podiform deposits and layers in serpentinised dunite and harzburgite, and as disseminated grains within dunite and harzburgite. Chromite has also been mined from blocks within the Patuki and Croisilles melanges near Croisilles Harbour. In total about 6000 t of chromite were mined and exported from east Nelson, mostly between 1862 and 1866. The ultramafic rocks of the Cobb Igneous Complex have seams of chromite-rich serpentinised peridotite. and detrital chromite is common within the Lockett Conglomerate.

Copper was produced in small quantities (a few hundred tonnes) from serpentinite of the Dun Mountain Ultramafics Group. Primary chalcopyrite occurs with pyrrhotite, with secondary mineral assemblages of native copper and malachite, and minor amounts of azurite.

cuprite, chrysocolla. and chalcocite. Copper smelters were briefly in operation in the Roding valley in 1886 and again in 1908. Disseminated copper mineralisation consisting of chalcopyrite. pyrite and magnetite occurs within calc-silicate skams and schist at Copperstain Creek in the Pariwhakaoho River. with an estimated resource of 10.7 Mt at 0.15%. Chalcopyrite occurs with pyrrhotite and pentlandite in the gabbros. pyroxenites and diorites of the Riwaka Complex in the lower Motueka valley area (see below). Minor copper mineralis:uion is associated with the porphyry molybdenum deposits in Karamea and Aorere valleys. and with other base metals within the Devil River Volcanics Group in the upper Takaka and Cobb rivers.

Surficial limonitic iron ore occurs in a belt between Onekaka and Parapara Inlet overlying Arthur Marble in fault-angle depressions (Bishop 1971). The deposits are thought to have been derived from laterite from the Tertiary erosion surface (Grindley & Wauers 1965). Production of 40 640 t of pig iron occurred between 1922 and 1935.

Numerous porphyry molybdenum prospects have been investigated between 1970 and 1990 in the country rock to Late Cretaceous Separation Point Suite granite plutons (Rabone 1989). Most deposits are hosted in Greenland Group metasedimentary rocks. and some deposits occur within Karamea Suite granite. Mineralisation typically consists of disseminated molybdenite occurring with minor pyrite. chalcopyrite, and pyrrhotite, and rare galena. sphalerite. and bismuth sulphosalts.

Lead·zinc mineralisation occurs within the Aorere Goldfield, such as at Johnston's United Mine, in small lenses of galena-sphalerite-pyrite-arsenopyrite-pyrrhotite-chalcopyrite and nearby in association with several gold and silver bearing vein deposits. A small galena-sphalerite-pyrite lode occurs in the Pariwhakaoho River and galena-sphalerite-Ag-Au quartz veins are associated with quartz diorite dikes north of Lake Stanley. Minor galena segregations occur in the Ordovician marble.

Nicke.l mineralisation occurs wilhin the Riwaka Complex in the Graham valley near Pokororo and the Skeet River area and was extensively explored between 1967 and 1979. The mineralisation is best developed in cumulate gabbro_ with lower concentrations in olivine pyroxenite and hornblende pyroxenite. Pentlandite occurs within pyrrhotite with subordinate chalcopyrite, pyrite. marcasite. and mackinawite. Several occurrences of nickel mineralisation occur in the Takaka and Cobb valleys within the Devil River Volcanics. Pentlandite occurs with pyrrhotite and minor chalcopyrite as lenses in ahered dolerite. Pentlandite also occurs within serpentinised peridOlite of the Dun Mountain Ophiolile Group with chromite. ilmenite. bravoite. pyrrhotite and chalcopyrite. Nickel-bearing awaruite has also been reported from these rocks (Challis & Long 1964).

Platinum group minerals (POM) occur in alluvial gravels in a number of localities in the Golden Bay area. The PGM mainly contain Ru-Os-Ir suggesting they are derived from an uluamafic source. and PGM occur in the Cobb Igneous Complex. POM containing Ir-Os-Ru occur in alluvial gravels in the Lee River. sourced from the adjacent Dun Mountain Ultramafics Group.

Silver mineralisation has been documented in many areas, occurring with copper. molydenum. gold and lead. although no production of silver has been recorded. Silver minerals have been found in quartz veins and fractures in Wangapeka Fonnation quartzites and sericite schists in the Slate River. occurring with galena. pyrite, arsenopyrite. sphalerite. pyrrhotite. chalcopyrite and chalcocite. Argentiferous galena is present with pyrite. chalcopyrite and tetrahedrite in quartz veins CUlling diorite and Haupiri Group amphibolites in the Aorere Goldfield, including Richmond Hill in the Parapara River. Silver occurs with auriferous pyrite-galena-chalcopyrite-sphalerite veins within Arthur Marble in the headwaters of Owen River. and with chalcopyrite-pyrite-arsenopyrite-titanite-galena-sphalerite in Waingaro Schist in the Baton River area.

Ilmenite occurs in beach sand deposits in the Karamea area with other heavy minerals such as garnet. magnetite. zircon and rutile.

Tungsten occurs in scheelite-bearing quartz veins and auriferous lodes in Caples Group schists. and the Wakamarina Goldfield area yielded 475 t of WO) concentrate between 1874 and 1944. Relatively minor production took place elsewhere in the Marlborough Schist Zone. Scheelite also occurs with pyrite. minor chalcopyrite. rare galena and rare molydenite in quartz veins associated with intrusions of Separation Point Suite granodiorite in the east of the lower Takaka valley. Stratabound scheelite is present in marble lenses within the Benson Volcanics of the Devil River Volcanics Group.

Coal

Coalfields within the map area include Collingwood. Takaka. Nelson-Richmond. Baton. Heaphy. Karamea, and Buller (northern part). The Collingwood Coalfield worked coal measures from the Late Cretaceous Pakawau Group. whereas the other coalfields in the Nelson QMAP area have exploited the Eocene Brunner Coal Measures.

The Buller Coalfield has had the largest past production (Fig_ 71), and the working mines immediately south of the map area are currently producing over I million tonnes per year. Coal production has been from the Middle to Late Eocene Brunner Coal Measures containing seams up to 50 m thick. Coal rank increases westward across the coalfield from high-volatile bituminous A-B to medium-volatile bituminous.

The Collingwood Coalfield has had significant past production of 868 000 t, most of which came from the Puponga mines before 1975, working the non-marine parts of the Late Cretaceous Pakawau Group. The seams are typically thin «3 m) and discontinuous, ranging in rank from sub-bituminous A to high-volatile bituminous C to the east. with low «0.5%) sulphur and 5-10% ash content. In-ground resources of the coalfield are difficult to assess due to the discontinuity of the seams.

The Takaka Coalfield worked Eocene Brunner Coal Measures at Motupipi, from which over 6900 t were extracted between 1842 and 1965. Coal seams of sub-bituminous B rank are up to 2.5 m thick with 0.5-2.7% sulphur, and highly variable ash (> 1.5%) content.

The Nelson-Richmond Coalfield is within a small area of BnlnnerCoal Measures along the Waimea Fault. Total production is estimated to have been about 5000 t between 1853 and 1910. The seams have been strongly sheared resulting in highly variable thickness (0-3.3 m), and are typically steeply dipping, of high-volatile sub-bituminous C rank with high sulphur (>3%) and ash (>5%) contents.

The Karamea Coalfield is within Eocene Brunner Coal Measures near Karamea township and the Garibaldi Ridge. Total recorded production is 320 t of low-volatile bituminous to sub-bituminous rank.

The Heaphy Coalfield consists of thin (<I m) discontinuous seams within Eocene Brunner Coal Measures between the Heaphy River mouth and the Lewis River junction. The coal is of sub-bituminous B rank with 2.4-3.7% sulphur and variable (1.3-10.7%) ash content. There has been no production due to the remoteness of the coalfield.

Agure 71 The Roger mine in Chasm Creek produced more than 60 000 t 01 coal from Eocene Brunner Coal Measures in the northern Buller Coalfield. *Photo: CN12267* D.L. *Homer*

The Balon Coalfield between the Baton and upper Tadmor valleys is wilhin Brunner Coal Measures containing thin « 1.8 m). extensively faulted, dipping seams of high-volatile bituminous rank. Two mines in Clarke River extracted 4000 I between 1929 and 1939.

The Owen Coalfield is structurally complex with thin and discontinuous. steeply dipping seams up 10 4.5 m thick of high-sulphur. high-ash coal. The coal has been mined interminently for local use.

Other non-metallic minerals and rocks

Large quamities of aggregate have been extracted from the Nelson QMAP area although the quality of the gravel varies according to 10 the degree of induration of the source rocks. Gravels have been extracted from most of the major rivers although the greatcst production has been from the lower Motueka River and the Waimea River and its tributarics. Gravel is also extracted from pits in the floodplain and aggradation terraces (Qla. Q2a) adjacent 10 the Waimea River. Most river gravel provides a high quality aggregate but rivers draining the Moutere Gravel, the Dun Mountain Ultramafic Group. and schist and semi-schist in the east of the Nelson QMAP area are generally unsuitable as an aggregate source, as is Separation Point Suite granite. Bedrock is also quarried at a number of localities, particularly in east Nelson where local rivers cannot meet demand. Bedrock units utilised are Brook Street Volcanics Group and Maitai Group. particularly the green volcanogenic sandstone in the Stephens Subgroup which is a high quality aggregate.

Chrysotile asbestos has been mined from sheared and serpeminised ultramafics of the Cobb Igneous Complex in the upper Takaka valley. Approximately 5000 t of fibre were extracted between 1941 and 1963. and a sizeable resource remains in the ground. Asbestos also occurs within talc-magncsite schists in the Cobb area, and in insignificant veins in serpentinitcs of the Dun Moumain Ultramafics Group.

Barite mineralisation occurs in small deposits of less than several thousand tonnes at Thomson Hill between the Wangapeka and Baton valleys. The barite-fluorite-quartz-adularia veins cut Arthur Marble near the intrusive contact with hydrothermally altered Separation Point Suite granite.

Production of clay for industrial use is ongoing in the Nelson QMAP area. Extraction of white kaolin china clay from deeply weathered Brunner Coal Measures resting on Separation Point Suite granite at Puramahoi in Golden Bay occurred between 1968 and 1988. Kaolinite has been mined from the basal Glenhope Formation in the Tadmor and upper Hope valleys. Clay from weathered Tertiary sedimentary rocks and Moutere Gravel is mined for bricks and pipes. Small clay deposits throughout the Nelson QMAP area have been worked for craft pottery.

Separation Point Suite granite at Tonga Bay was quarried for building slone to a limited extent in the 18905 but proved to weather quickly and production ceased. Limited use has been made of Arthur Marble from quarries near Takaka and Riwaka. including for Parliament Buildings in Wellington and Nelson Cathedral. More recently, marble and dolomitic marble from Mt Burnett near Collingwood have been quarried for decorative building stone.

Dolomite from the Arthur Marble at Mt Burnett is used for riverbank and coastline protection. for agricultural limestone. and for glass production.

Dunite from the Dun Mountain Ultramafics Group occurs at Dun Mountain and the Red Hills. Due to the inaccessibility of the rock. no production has been recorded other than a trial shipment from Dun Mountain and the recovery of loose blocks from streams draining the Red Hills. Dunite is used as a refractory and in fertilizers.

Production of plagioclase feldspar and orthoclase from a thick pegmatite dike intruding Separation Point Suite granite has been recorded from the BalOn area.

Fluorite occurs with the barite deposits at Thomson Hill between the Wangapeka and Baton valleys. and within granite at Wekakura Point north of the Heaphy River mouth.

Semi-precious gemstones and specimen grade mineral localities occur widely through the Nelson QMAP area. Minerals include asbestos. barite. beryl. chrysotile. fluorite. sapphire, titanite, tourmaline, uvarovite. fuchsite. chromite. and kyanite. Type localities for the rock types dunite and rodingite are within the Nelson QMAP area.

Impure graphite was briefly mined in the 18505 and 18605 south of Pakawau Inlet from a carbonaceous layer in Onekaka Schist within the aureole of a small granite pluton.

Abundant limestone and marble occur within the Nelson QMAP area. Three main sources have been quarried. The Arthur Marble is used for agriculture. building, and manufacturing as well as a source of dolomite. The limestones of the Maitai Group have been mined in relatively small amounts due to inaccessibility of the larger deposits and small size of the accesible deposits.

They are used as a source of agricultural lime. blocks for river bank protection and for cement manufacture at the Lee valley cement works. Tertiary limestones. particularly the Takaka Limestone at Tarakohe have been mined in large quantities for cement production as well as agricultural uses.

Silica deposits have been identified and worked within the MOlupipi Coal Measures around Parapara for masonry and at Tarakohe in cement production. Quartzites from the Golden Bay Schist. Onekaka Schist. and Hailes Quartzite have been suggested as relatively pure sources orsilica.

Serpentine from serpentinite has been quarried for superphosphate production from Dun Mountain Group ultramafic rocks in Serpentine River (2500 t), Collins valley (323 000 t). and Lee valley (413 000 I).

Talc and magnesite from talc-magnesite and quartz-magnesite lenses within serpentinite of the Cobb Igneous Complex have been worked in a limited way for agricultural and industrial purposes.

Lenses of fibrous wollastonite occur within skarn deposits in Mount Anhur Marble and Onekaka Schist in the Riwaka valley within a proven resource exceeding 19 000 t. but no production has occurred.

Oil and gas

The Nelson QMAP area is peripheral to the Taranaki Basin. New Zealand's only producing oil and gas field. All production wells within the Taranaki Basin lie beyond the Nelson QMAP area but seven exploration wells have been drilled within the offshore map area (see King & Thrasher 1996).

Other potential hydrocarbon fields within the map area are the Moutere Depression. the Murchison Basin. and the Paparoa Trough of the West Coast.

The Moutere Depression has been the focus of regional gravity. mainetic and seismic surveys by petroleum exploration companies. One stratigraphic hole, Ruby Bay-I. and one exploration well. Tapawera-I. have been drilled but target reservoirs were not met and no hydrocarbons were encountered. No hydrocarbon seeps or shows have been recorded in the Moutere Depression although the Late Eocene Brunner Coal Measures which may be present at depth contain gas-prone kerogen.

Numerous oil and gas seeps have been recorded in the Murchison Basin but because of the intensity of faulting and the lack of suitable porous reservoir rocks. the potential for significant hydrocarbon accumulation is limited (Nathan & others 1986).

The largely onland Paparoa Trough comprising Late Cretaceous-Oligocene sediments extends from south of Greymouth to north of Westport and the southwest comer of the Nelson QMAP area. Hydrocarbons occur in seeps and as shows in exploration wells in the southern part of the trough. Two wells. Toropuihi-I and Kongahu-I. have been drilled offshore but no hydrocarbons were reported.

Groundwater

Groundwater is obtained from confined and unconfined aquifers within Quaternary gravels adjacent to the Waimea River for use in irrigation, industry and for urban supply (Dicker & others 1992). Within and adjacent to Motueka, water is obtained from unconfined aquifers in Quaternary gravels and from confined aquifers in the MoutereGravel (Thomas 1989). Groundwater, both from river gravels and karst systems in the Tertiary and Ordovician calcareous sediments. is of importance in the lower Takaka valley. Groundwater is obtained from alluvial gravel and schist adjacent to the Wairau and Pelorus rivers.

This section provides background information for site investigations or assessments of geological hazards but must not be used as a substitute for detailed sile investigation. Potential engineering difficulties with some rock types are highlighted.

Paleozoic to Mesozoic rocks

Paleozoic and Mesozoic rocks are typically strong and hard when fresh, but variably jointed. Some rocks are deeply weathered, for example. the Separation Point Suite granite. Fresh rock will siand in steep faces. Closely fractured and sheared rocks, such as in melanges or within brinle fault zones, as a whole have low strength.

Tertiary sedimentary rocks

The variety of Tertiary sedimentary rock types has resulted in a range of engineering properties. The mudstone units are typically soft. even when fresh. whereas sandstones and conglomerates tend 10 be harder. stronger. and form cliffs. The limestones. although typically hard and strong. form characteristic karst landscape with steep sided cliffs and ravines. and sinkholes. Coal measures can be prone to failure where sheared. as along major faults. Steep faces, particularly escarpments of limestone or sandstone, are prone to isolated rockfalls.

Quaternary sediments

Quaternary sediments include soft peats, unconsolidated sands, and partly consolidated river gravels. Because of the range of materials likely to be encountered and their generally unconsolidated nature, site-specific investigations are particularly important. Steep faces comprising Quaternary sediments are rare and tend to be unstable.

Figure 72 The soft Tertiary rocks of the Nelson urban area are prone to landsliding. Although the Tahunanui landslide was initiated several thousand years ago, the hillside between Magazine Point (left) and Tahunanui Beach continues to slowly settle. *Photo: CN33106 D.L. Homer*

Landsliding

The distribution of landslide deposits has been discussed on p. 48. Rotational slides occur in a number of rock types, particularly the soft but consolidated Tertiary rocks (Fig. 72) and very shallered Triassic Richmond Group rocks along the Waimea-Flaxmore Fault System and locally along the west flank of the Pikikiruna Range. Basement rocks have fewer slope failures although some units such as the Drumduan Group, Brook Street Volcanics Group, and the Croisilles and Patuki melanges are locally prone to sliding.

Seismic shaking during the 1929 Murchison earthquake and to a lesser eXlent the 1967 Inangahua earthquake has been the dominant factor in landsliding within Northwest Nelson. Numerous rock and debris slides occurred in the Matiri, Owen, and Mokihinui catchments. Debris avalanches occurred at Lake Stanley, and within Terliary mudstone and sandstone at Karamea. Widespread damage resulting from landslides included temporary and more permanent damming of rivers (Figs 7,69). Some large prehistoric landslides may have been initiated by seismic ground shaking. They include the still active Tahunanui Slump (Fig. 72) within Tertiary sediments (Denton & Johnston 1996) and the failure of semi-schist in the Richmond Range resulting in damming of a river and the formation of Lake Chalice.

Seismotectonic hazard

The Nelson QMAP area has experienced moderate levels of seismic (earthquake) activity relative to other areas of the country in recent times. The area is characterised by shallow seismicity (<15 km) largely concentrated in the west, an absence of mid-depth seismicity (15-40 km), and deep seismicity «40 km) in central and eastern parts of the map area related to the subducting Pacific Plate (Anderson & Webb 1994).

Earthquakes are measured in terms of their released energy according to the Richter magnitude (M) scale. The effects of earthquakes or felt intensities are assessed according to the Modified Mercalli Intensity Scale (MM). No large (>M=6.0), shallow (<15 km) earthquake epicentres have been located within the map area in historic times but shaking intensities of MM7 or greater have occurred at least six times in the past 150 years from earthquake sources adjacent to the map area (Johnston & others 1993, Coote & Downes 1995). These events include the 1848 Marlborough earlhquake (M=7.1), 1855 Wairarapa earthquake (M=8.0-8.2), 1868 Cape Farewell earthquake (M=7.0-7.2), 1893 Nelson earthquake (M=7.0), 1929 Murchison earlhquake (M=7.8). and the 1968 lnangahua earthquake (M=7.4). The Nelson QMAP area might expect a MMVI event on a average return time of 5-10 years. a MMVII period

Modified Mercalli Intensity Scale (in part; summarised from Downes 1995)

MM II	*Felt by* persons *at rest, on upper floors or favourably placed.*
MM III	*Felt indoors; hanging objects may swing, vibration similar to passing of light trucks.*
MM IV	*Generally noticed indoors but not outside. Light sleepers may be awakened. Vibration* may *be likened to the* passing *of heavy traffic.* Doors *and windows rattle.* Walls *and frames of buildings may be heard to creak.*
MM VI	*Felt by all. People and animals alarmed. Many run outside. Objects fall from* shelves. *Glassware and crockery broken. Unstable fumiture overturned. Slight damage to some* types *of buildings.* A *few* cases *of chimney damage.* Loose *material may be dislodged from sloping ground.*
MM VII	*General* alann. *Fumiture moves on smooth floors. Unreinforced* stone *and brick* walls *crack.* Some *pre-earthquake code buildings damaged. Roof tiles may be dislodged. Many domestic chimneys broken. Small* slides *such* as *falls of sand and gravel banks.* Some *fine cracks appear in sloping ground.* A *few* instances *of liquefaction.*
MM VIII	*Alann may approach panic. Steering of cars greatly affected.* Some serious *damage to pre-earthquake code masonry buildings. Most unreinforced domestic chimneys damaged, many brought down. Monuments and elevated tanks twisted or brought down.* Some *post-1980 brick veneer dwellings damaged.* Houses *not secured to foundations may move. Cracks appear on steep* slopes *and in wet ground. Slides in roadside cuttings and unsupported excavations. Small earthquake fountains and other instances of liquefaction.*
MM IX	*Very poor qualify unreinforced masonry destroyed. Pre-earthquake code* masonry *buildings heavily damaged,* some *collapsing. Damage ordistortion* tosome *post-1980 buildings and bridges. Houses not secured to foundations shifted off. Brick veneers fall and expose framing. Conspicuous cracking of flat and sloping ground. General lands/iding on steep slopes. Liquefaction effects intensified, with large earthquake fountains and sand craters.*
MM X	Most *unreinforced* masonry *structure de*stroyed. *Many pre-earthquake code build*ings *destroyed. Many pre-1980 buildings and bridges seriously damaged. Many* post-*1980 buildings and bridges moderately damaged or pennanentlydistorted. Widespread cracking of flat and sloping ground. Widespread and severe landsliding on sloping ground. Widespread and severe liquefaction effects.*

Figure 73 The Alpine Fault in the middle reaches of the Wairau Valley splits into two active strands (arrowed) marked by trenches, ponds and offset stream channels. *Photo: CN'7851 D.L. Homer*

<50 years. a MMVlII event <200 years, and a MMIX event <500 years (Smith & Berryman 1992).

The major consequences of a large shallow earthquake in or adjacent to'the Nelson QMAP area are surface fault rupture, strong ground shaking and shaking-induced slope instability. Known surface fault rupture within the last 125 000 years has occurred on segments of the Alpine Fault in the Wairau valley (Fig. 73) and the Waimea-Flaxmore Fault system. The Lyell. Glasgow and While Creek faults have also had recent surface fault rupture in sections 10 the south of the Nelson QMAP area. Offshore. the Cape Foulwind Fault along the West Coast is believed to be active. Seismic activity has been recorded at mid-crustal depths beneath the Karamea Fault in the past few years suggesting fault movement at depth.

Unconsolidated, saturated. fine-grained sediments such as swamp deposits, estuarine mud and silt. marine sand and gravel. and landfill are of low strength and likely to have significant amplification of ground-shaking intensity during an earthquake. Many of the urban centres are founded on such sediments. Earthquake-induced slope instability is likely to be greatest in areas of steep gradient formed on the weaker Tertiary rocks.

Coastal erosion

Coastal erosion during major storms is likely to affect natural barriers such as Farewell Spit and Boulder Bank but local breaching is likely to be only II temporary problem. Long term sea level rise may accentuate the effects of coastal erosion in some low-lying areas within Tasman Bay.

Tsunami

Tsunami are large ocean waves resulting from fault rupture at the sea flooror largescale submarine slumping. Tsunami may be generated either by local earthquake events or distant evems well beyond New Zealand's continental margins. Tsunami pose a risk for the low lying coastal areas around Tasman Bay. Golden Bay and the West Coast although the shallow water depth and natural barriers such as Farewell Spit and Boulder Bank tend to mitigate against larger waves. Waves up to 1.5 m high were reported around Nelson in 1868 but more recent tsunami have had only a minor effect on tidal ranges (Johnston & others 1993). Several tsunami-induced inundations of the inlets of Abel Tasman National Park have been inferred to have occurred since 1600 yr BP (Goff & Chagué-Goff in press) from cores.

AVAILABILITY OF QMAP DATA

The geological map accompanying this book is derived from information stored in a geographic infonnation system (GIS) database maintained by the Institute of Geological & Nuclear Sciences. The data portrayed on the map are a subset of the available information. Customised single-factor and multi-factor maps can be generated on request from the GIS. for example, maps showing tectonostratigraphic terranes. or mineral localities in relation to specific rock types. Other digital datasets which may be integrated with the QMAP geological data include gravity and magnetic surveys, active faults. earthquakes, landslides. mineral occurrences (from GERM). fossil localities (from FRED). and petrological samples (from PET). These data can be presented for user-defined specific areas including irregular shapes such as authority boundaries or within specified distances of features such as roads orcoastlines. The data can be presented at varying scates, although locational accuracy becomes conspicuous at larger scales than 1:50 000 and data overcrowding would be a problem at smaller scales than 1:500 000.

The digital data have been captured from data record maps compiled on standard 1:50000 NZMS 260 topographic maps. These record maps are filed in GNS offices at Gracefield in Lower Hutt, and although unpublished, are available for consultation. They are stored on transparent film from which copies may be made. The geological legends and map units used on the detailed maps are based on a lithostratigraphic mapping philosophy and may differ from the published QMAP sheet.

The QMAP database will be maintained and where appropriate updated whcre further geological mapping improves upon existing infonnation. For new or additional geological infonnation, for prints of this map at other scales, for selected data or combinations of datasets. or for derivative or single·factor maps based on the QMAP data, please contact:

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APPENDIX I

Cambrian stratigraphy of the Takaka terrane

Since the most recent previously published regional maps of Northwest Nelson (Bishop 1971, Grindley 1971. 1980. Coleman 1981), Cambrian stratigraphy of the Takaka terrane has been revised (summarised in Cooper 1989, Cooper and Tulloch 1992). Further revision has resulted from student thesis mapping, particularly by Pound (1993b), Stewart (1988). McLean (1994), Mtinker (1993), Stallard (1984), and Jongens (1997). Further revision, particularly of **the** volcanic units has resulted from mapping and geochemical studies by MUnker & Cooper (1995), Miinker, Wombaker. Siebel, & Hertel (unpublished), and MUnker & Cooper (unpublished). The volcanic rocks present are now recognised as being more diverse Ihan previously thought and their relationship **with** nonvolcanic strata is particularly complex. and varies among **the** fault slices (Fig. 17. Appendix Table I). Also, several new units are recognised among the non-volcanic rocks.

The Devil River Volcanics Formation of Grindley (1960) is upgraded to group status and divided into three units of formation status - Benson Volcanics (€db. new), Mataki Volcanics (€dm, new), Cobb Igneous Complex (€dc). The Benson Volcanics comprise a number of (informal) volcanic suites (MUnker & Cooper 1995), of which seven are shown in Fig. 17, and Appendix Table 1.

Non-volcanic rocks of the Haupiri Group. which here excludes all rocks of primarily volcanic origin. are mapped as Lockelt Conglomerate (€hl), Tasman Formation (€ht), Christmas Conglomerate (€hc. new, after McLean 1994), Salisbury Conglomerate (€hs, new, after Pound 1993b), Mount Benson Sandstone and Lake Peel Formation (MUnker & Cooper 1995, here mapped together with Tasman Formation, €ht). The Heath Creek beds (of Cooper 1989 and Cooper & Tulloch 1992), and Ruby Saddle Formation (MUnker & Cooper 1995) are here treated as informal units and mapped as undifferentiated Haupiri Group.

Table 1 Stratigraphic units of the Devil River Volcanics and Haupiri groups (after MUnker & Cooper 1995, unpublished) among the fault slices in the western Takaka terrane, and shown in the correlation diagram (Fig. 17). They are grouped into larger units on the map, identified by letter symbol in square brackets. leiter symbols are as used in Fig.l? with leiter symbols used on map shown in bold.

AnalOki Rallge	*Mount Sllowden*	*MOlnl Bellsoll Mount Peel*		*Cobb Valley*	*f1ealh Creek Malak; Creek*	
Waingaro fault slice				**Lockett** fault slice	Heath · Salisbury fault slice	
					Heath volcanic **suite*** € dbh	
Paradise volcanic suite' €dbc [€db]	Lake Peel Fonnation €hp[€ht] Snowden volcanic suite' €dbs [€db]	Peel volcanic **suite*** €dbl[€db]	Lake Peel Formation €hp(€ht]	Lockett Conglomerate €hl		
Circular Bush volcanic suite· **Ɛdbc** l€db)	Snowden volcanic conglomerate' €dbv [€db]	Cobb Aat volcanic suite' €dbf[€db]	Ruby Saddle fonoation' **Ɛh**	Tasman Fonoation **Ɛht**	Mataki Volcanics **Ɛdm**	Salisbury Conglomerate **Ɛhs**
Christmas Conglomerate **Ɛhc**	Christmas Conglomerate **Ɛhc**	Benson volcanic suite· €dbb[€db]	Mount **Benson** Sandstone €hb[€ht]	Christmas Conglomerate? **Ɛhc**	Cobb Igneous **Complex** **Ɛdc**	
					Heath Creek beds **Ɛh**	

·denotes mformal name

This full colour, large format geological map illustrates the geology of the greater Nelson area (South Island, New Zealand), including Northwest Nelson, at a scale of 1:250 000. The map is part of a new series initiated in 1996 which covers the whole of the country.

Onshore geology, offshore bathymetry and geology, and major structural elements are shown, derived from published and unpublished mapping by lostilUte of Geological & Nuclear Sciences, university, and mineral exploration geologists. All geological map data are held in a geographic information system and are available in digital form and as thematic maps 0il various scales. The accompanying 67'page, fully illustraled text summarises the regional geology and tectonic development, as well as the economic and engineering geology and potential geological hazards of the map area.

The map area includes the Cambrian to Devonian volanogenic and sedimentary rocks of New Zealand's oldest basement terranes in Northwest Nelson, extensively faulted and intruded by Late Devonian granitic and ultramafic rocks, and Early Cretaceous granitoids. Permian to Cretaceous basement terranes form the hills to the east of Nelson, displaced from similar rocks in northwest Otago by movement along the Alpine Fault. Remnants of a once widespread cover of Late Cretaceous to Miocene sedimentary succession are scattered throughout the central and western parts of the map area. The succession has been broken up by Late Cenozoic faulting and eroded from mountainous areas such as the Tasman Mountains. Large volumes of Pliocene and Quaternary gravels have been deposited (largely eroded from the rapidly rising Southern Alps), particularly in the Moulere Depression.

The karst topography of the Matiri Range, looking southeast to the Thousand Acres Plateau (middle right), is formed on Oligocene limestone overlying Eocene sandstone deposited on a mid-Tertiary erosion surface cut into late Devonian granite. SUbsequent uplift along faults has resulted In mountainous areas of Paleozoic basement rock such as the Ordovician marble and sandstone at Mt Owen (distant lell).

Photo CN26175: D.L. Homer

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