Photo: Lloyd Homer, GNS Science Photo Library

Geoscience Society of New Zealand 2011 Conference

FIELD TRIP GUIDE

St Arnaud, Lake Rotoiti, Alpine Fault

Mt Owen marble massif

Marlborough Sounds

Awaroa Bay, Abel Tasman National Park

NELSON 27 November - 1 December 2011

Abel Tasman National Park

Geosciences 2011

Annual Conference of the Geoscience Society of New Zealand
Nelson, New Zealand

Field Trip Guide

Conference Conveners
Kate Clark & Nicola Litchfield, GNS Science

Organising Committee
Kyle Bland, Carolyn Hume, Julie Lee, Dallas Mildenhall,
Anya Seward (GNS Science), and Joshu Mountjoy (NIWA)

Administration
Janet Simes, Absolutely Organised Ltd
Prepared for publication by Penny Murray

Field Trip Leaders
Malcolm Arnot, Greg Browne, Hamish Campbell,
Roger Cooper, Warren Dickinson, Neil Hartstein, Mike Johnston,
Rob Langridge, Nick Mortimer, Andy Nicol, Mark Rattenbury, Russ Van Dissen,
Karen Warren and Paul Wopereis

Geosciences 2011

Annual Conference of the Geoscience Society of New Zealand,
Nelson, New Zealand

Field Trip 2
Tuesday 29 November 2011

The Magnificent Marlborough Schist

Leader: Nick Mortimer
GNS Science, Dunedin

Bibliographic reference:
Mortimer, N. (2011). The Magnificent Marlborough Schist. *In*: Lee, J.M. (ed).
Field Trip Guides, Geosciences 2011 Conference, Nelson, New Zealand.
Geoscience Society of New Zealand Miscellaneous Publication 130B. 16 p.

ISBN 978-1-877480-14-0
ISSN (print) 2230-4487
ISSN (online) 2230-4495

HEALTH AND SAFETY

PLEASE READ!

Certain hazards will be encountered on this field trip. At all times, participants must heed and observe the warnings and directions of the leader.

Participants should carry their own sunscreen and insect repellent, and any personal medications for allergic reactions (e.g. insect stings, pollen, food allergies). Wasps are a known problem in the forests of Nelson, and sandflies are present near water.

We expect the weather to be warm and sunny, but participants also need to be prepared for cold and wet conditions. Sturdy, enclosed, boot-like footwear and eye protection (e.g. glasses or sunglasses) are required. A sunhat, sunscreen, and waterproof and windproof jacket are recommended. Please don’t underestimate the potential to get sunburnt.

An average level of fitness and mobility is required for this trip. Participants must be sure-footed enough to walk a few hundred metres along boulder beaches, and be able to scramble up and down moderately steep tracks and river banks. Underfoot conditions will include sand, slippery boulders, hard angular rocks, gravelly tracks and grass slopes. Visits to coastal and stream sections may involve getting wet feet, walking/wading through knee-deep surf (unlikely), or walking through and next to streams and rivers. Wave, tidal and river conditions can be potentially dangerous. Coastal access is tide-dependent.

Caution should be exercised when examining rocks at the base of natural or man-made cliffs and banks, due to the risk of rock fall from above. If you hammer rocks, wear eye protection and pay special heed to the safety of other participants.

Access to stop 2 (Whangamoa Quarry) is controlled by Nelson Forests Ltd and the directions of the Estate Forester must be followed at all times. High-visibility vests and hard hats (provided), as well as boots and eye protection (your responsibility) must be worn at this stop. Fire hazard may dictate that quarry access is denied.

Despite all the above, we intend to have a good time and see some great rocks and fine scenery. Lunch is provided. Bring swimming gear and towel if you like. A hammer and hand lens will be useful but not essential.

Route and itinerary

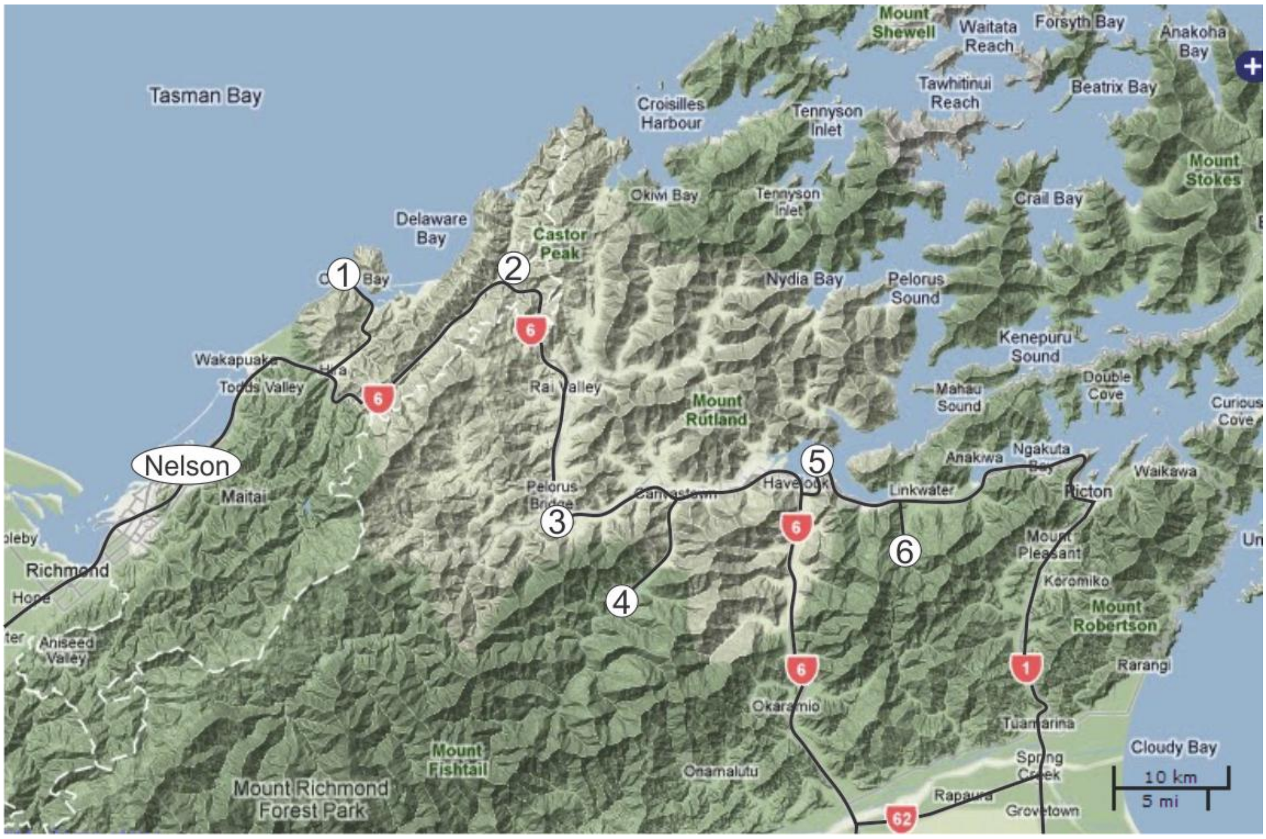

Figure 1 Route map.

Stop	Place	Geology	Drive (hr)	Stop (hr)	Toilet	Elapsed (hr)
	Nelson depart at 0830hrs					
1	Cable Bay (low tide 0710hrs)	Median Batholith	0.5	0.75	T	1.25
2	Whangamoa Quarry	DMOB serpentinite	0.5	0.75		2.50
3	Pelorus Bridge (lunch)	TZ I-IIA Caples schist	0.4	1.00	T	3.90
4	Butchers Flat	TZ IIA-IIB Caples schist	0.5	0.75	T	5.15
5	Cullen Point Lookout	View Q.C. Fault Zone	0.7	0.30	T	6.15
6	Cullensville	TZ III Caples schist	0.3	0.75		7.15
	Return to Nelson by c. 1730hrs		1.3			
			4.2	4.3		8.50

Introduction

This is an all-day, scenic, east-west transect across some of the major geological units of Zealandia's Jurassic-Cretaceous accretionary margin (Figs. 1, 2). Travelling between Nelson and Linkwater, we will see some major rock units of New Zealand's pre-Cretaceous Gondwana basement starting with a Median Batholith pluton and its geothermal system followed by Maitai Terrane serpentinite and rodingite.

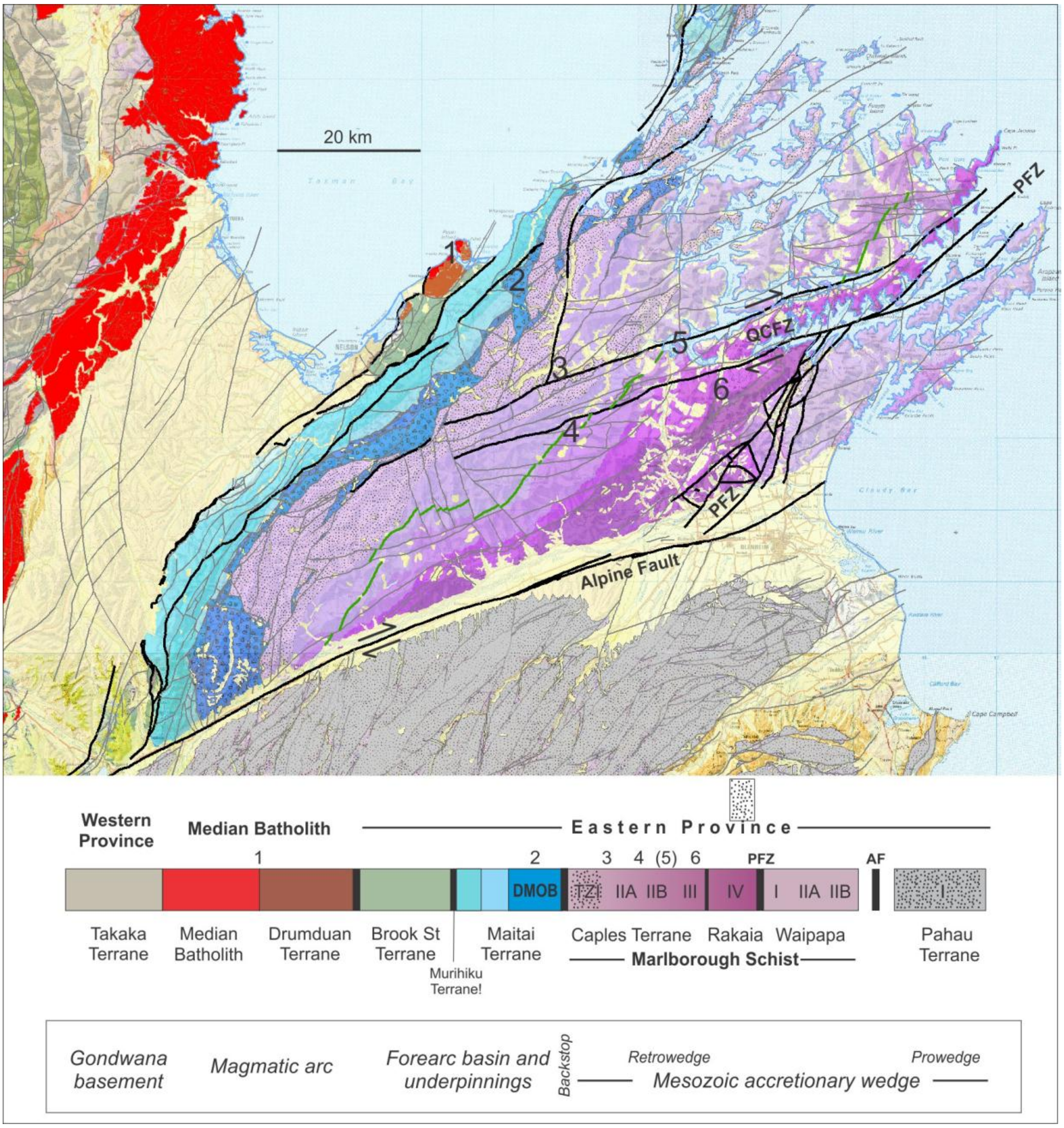

Figure 2 Simplified geological map of the fieldtrip (seamless QMAP GIS after Rattenbury et al. 1998 and Begg & Johnston 2000). Legend shows major geological units in west to east order. Interpreted Jurassic-Cretaceous tectonic settings of the units are shown at bottom of panel (see also Fig. 3). Goulter Synform axial trace in green. QCFZ=Queen Charlotte Fault Zone, PFZ=Picton Fault Zone. Darker shades of purple show textural zones I, IIA, IIB, III and IV in the western Marlborough Schist.

Most of the day will be spent in the Marlborough Schist looking at progressively deformed and recrystallised Caples Terrane. The trip involves approximately equal times spent driving and looking at rocks. Recurring themes will include rock and mineral identification, the distinction between protoliths and later recrystallisation, structure, metamorphism, exhumation and Neogene strike-slip tectonics. This written field guide provides only a “bare bones” outline.

At each stop we will discuss:

- what can we observe and interpret on the outcrop and in float
- what extra analytical work has been done that reveals things we can’t see
- how the geology relates to the other fieldtrip stops and what it all means

Geological map coverage along the route comes from Johnston (1981), Johnston (1993), Rattenbury *et al*. (1998) and Begg & Johnston (2000). Papers dealing with more thematic aspects of the geology include Coleman (1966), Mortimer (1993), Adams *et al*. (1999), Adams *et al*. (2009) and Nicol (2011).

Geological background

The Marlborough Schist is part of the 2000 km long Haast Schist Belt that wraps around New Zealand’s oroclinal bend and is offset by the Alpine Fault. It stretches from the Chatham Islands to near Lake Taupo. The Haast Schist is one of the major units of Zealandia’s pre-Cretaceous geological basement and overprints the sandstone and mudstone-dominated Caples, Waipapa and Torlesse (Rakaia) terranes of New Zealand’s Eastern Province.

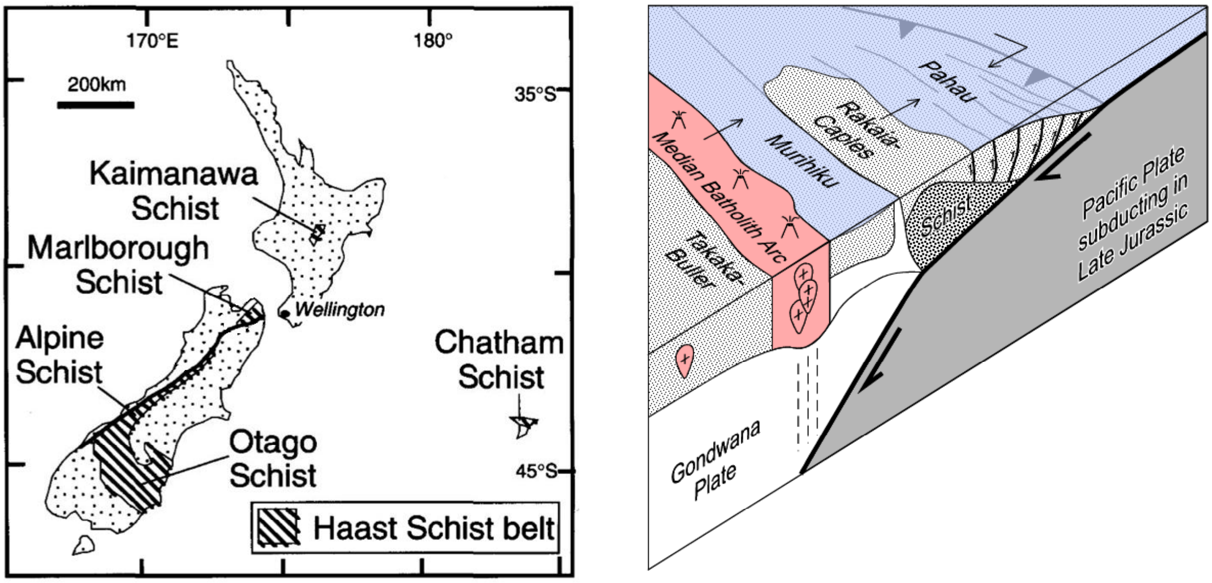

Figure 3 Left: The Marlborough Schist today - as part of the Otago Schist offset dextrally along the Alpine Fault. Right: Origin of the Haast Schist belt in a Jurassic-Cretaceous accretionary wedge setting (see also Figure 2 box)

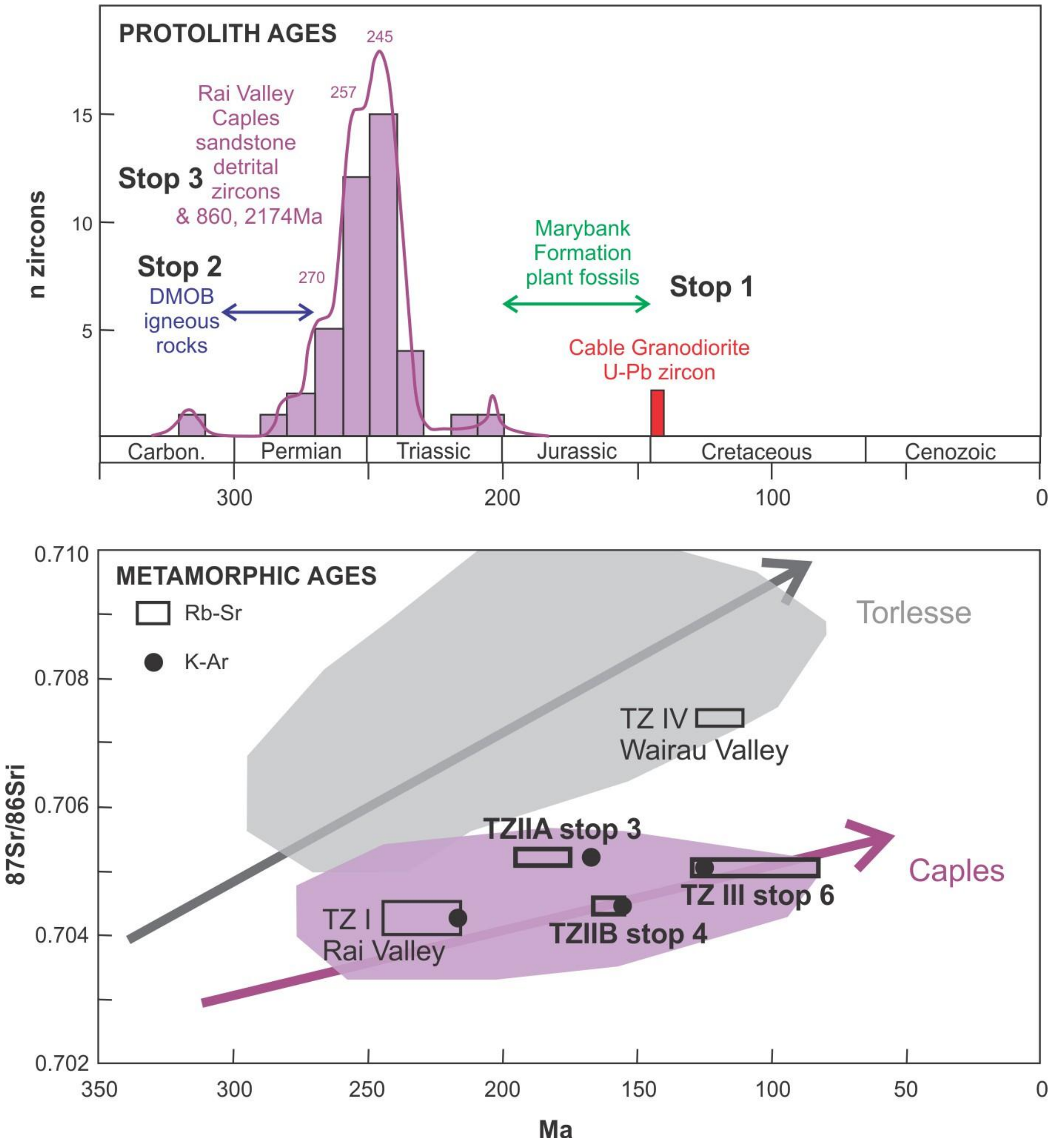

Figure 4 Paleontological and geochronological constraints on the age of rocks seen on the fieldtrip. Sources Johnston et al. (1986), Kimbrough et al. (1992, 1994). Adams et al. (1999, 2009), Sivell & McCulloch (2000).

The Haast Schist was metamorphosed to greenschist facies, deformed and at least partially exhumed in the Jurassic and Cretaceous (Fig. 4). The amphibolite facies rocks of the Alpine Schist represent additional exhumation in the Neogene in the hanging wall of the Alpine Fault. In New Zealand, textural zones (Table 1) have been – and continue to be – used to subdivide the schist on a 1:50 000 to 1: 250 000 scale in New Zealand (Hutton and Turner 1936, Turnbull *et al.* 2001). The reason for this is that textural zones are readily determined in the field, whereas a lot of petrographic work is needed to define regional metamorphic mineral zones and facies in these fine grained and low grade rocks.

Table 1 Main defining features of New Zealand textural zones (TZs). From Turnbull et al. (2001).

TZ	Met. micas	Rock names	Foliation	Veins & segregation	Other features	Met. facies
I	detrital micas visible	sandstone, mudstone, greywacke, argillite	Cleavage in mudstone only	Local quartz veins only	bedding visible	prehnite-pumpellyite
IIA	<5um thick <75um long	foliated greywacke, argillite, semi-schist, slate	Weak, anastomosing foliation in sandstones; bedding transposed	Local veins only, some ptygmatically folded	breaks into wedge-shaped blocks	pumpellyite-actinolite
IIB	5-15um thick <75um long	greyschist, semischist, phyllite, slate	Strong, penetrative foliation in all rocks; BP totally transposed to S1	Strongly flattened veins but no segregation	breaks into parallel sided slabs	pumpellyite-out isograd within TZIIB
III	15-25um thick 75-125um long	quartzofeldspathic schist, greyschist	Strong, penetrative, undulating on mm scale	<1mm thick scattered, foliation-parallel quartz "sweats"	sand-mud contacts still sharp	greenschist facies, chlorite zone
IV	25-50um thick 125-500um long	quartzofeldspathic schist, greyschist, gneiss	Strong, penetrative, undulating on cm scale. S1 or S2	>1mm thick prominent, foliation-parallel segregations	sand-mud contacts blurred at mm scale	greenschist facies, biotite zone

Table 2 Major element analyses of rocks relevant to fieldtrip stops

Terrane	Drumduan	Cable	Maitai	Maitai	Maitai	Maitai	Caples	Caples	Caples	Rakaia
Rock	**Rhyolite**	**Granodiorite**	**Dunite**	**Serpentinite**	**Rodingite**	**Sandstone**	**Sandstone**	**Mudstone**	**Ss-schist**	**Ss-schist**
Location	**Cable Bay**	**Cable Bay**	**Dun Mtn**	**Lee River**	**Whangamoa**	**Whangamoa**	**Balclutha**	**Balclutha**	**Linkwater**	**Cromwell**
Number	**VU19618**	**P45742**	**P05728**	**Nelson**	**P26454**	**P26456**	**BR821**	**BR820**	**P52375**	**P50622**
SiO2	72.54	56.06	39.53	38.37	42.90	65.00	60.13	62.60	59.40	71.00
TiO2	0.40	1.31	0.01	0.05	0.70	0.65	0.77	0.56	0.90	0.55
Al2O3	15.73	15.39	0.93	1.51	17.30	14.80	17.86	18.46	18.56	14.59
Fe2O3	0.34	4.08	0.65	2.08	2.05	1.90	7.26	6.19	7.55	4.75
FeO	1.69	4.76	7.62	4.82	4.25	3.75	-	-	-	-
MnO	0.05	0.16	0.12	0.35	0.14	0.07	0.12	0.07	0.11	0.08
MgO	0.71	3.22	48.83	41.41	6.55	1.65	3.97	2.91	2.65	1.42
CaO	0.75	6.41	0.00	0.00	19.60	2.40	3.95	3.09	3.54	1.70
Na2O	3.14	3.97	0.00	0.00	0.16	5.90	4.73	1.54	5.51	3.80
K2O	4.59	1.85	0.00	0.00	0.12	1.65	1.11	4.50	1.61	1.96
P2O5	0.05	0.36	na	na	0.15	0.20	0.09	0.06	0.17	0.14
LOI	1.65	1.52	1.11	11.11	5.42	2.13	2.94	4.48	3.09	2.38
Orig sum	-	99.09	100.13	100.00	99.37	100.27	100.08	100.24	99.93	99.42

The Marlborough Schist is actually a schist of two halves, separated by the Picton Fault Zone (Fig. 2, Mortimer 1993). The metamorphic grade in both halves increases to the east. The western half, which we will examine on this trip, is a faulted and rotated piece of Otago Schist. The eastern half, which we will not see, is an along-strike continuation of the steep, low grade schist of the North Island Axial Ranges.

Paleontological and geochronological work relevant to the fieldtrip stops is shown in Fig. 4 and some geochemical data in Table 2.

Start of trip

Leave Nelson at 9 a.m. Drive north on S.H. 6. The high hills behind Nelson are Kaka Formation of the Brook Street Terrane. Turn left along Cable Bay Road (O27/430994 BQ26/330377).

Stop 1 Cable Bay

Marybank Formation and Cable Granodiorite

Park at the west (near) end of the tombolo connecting Pepin Island with the mainland (O27/446051, BP26/346434) and walk west (Fig. 5).

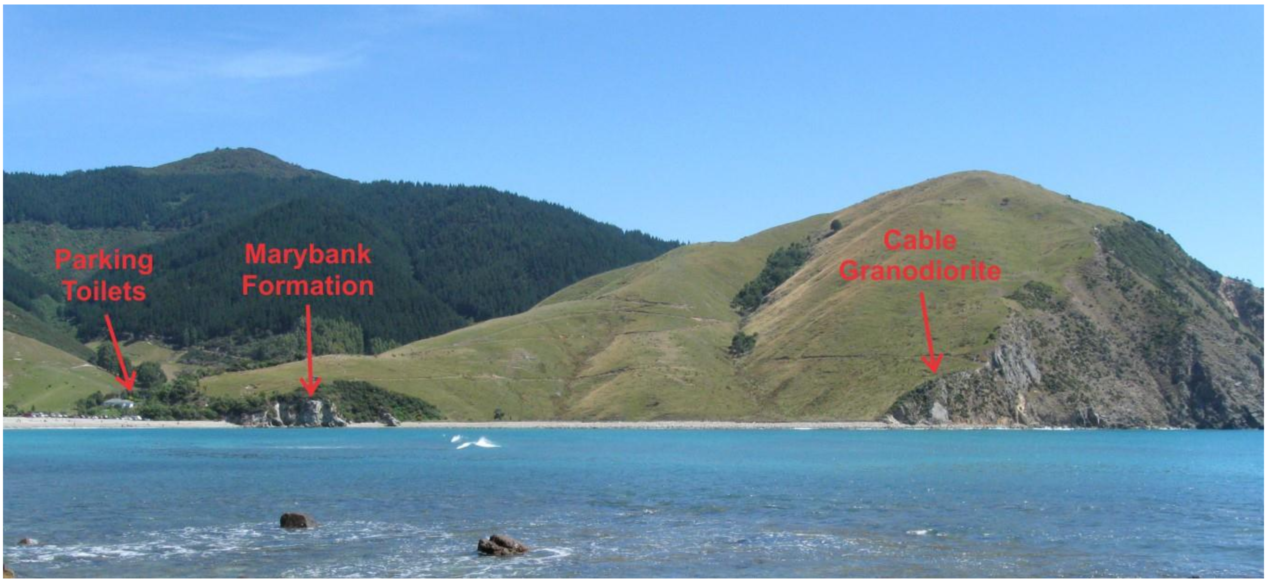

Figure 5 The Cable Bay section viewed from Pepin Island.

MARYBANK FORMATION: The first bleached outcrops to the west in Cable Bay (O27/446052, BP26/346435) are steeply dipping (BP 000/80E) metasomatised and hornfelsed rhyolitic lavas and tuffs of the Marybank Formation of the Drumduan Terrane. Near Nelson City, Marybank Formation consists of plant-bearing non-marine sandstone and mudstone of Jurassic age and containing metamorphic lawsonite (Johnston *et al*. 1986). Locally it grades into Wakapuaka Phyllonite. The potassic alteration (Table 2, column 1) is typical of the Marybank Formation within the contact metamorphic aureole and hydrothermal system around the Cable Granodiorite. Blattner *et al*. (1997) show a graph (but, ahem, no location or analytical data) in which the d^{18}O of Drumduan Group rocks and/or minerals range from -7 to +4 per mil. These values are unusually negative and suggest the involvement of relatively cold meteoric water mixed into the geothermal system. The implication is that, in the earliest Cretaceous, the Cable geothermal system was active at higher latitudes and/or altitudes than its present location.

CABLE GRANODIORITE: Continue along the beach about 0.5 km (no exposure) until dull brown-weathering exposures of Cable Granodiorite are reached (O27/444054, BP26/344437). Medium to coarse grained hornblende diorite is the most common rock type. Xenoliths of meta-andesite and fine grained diorite are common. There is much epidote (apple green) and chlorite (dark green) alteration. Cable Granodiorite has a U-Pb zircon age of 143+3/-1 Ma (Kimbrough *et al*. 1994). It is a typical I-type granitoid (Table 2, column 2) regarded as part of the Darran Suite. More voluminous plutons of similar age and composition within the Median Batholith include Rotoroa Complex (Nelson), Darran Complex (Fiordland) and Anglem Complex (Stewart Island). The Median Batholith is a long-lived Cordilleran scale batholith that intruded and grew episodically along the Gondwana margin.

The valley back to State Highway 6 partly follows the Wakapuaka Phyllonite, Delaware Fault and Waimea Faults (the old Median Tectonic Line). Continue east on State Highway 6. The road winds up to and down from Whangamoa Saddle through steeply dipping sandstones of the Early Triassic Greville Formation (Maitai Terrane). The active Whangamoa Fault controls the straight and wide Whangamoa valley.

Stop 2 Whangamoa Quarry

Maitai Terrane serpentinite and rodingite

Permission to enter the plantation forest must be obtained in advance from Nelson Forests Ltd. Leave S.H. 6 at Kokorua Road then turn up Serpentine Road. Drive about 2 km and park at O27/552056, BP27/452439. After donning hard hats, high visibility vests and eye protection, enter the quarry.

Figure 6 Whangamoa quarry. Light coloured rodingite block surrounded by dark sheared serpentinite. Kilroy was here... petrologists Colin Hutton (NZGS and Stanford University) and Bob Coleman (USGS and Stanford University). Hutton identified and named the mineral hydrogrossular, Coleman made a classic study of New Zealand serpentinites and rodingites.

We are now in the Patuki Melange, a serpentinite-matrix melange of the Dun Mountain Ophiolite Belt (Johnston 1993). Serpentinite is metamorphosed and hydrated peridotite (Table 2, columns 3 and 4). These are the oldest rocks we will see on the trip (inferred Early Permian). The rocks in the quarry have been described in moderate detail by Coleman (1966). He notes that the peridotite here is totally serpentinised; there is no relict olivine or pyroxene.

The dark coloured rocks are serpentinite (Fig. 6). The light coloured rocks are rodingites - calcium-metasomatised rocks that, here in the quarry, comprise (i) gabbro and dolerite dikes altered to hydrogrossular-bearing assemblages and (ii) tectonic inclusions (knockers) of Maitai Terrane lavas, sandstones and mudstones altered to albite-amphibole assemblages. Table 2 (columns 5 and 6) shows analyses of two samples from the quarry: the core and rim of metasedimentary inclusions.

Rodingite is one of only three rocks (along with dunite and ignimbrite) to have first been described from New Zealand. Original textures are usually well-preserved in rodingites but primary mineralogy is totally replaced. Rodingites have been described as "the toughest rocks on Earth" (Coleman, pers. comm.) and nearby "argillite" (archeological term) was quarried by Maori for implements. As with nephrite-pounamu, the toughness is due to the interpenetrating secondary mineral textures.

There are good views south up the fault-controlled Whangamoa Valley. The Patuki Melange underlies the ridge to the east of the Whangamoa Valley and Maitai Terrane Greville Formation is to the west.

Mineral checklist (not exhaustive, many minor phases omitted):

Serpentinite

Lizardite serpentine: massive dark green-black with blue and red flecks
Chrysotile serpentine: lighter green, sheared
(Coleman 1966 does not report antigorite serpentine from here)

Rodingite

Tremolite-actinolite amphibole: green, fibrous. As rinds around some argillite inclusions
Chlorite mica: dark green, replacing original pyroxene in metagabbros and as rinds
Hydrogrossular: white, grey or pale brown, fine grained, replacing original plagioclase
Stilpnomelane: black, shiny, biotite-like
Prehnite: white to clear, blocky habit, commonly as veins

Drive back to S.H. 6 and continue east towards Picton.

Stop 3 Pelorus Bridge

Caples Terrane Marlborough Schist TZI-IIA

Pull out on the left (north) side of the road at this popular recreational spot (O27/579896, BQ27/479279). Walk a short distance along the Totara Track then down to the Pelorus River to the east (downstream) end of a sandy beach just upstream from the junction of the Pelorus and Rai Rivers).

Here we are in the Pelorus Group of the Caples Terrane (Johnston 1993, Rattenbury et al. 1998). The rocks are dark grey-black metamorphosed mudstone (argillite) with minor interlayered light grey metamorphosed sandstone (greywacke). With a hand lens, original detrital sand grains are still recognisable in the sandstones. However, the main steep fabric here (016/80°E) is not bedding (S0) but a first generation foliation (S1).

Figure 7 Thin section image of typical TZIIA prehnite-pumpellyite facies volcaniclastic meta-sandstone and mudstone of Pelorus Group Marlborough Schist P52862. Plane polarised light, width 5 mm. Detrital sand grains of quartz, feldspar and lithics are prominent. There is a very weak flattening foliation: a pressure solution cleavage.

Technically we are just in the Marlborough Schist, in textural zone (TZ) IIA rocks (Fig. 7, Table 1). Occasional hook-like isoclinal folds in bedding can be seen: the axial plane of the folds is parallel to the S1 foliation. The tectonic flattening fabric is also indicated by ptygmatically folded quartz veins. A bedding-cleavage intersection lineation pitches 80° north. Johnston (1993) has mapped most Pelorus Group hereabouts as TZ I but maps ductile shear zones within TZ I, demonstrating that the transition from "greywacke" to schist is heterogeneous.

Adams et al. (2009) have dated the zircon grains in Pelorus Group metasandstones 10 km north of here. The range in ages of the grains (Fig. 4) is typical of Caples Terrane rocks from Northland to Southland: a fairly unimodal Late Permian to Triassic peak with only rare older grains. Caples Terrane rocks are distinctively unradiogenic in terms of their strontium isotope ratios (Fig. 4). Mineralogy, geochemistry and isotopic composition have joined age, stratigraphy and lithofacies as defining features of New Zealand terranes (Table 2, rightmost five columns).

Upstream, the ratio of sandstone to mudstone increases. More examples of transposed bedding are seen, including isolated lenses (boudins) of sandstones. Some steep east-west striking fractures (100/80°N) have dextral offsets of up to 0.5 m. These may be a low strain expression of the dextral Queen Charlotte Fault Zone which we will discuss more at Stop 5.

The rocks get progressively lichen-covered towards the road bridge. Scramble up the banks before the bridge is reached and return to the car park. Drive east on S.H. 6.

Stop 4 Butchers Flat, Wakamarina River

Caples Terrane Marlborough Schist TZIIB

Turn off S.H. 6 at Canvastown. Drive up the Wakamarina valley (seal ends at 10 km) to the road end and the open DOC camping ground at Butchers Flat (O27/597812, BQ27/497195). Walk down to the Wakamarina River at the north end of the lower campground.

We are about 8 km south of Stop 3 and have travelled across strike. The protolith is still the same Caples Terrane meta-sandstone and mudstone (Fig. 4), but there are two main differences to note here compared with Pelorus Bridge.

- foliation is better developed, more penetrative and parallel sided and the foliation surfaces have more of a "mica sheen" than at stop 3. This is typical of textural zone IIB. Rock terms such as phyllite are appropriate (Table 1). We are in the pumpellyite-actinolite facies but thin sections are needed to identify the minerals (Fig. 8).
- the foliation dip is much lower (strike/dip 040/7SE). A weak lineation plunges to 100. This represents kinematic "a" or stretching direction and is common throughout the Otago and Marlborough Schists in TZ IIB-IV rocks.

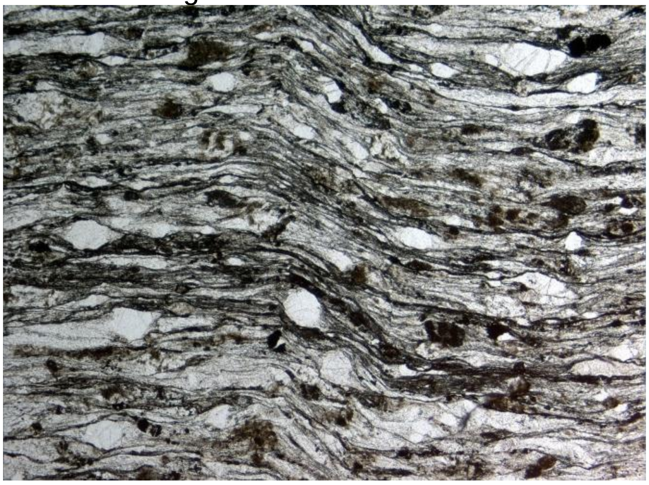

Figure 8 Thin section image of typical TZIIB Marlborough Schist P53388. Plane polarised light, width 5 mm. Detrital sand grains of quartz and feldspar are still visible but most of the rock consists of metamorphic minerals that define a penetrative foliation. However, there are no segregations or "sweats" of metamorphic quartz. Much of the grey, fine grained material is pumpellyite. A kink fold crosses the centre of the image. Compare with Fig. 7.

Pebbles and boulders in the stream come from still further across strike (that's down section or up metamorphic grade). Lithologies include deformed conglomerate, chipwacke, metachert, piemontite schist and strongly quartz-veined schists.

Drive back to S.H. 6 and turn east to Havelock.

Stop 5 Cullen Point lookout: Queen Charlotte Fault Zone

Turn west onto Queen Charlotte Drive (signposted to Picton) after passing through most of Havelock. After about 4 km, pull out left along the 2WD track to Cullen Point lookout (P27/756930, BQ28/656313 DOC, signposted). There is no need to walk out on the tracks as better views are not obtained.

No rocks to look at here, but there are good views west up the Pelorus River (from where we've come) and east along Pelorus Sound. This broad lineament is, of course, fault controlled and is a major strand (Kenepuru Fault) of the Queen Charlotte Fault Zone (Fig. 2). Isotects, and the axial trace of the Goulter Synform, are offset 10-15 km dextrally across the Kenepuru Fault (Johnston 1993). The Alpine (Wairau) Fault is generally regarded as the northernmost part of the dextral Marlborough Fault System. But, possibly, the Queen Charlotte Fault Zone should be regarded as such.

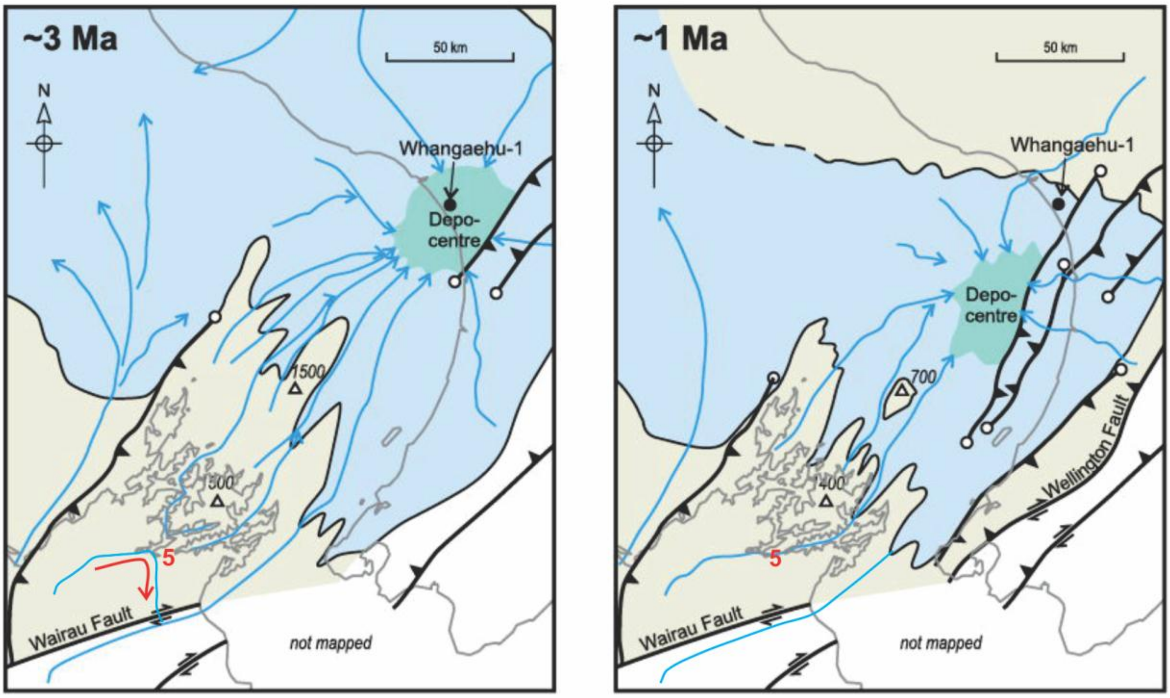

Figure. 9 Maps, adapted from Nicol (2011), showing location of stop 5 and former drainage direction of Pelorus River into the Wairau. Ages of drainage capture are open to debate.

South of Havelock is the Kaituna valley, as broad as the Pelorus. The Kaituna "River" flows north into Pelorus Sound but is an underfit stream. Based on the Caples and Maitai-dominated composition of (undated) gravels in water bores in the Kaituna and Wairau valleys, Mortimer & Wopereis (1997) proposed that the Pelorus River formerly flowed south down the Kaituna Valley to near Blenheim. The paleo-Pelorus River was likely captured by headwater erosion in the drainage system that presently occupies Pelorus Sound (Fig. 9). Such a capture would presumably have been enhanced by: (1) increased erosional vigour of the capturing river due to periodic low sea level stands (2) weaker bedrock near Havelock due to cataclasis in the Queen Charlotte Fault Zone. Northward tectonic tilting is also possible but less likely. The wider geomorphic development of the Marlborough Sounds has been discussed more recently by Nicol (2011).

Continue along Queen Charlotte Drive towards Picton.

Stop 6 Cullensville

Caples Terrane Marlborough Schist TZIII

At Linkwater turn right on a gravel road to Cullensville (signposted). Park in the car park at the end. Interpretive panels explain about the former town of Cullensville, founded 1888. At one time there were three hotels, two billiard saloons, a bank, courthouse, and five bakeries here. Walk a short distance south along the track to Cullen Creek, then walk downstream to low schist exposures on the true left bank at P27/815878, BQ28/715261.

Unfortunately, Cullen Creek aggraded considerably in the 28 December 2010 floods and there is not much in situ rock left to see. Low, weathered schist exposures in the true left bank are TZIII schist (Fig. 10, Table 1). We are in the chlorite zone of the greenschist facies, the rocks probably attained maximum temperatures of 300-350°C. Strike and dip of foliation is 045/28NW. Textural grade is noticeably higher than at previous stops because coarser micas “glitter” on foliation surfaces, and quartz segregations are present. There is also an abundance of folded quartz veins.

A prominent stretching lineation plunges to 286 (similar azimuth to stop 4) and grooves (mullions) on the quartz veins share this plunge. We are now on the SE limb of the Goulter Synform, about 8 km across strike from stop 4. The NW dipping foliation and W-dipping lineation are regional throughout this part of Marlborough Schist. Upstream (down-section), the headwaters of Cullen Creek are deeper in the schist pile and bring down boulders and pebbles of more thickly segregated and veined TZIV greyschist, as well as greenschists (metavolcanics) and quartzites (metacherts). The Waikakaho gold lodes occur in Torlesse (Rakaia) Terrane at the Cullen Creek headwaters.

Figure 10 Thin section image of typical Caples Terrane TZIII Marlborough Schist near Cullensville, P52375. Plane polarised light, width 5 mm. Former detrital sand grains of quartz and feldspar are completely recrystallised and all of the rock consists of metamorphic minerals that define a penetrative foliation. Segregation lamellae <1mm thick (a defining feature of TZ III) are present. Compare with Figs. 7 and 8.

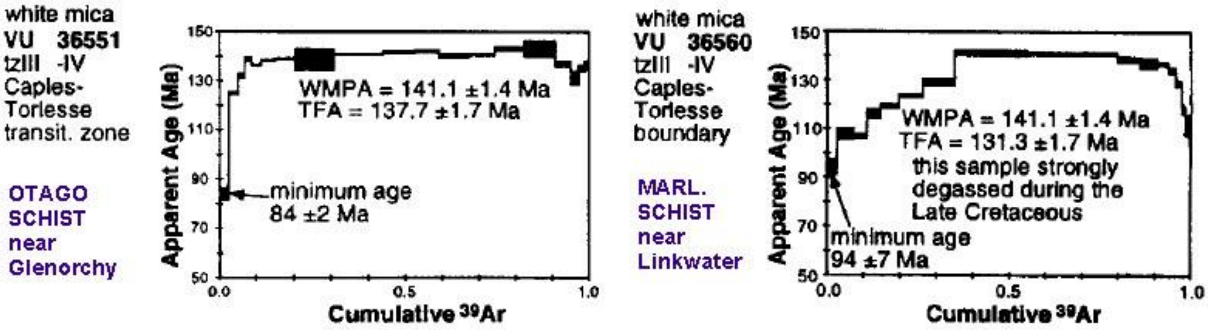

Figure 11 Comparison of argon step heating spectra of similar structural-metamorphic levels of the Otago and Marlborough Schists (Little et al. 1999).

The following is a quote from Little & Mortimer (2001): “On the basis of their similar lithological assemblages, metamorphic and textural zonation, structural and microstructural fabric elements, sense of shear, $^{40}Ar/^{39}Ar$ cooling ages on phengitic white mica [Fig. 11], and geometric relationship to ductilely deformed, fibrous quartz extension gashes, we believe that LS-tectonite fabrics near the Caples ... boundary in the NW part of the Otago Schist near Glenorchy are in every way equivalent to those near the same contact in the Marlborough Schist [near Cullensville]. Both lie on the eastern limb of the once continuous Earnslaw–Goulter synform. Today, these once contiguous parts of the Haast Schist occur on opposite sides of the Alpine Fault, have distinct strikes, and lie on different parts of the South Island’s oroclinal bend”. Little and Mortimer (2001) showed that the combined foliation, lineation and veins fabric in Marlborough Schist are rotated 42±9° clockwise about a steep NW-plunging fold axis, relative to Otago Schist at Glenorchy. The vertical axis component is 22±10°.

This completes our traverse of the Marlborough Schist and associated terranes between Nelson and Linkwater. Still higher grade schists (TZIV Torlesse Terrane) can be seen on the shore at Governors Bay, a few km from Picton. Unfortunately, time and tides are against us today.

We will have a short debrief in the car park on the day’s traverse before we return along S.H. 6 to Nelson.

Acknowledgements

Mike Johnston and Mark Rattenbury provided useful information on the fieldtrip stops. The Geoscience Society acknowledges the helpful assistance of Phil Madill and Craig Brown of Nelson Forests Ltd. for providing access to Whangamoa quarry for the 2011 conference fieldtrip.

References

Adams, C. J., I. J. Graham and M. R. Johnston 1999. Age and isotopic characterization of geological terranes in Marlborough Schist, Nelson/Marlborough, New Zealand. *New Zealand Journal of Geology and Geophysics 42*: 33–55.

Adams, C. J., H. J. Campbell and W. J. Griffin 2009. Tracing the Caples Terrane through New Zealand using detrital zircon age patterns and radiogenic isotope signatures. *New Zealand Journal of Geology and Geophysics 52*: 223–245.

Begg, J. G. and M. R. Johnston 2000. Geology of the Wellington area: scale 1:250,000. Lower Hutt: Institute of Geological & Nuclear Sciences. Institute of Geological & Nuclear Sciences 1:250,000 Geological Map 10. 64 p. + map.

Blattner, P., G. W. Grindley and C. J. Adams 1997. Low- ^{18}O terranes tracking Mesozoic polar climates in the South Pacific. *Geochimica et Cosmochimica Acta 61*: 569–576.

Coleman, R. G. 1966. New Zealand serpentinites and associated metasomatic rocks. *New Zealand Geological Survey Bulletin 76*.

Hutton, C. O. and F. J. Turner 1936. Metamorphic zones in north-west Otago. *Transactions of the Royal Society of New Zealand 65*: 405–406

Johnston, M. R. 1981. Sheet O27AC–Dun Mountain. Geological Map of New Zealand 1:50 000. Wellington, New Zealand, Department of Scientific and Industrial Research.

Johnston, M. R. 1993. Geology of the Rai Valley area. Sheets O26 & O27BD, scale 1:50 000. *Institute of Geological & Nuclear Sciences Geological Map 5*.

Johnston, M. R., Raine J. I. and W. A. Watters 1987. The Drumduan Group of east Nelson, New Zealand: plant-bearing Jurassic arc rocks metamorphosed during terrane interaction. *Journal of the Royal Society of New Zealand 17*: 201–251.

Kimbrough, D. L., J. M. Mattinson, D. S. Coombs, C. A. Landis and M. R. Johnston 1992. Uranium-lead ages from the Dun Mountain Ophiolite Belt and Brook Street terrane, South Island New Zealand. *Geological Society of America Bulletin 104*: 429–443.

Kimbrough, D. L., A. J. Tulloch, D. S. Coombs, C. A. Landis, M. R. Johnston and J. M. Mattinson 1994. Uranium-lead zircon ages from the Median Tectonic Zone, New Zealand. *New Zealand Journal of Geology and Geophysics 37*: 393–419.

Little, T. A. and N. Mortimer 2001. Rotation of ductile fabrics across the Alpine Fault and Cenozoic bending of the New Zealand orocline. *Journal of the Geological Society (London) 158*: 745–756.

Little, T. A., N. Mortimer and M. O. McWilliams 1999. An episodic Cretaceous cooling model for the Otago-Marlborough Schist, New Zealand, based on $^{40}Ar/^{39}Ar$ white mica ages. *New Zealand Journal of Geology and Geophysics 42*: 305–325.

Mortimer, N. 1993. Metamorphic zones, terranes and Cenozoic faults in the Marlborough Schist, New Zealand. *New Zealand Journal of Geology and Geophysics 36*: 357–368.

Mortimer, N. and P. Wopereis 1997. Change in direction of the Pelorus River, Marlborough, New Zealand: evidence from composition of Quaternary gravels. *New Zealand Journal of Geology and Geophysics 40*: 307–313.

Nicol, A. 2011. Landscape history of the Marlborough Sounds, New Zealand. *New Zealand Journal of Geology and Geophysics 54*: 195–208.

Rattenbury, M. S., R. A. Cooper and M. R. Johnston 1998. Geology of the Nelson area: scale 1:250,000. Lower Hutt: Institute of Geological & Nuclear Sciences Limited. Institute of Geological & Nuclear Sciences 1:250,000 Geological Map 9. 67 p. + map.

Sivell, W. J. and M. T. McCulloch 2000. Reassessment of the origin of the Dun Mountain Ophiolite, New Zealand: Nd-isotopic and geochemical evolution of magma suites. *New Zealand Journal of Geology and Geophysics 43*: 133–146.

Turnbull, I. M., N. Mortimer and D. Craw 2001. Textural zones in the Haast Schist – a reappraisal. *New Zealand Journal of Geology and Geophysics 44*: 171–183.