Geosciences 2016

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Field Trip 5
28 November 2016

Field Trip 10
2 December 2016

Central Otago Schist and Scenery

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GNS Science

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FT5: Monday 28 Nov.

Departs Wanaka 08h30, departs Queenstown airport 11h00, returns Wanaka 17h30

FT10: Friday 2 December

Departs Wanaka 08h00, arrives Queenstown airport 14h30, returns Wanaka 17h00

This one day Central Otago Schist and Scenery fieldtrip is being offered as pre- and post-conference roundtrip Wanaka-Wanaka excursions, with pickups and drop-offs at Queenstown airport. The pre-conference trip will travel in an anticlockwise direction from Wanaka to Cardrona, Queenstown, Cromwell, Tarras and Wanaka and the post-conference trip in a clockwise direction. Those being dropped off or picked up at the airport will not get to drive over the Crown Range, but they will get stunning aerial views of the Queenstown-Lakes District that the ground-based people will not.

The simple story of the trip is that 120 million years ago, the Otago Schist rocks were 30 km below the Earth's surface. We map, sample and analyse them to better understand how they got buried, how they came back up again, and how they are relevant to science and society.

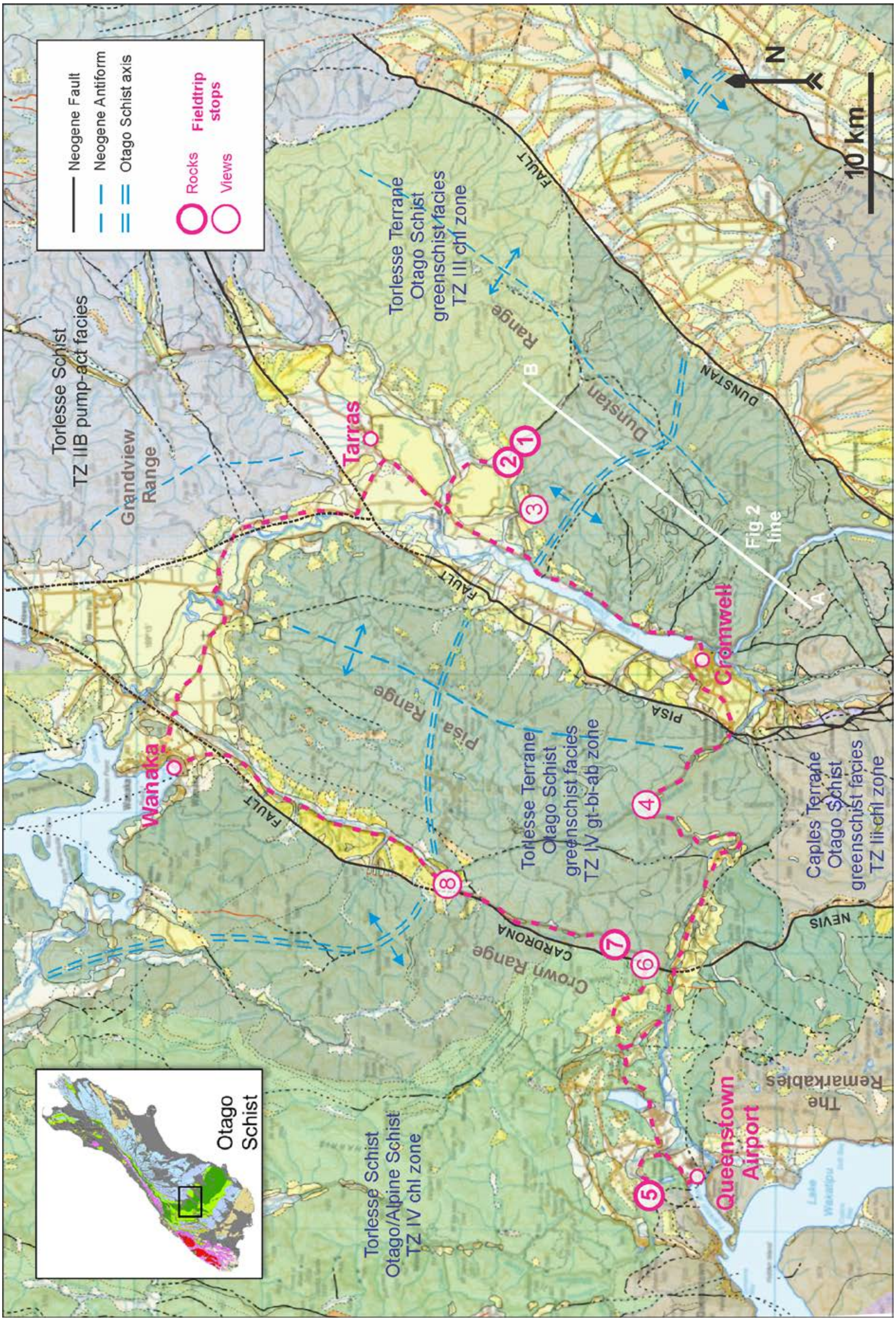
Current geological understanding of the Otago Schist is that it formed in a Late Jurassic to Early Cretaceous (c. 160-105 Ma) accretionary wedge along the SE Gondwana margin. Models on how, when and why the schist got to the surface are still developing. The Rise and Shine Shear Zone (Stops 1a, b, c and d), where we will spend most of our time, is a great place to see and discuss new data and emerging ideas on schist exhumation.

Central Otago is one of the most arid parts of the Zealandia continent. The iconic landscape is dominated by fault-controlled elongate valleys and mountains of the Otago Basin and Range province. Glacially-formed landforms abound and most schist dip slopes are underlain by landslides. Welcome to 45°S.

Special Requirements: There will be short walks over steep and uneven ground. Closed footwear is required (no sandles or jandals). Bring a headlamp or flashlight if you want to go in the adit (we will supply some hard hats). Dress for changeable weather (rain jacket and sunscreen). Take care getting in and out of vans and watch for traffic on roads. Gravelly slopes can be slippery. Watch for unfenced trenches in mining areas. Always follow the instructions of your leader.

Fig. 1. (next page) Route and geological map for the fieldtrip.

Stops: 1 Thomsons Gorge Rd at Come-in-Time workings. 2 Lower Thomsons Gorge Rd. 3 Welshtown, Bendigo Historic Reserve (lunch). 4 Roaring Meg Hydro Station, Kawarau Gorge. 5 Tucker Beach, Shotover River. 6 Chain Bay Four, Crown Range Road. 7 Chain Bay Three, Crown Range Road. 8 Cardrona Township.



Neogene Fault
Neogene Antiform
Otago Schist axis
Rocks
Views
Fieldtrip stops
10 km
N
Otago Schist
Torlesse Schist
TZ IIB pump-act facies
Grandview Range
Tarras
Torlesse Terrane
Otago Schist
greenschist facies
TZ III chl zone
Dunstan Range
DUNSTAN FAULT
B
A
Fig 2 line
Cromwell
Wanaka
Pisa Range
PISA FAULT
Torlesse Terrane
Otago Schist
greenschist facies
TZ IV gt-bi-ab zone
Caples Terrane
Otago Schist
greenschist facies
TZ III chl zone
NEVIS
CARDRONA FAULT
Crown Range
Torlesse Schist
Otago/Alpine Schist
TZ IV chl zone
Queenstown Airport
The Remarkables
Lake Wakatipu

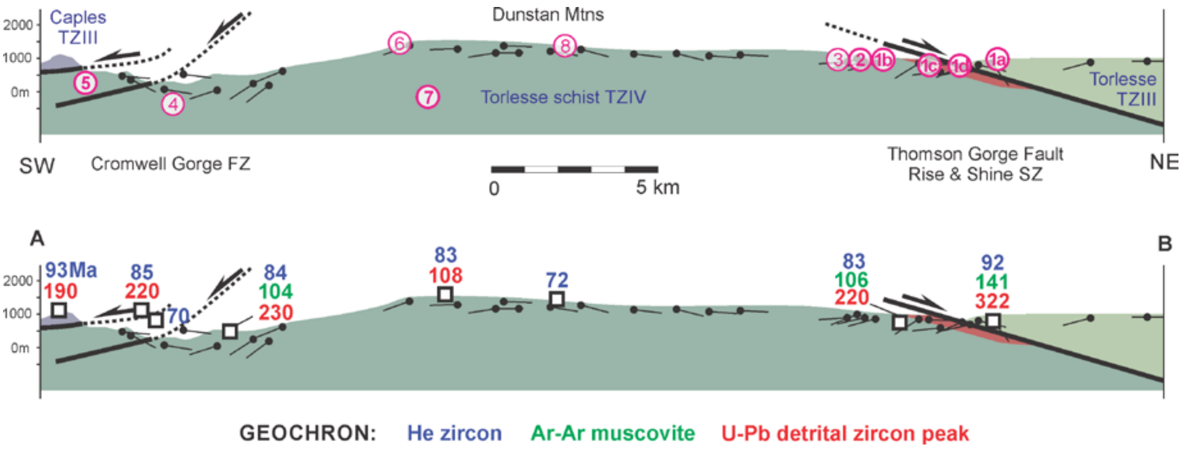


Fig. 2. Cross section (no vertical exaggeration) along the Dunstan Mountains crest. Upper section shows fieldtrip stops projected in to the cross section line. Lower section shows ages (in Ma) of different geochronometers. Rise and Shine Shear Zone is the red band with the Thomsons Gorge Fault as its structurally upper limit. Schist dips shown by line and ball symbols.

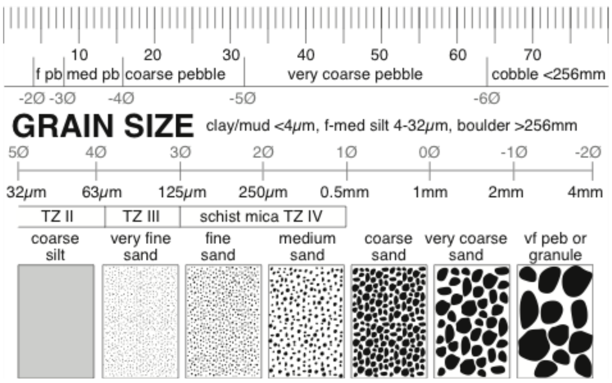


Fig. 3. Grain size card from the GSNZ field wallet. As well as showing sand grain size descriptors, the card is handily calibrated for textural zone metamorphic mica diameter. TZIII rocks have 'very fine grained' micas and TZIV rocks have 'fine- to medium-grained' micas (Turnbull et al. 2001). Textural grade is a 'cheap and cheerful' way to establish proxies for low metamorphic grade schists.

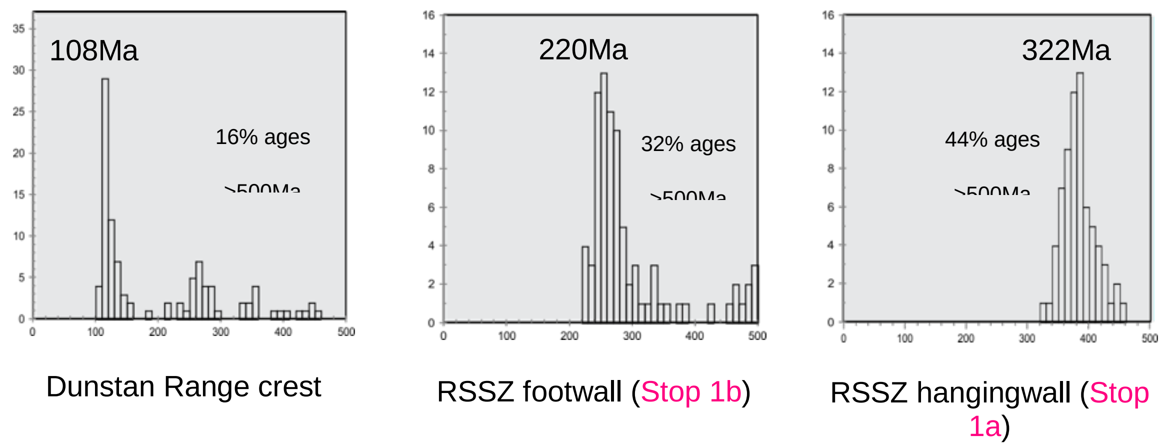


Fig. 4. U-Pb detrital zircon age histograms from the Otago Schist in the Dunstan Mtns (Mortimer, Lee & Stockli 2015). The modal age peak is inferred, with certain assumptions, to approximate to the original depositional age of each schist sample. All samples can be referred to parts of the Torlesse Composite Terrane.

STOP 1. DUNSTAN MOUNTAINS, THOMSON GORGE ROAD

park at WGS84 lat/long -44.9351, 169.4126, elev. 600 m

Rise and Shine Shear Zone, Come-in-Time workings

Take Thomson Gorge Road southeast and up into the Dunstan Mtns. The road gets increasingly rough but, despite the warning signs, is passable using 2WD vehicles as far as we are going. Leave gates how you find them. Park at the green Dept of Conservation signs at the Come in Time Workings. We will spend up to two hours here looking at four different exposures, all within a short walk of the vehicles (Fig. 5).

Watch for unfenced shafts and trenches. Bidibids are an annoyance.

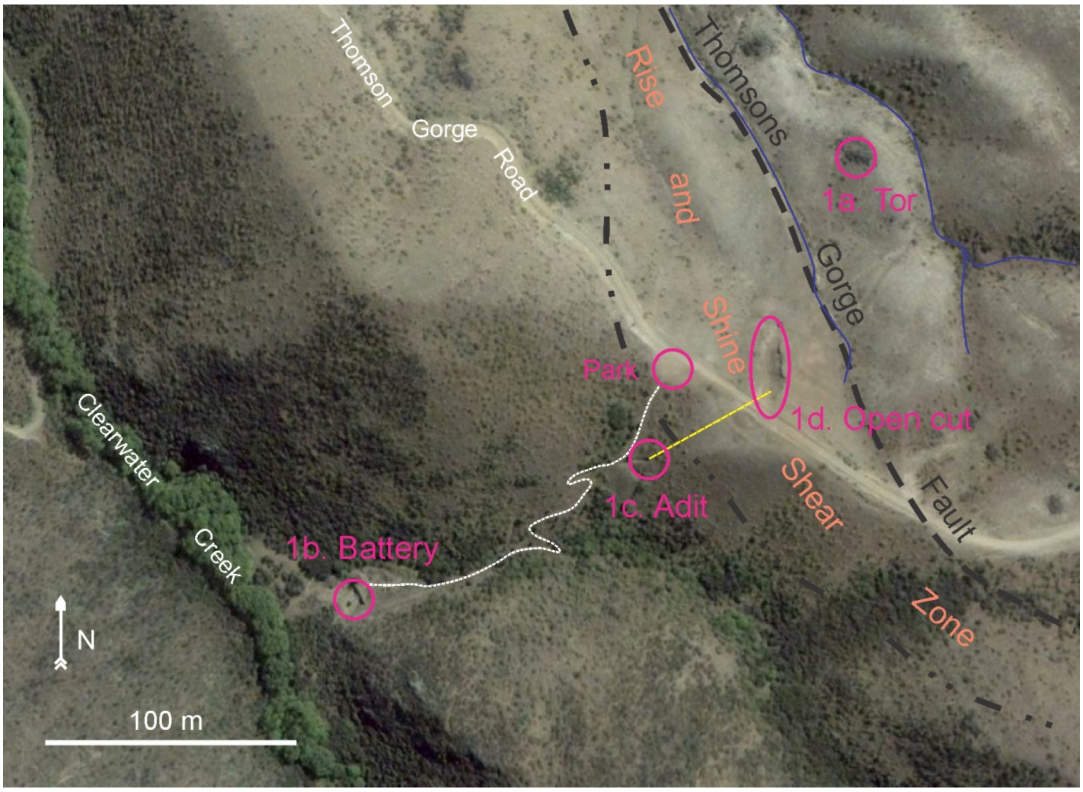


Fig. 5. The Come-in-Time area, Thomson Gorge Road, Dunstan Mountains

BACKGROUND. The Rise and Shine Shear zone (RSSZ) was recognised as a gently NE-dipping, mineralised fault zone in the schist in the 1980s (Fig. 2, Corner 1988, Winsor 1991, Martin & MacKenzie 2016) but information on its tectonic significance and age has only emerged in the 2000s. Mortimer (2000, 2003) and Turnbull (2000) were the first to identify a break in metamorphic and textural grade of schist across the fault: TZIII chlorite zone greenschist facies in the hangingwall (stop 1a) and TZIV garnet-biotite-albite zone greenschist facies in the footwall (stop 1b) (Fig. 3). Deckert et al. (2002) showed that numerous indicators of a normal sense of displacement occur in semi-brittle sheared schist and they proposed a net-normal dip-slip displacement of 8-15 km across the RSSZ based on the missing metamorphic section and an average strike and dip of the shear zone of 115/15°NNE.

Shear zone architecture and mineralisation were summarised by Cox et al. (2006). The structural top of the mineralised Rise and Shine Shear Zone is marked by the Thomsons Gorge Fault (Fig. 2). Most of the 8-15 km displacement appears to be taken up on the Thomsons Gorge Fault. Metallic minerals in the RSSZ include pyrite, arsenopyrite and gold, and there is a strong orange ankerite $Ca(Fe,Mg)(CO_3)_2$ alteration as well as quartz veins and silicified breccias associated with mineralisation (Cox et al. 2006).

Over much of the Otago Schist, Ar-Ar ages of white micas decrease with structural depth (Mortimer 2003). Ar-Ar dating of schist in the Dunstan Mtns. (Forster & Lister 2003, Gray & Foster 2004, Scott, 2005) has revealed a discontinuity in the age-depth profile across the Rise and Shine Shear Zone, as would be predicted by the metamorphic grade break. Footwall Ar-Ar ages are c. 101-113 Ma and hangingwall ages 141-145 Ma (Fig. 2). Breaks across the shear zone are also highlighted by reconnaissance U-Pb and U-Th-He zircon age datasets (Mortimer et al. 2015). U-Pb zircon dating reveals the hangingwall block consists of Carboniferous Torlesse protoliths and the footwall block Late Triassic and Early Cretaceous Torlesse protoliths (Fig. 4). U-Th-He zircon ages (the time at which the rocks were last at c. 180°C) are 92±7 Ma in the hangingwall and 83±6 Ma in the footwall of the Thomsons Gorge Fault, indicating cessation of fault movement in the 92-83 Ma interval.

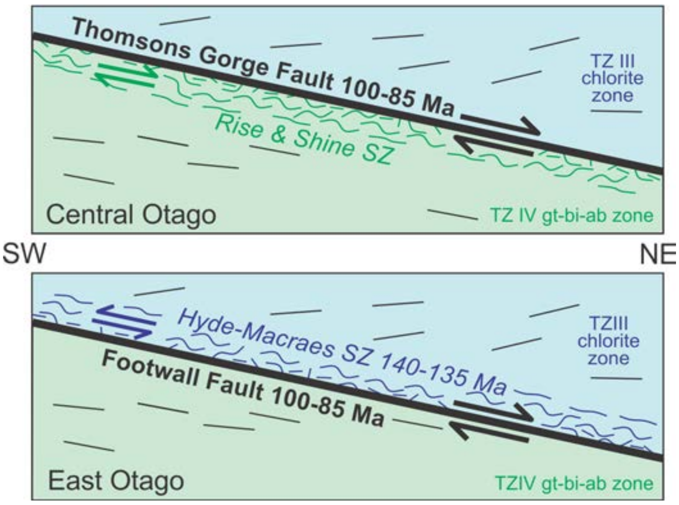


Fig. 6. Similarities and differences in the low-angle shear zone and fault systems that occur on the NE flanks of the Otago Schist

The Thomsons Gorge Fault is one of only a few major low-angle brittle structures in the Otago Schist that we can confidently identify as having played a role in the unroofing of the schist (Fig. 6). Forster & Lister (2003) proposed a metamorphic core complex model for the schist of the Dunstan Range to the south of here but, puzzlingly, they did not use the Thomsons Gorge Fault as supporting evidence for a low angle brittle detachment. A Late Cretaceous core-complex style of exhumation seems plausible.

This Come-in-Time part of the Rise and Shine Shear Zone was worked around 1912; a small open cut and some near-surface adits are still observable. Since then it has been extensively drilled as have other mineralised areas along strike (Martin & MacKenzie 2016).

STOP 1a. ROCKS c. 130 m NE OF ROAD

-44.9340, 169.4134

Chlorite Zone TZIII Torlesse Schist: Carboniferous protolith

From the carpark, follow a weakly marked track NE past a collapsed shaft and open cut (caution!) and contour round the hill to some scrub-covered rocks on the facing hillside. Collect bidibids in your socks as you go.

ROCKS: These unassuming and slightly weathered exposures are typical interlayered psammitic and pelitic schist (formed from sandstone and mudstone protoliths). *In situ* foliation has a strike and dip of 070/5°SE. Foliation is cut at a high angle by 1-7 mm thick spaced quartz veins, and open folds and crenulations are also present. The schist is textural grade III, meaning that the micas are very fine grained (Fig. 3), and the schist is well foliated (splittable) but only incipiently segregated (quartz segregations are <1mm thick and short). Thin sections show metamorphic grade is chlorite zone of the greenschist facies (quartz + albite + muscovite + chlorite + epidote + titanite).

In all metamorphic and structural respects, this schist is typical of the entire northern Dunstan Mtns and much of the northern flanks of the Otago Schist: it cooled through 350°C at c. 141 Ma and through 180°C at 92 Ma (Fig. 2). However, U-Pb dating of zircons from a nearby sample (Fig. 4, right panel) showed a surprising absence of Permian-Triassic Rakaia Terrane zircons. Instead we seem to have a rare, Carboniferous sandstone unit in the Torlesse Composite Terrane. We are structurally above the Rise and Shine Shear Zone; the low angle Thomsons Gorge Fault projects a few tens of metres beneath our feet. We will see much more deformed and metamorphosed schist at stops 1b, c and d.

STOP 1b. COME-IN-TIME BATTERY

-44.9360, 169.4102

Garnet-biotite-albite zone TZIV Torlesse Schist: Triassic protolith

From the carpark, walk c. 250 m west downhill along a footpath to the battery site (Fig. 7).

Fig. 7. The repaired and rebuilt Come-in-Time stamper battery (Stop 1b)

An impressive stamper battery has been restored here. Information signs explain about its use. *In situ* schist can be examined behind the battery.

ROCKS: Like Stop 1a, schist here is unmineralised and unsheared. However, the textural and metamorphic grade is higher and there is a lot more quartz "splashed around". First of all note that, on sunny foliation surfaces, the schist is more glittery than TZ III schist at Stop 1a; the grain size of micas is larger and quartz segregations are also thicker (1-10 mm) and longer. These simple field observations tell us we are in textural zone IV (Fig. 3). Thin sections reveal that we are in the garnet-biotite-albite zone of the greenschist facies (mineral assemblages are quartz + albite + muscovite + chlorite + biotite + garnet + titanite). We are about 250 m structurally below the schist at stop 1a. The increase in textural and metamorphic grade between stops 1a and 1b is too great to be explained without an intervening fault (Mortimer 2000, 2003). We will see evidence for the tectonic contact at stops 1c and 1d.

Foliation behind the stamper battery is 130/30°NE (steepening to 60°NE at the left end of the face). Isoclinally folded quartz veins can be seen in layered and mesoscopically folded pelitic and psammitic greyschist. Such schist is typical of the southern Dunstan Mtns and much of the core of the Otago Schist between Wanaka and Dunedin.

U-Pb dating of zircons from a nearby schist sample gave a detrital histogram typical of Late Triassic Rakaia Terrane of Torlesse Composite Terrane (Fig. 4, centre panel). However, a sample from the crest of the Dunstan Mtns c. 15 km SW gave a surprising Early Cretaceous peak, (Fig. 4 left panel). This latter pattern is typical of Pahau Terrane of Torlesse Composite Terrane e.g. in Marlborough or East Coast North Island. The occurrence of Torlesse schist protoliths of such different ages indicate substantially greater structural complexity in the accretionary wedge than hitherto realised, and this is something we can discuss at the outcrop.

STOP 1c. RED MINE ADIT

-44.9354, 169.4121

Mineralised Rise and Shine Shear Zone

Walk uphill back along the track. A short distance before the road, the entrance to an adit is seen. Take care inside the adit, use a flashlight and watch your heads.

The adit (Fig. 8) is c. 65 m long and trends 062, its end (collapsed) is beneath the Open Cut (Stop 1d). Corner (1988) thought it was simply a haulage way along which to transport ore from the open cut to the stamper battery.

ROCKS: Schist foliation dips 060/20°NW at the adit entrance, so it has swung round from that measured at the stamper battery. Textural grade is still TZ IV, as it was at Stop 1b below. Between 15 and 55m into the adit, Corner (1988) mapped many steep- to moderately-dipping brittle shears (microfaults) with down-dip slickensides; these cut more shallowly-dipping schist (Fig. 8). Schist foliation steepens to c. 45° towards the NE termination of the adit and still is cut by more steeply NW-dipping microfaults. Quartz stringers, some sulphide-bearing, along with crush and gouge zones are visible in the adit walls. Such brittle deformation, veining and mineralisation are absent at Stop1b: we have walked structurally up into the Rise and Shine Shear Zone.

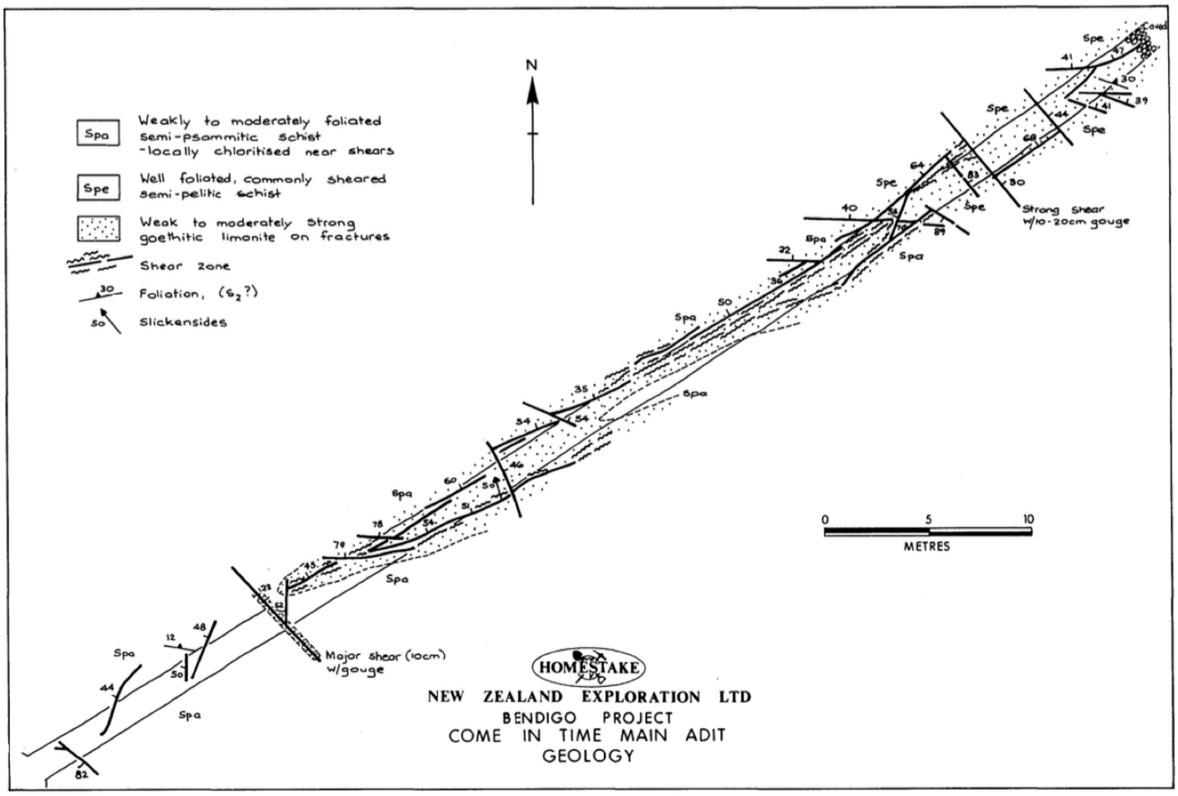


Fig. 8. Geology of the adit at Stop 1c (Corner 1988)

Corner (1988) reported anomalously high concentrations of arsenic and gold throughout the length of the adit. The highest concentrations of 4900 ppm As and 0.91 ppm Au were in the 50-60m interval i.e. 5-10m from the collapsed NE end of the adit.

STOP 1d: OPEN CUT, NE SIDE OF THOMSONS GORGE ROAD

-44.9349, 169.4127

Rise and Shine Shear Zone

Cross the road and carefully enter the open cut. The loose gravel can be slippery.

ROCKS: The schist in the cut is 'horriblised' (structurally very complex). We are in the heart of the Rise and Shine Shear Zone. Mesoscopically folded, fractured and sheared schist is still textural zone IV (thick quartz segregations) but has a prominent bright orange ankeritic alteration. Where visible, foliation is variable and typically ranges from 055/30°NW to 015/25°NW.

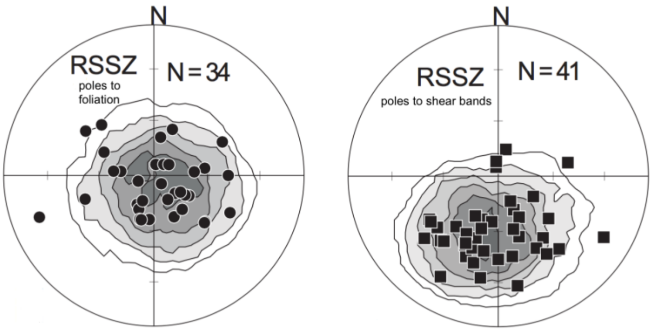


Fig. 9. Shear bands, of mainly normal displacement sense, dip steeper than foliation in the Rise and Shine Shear Zone (Deckert et al. 2002).

Later shears are generally steeper (e.g. 120/35°NE in the pit; Fig. 9). Despite the structural complexity, many microfaults indicate a normal sense of displacement (Deckert et al. 2002). Examples of this are best seen at the top SE side of the trench (uphill, closest to the road). Locally, the RSSZ/Thomsons Gorge Fault has played a major role in exhuming TZIV schist. It remains an open question as to how many more such structures exist in Otago.

STOP 2. LOWER THOMSONS GORGE ROAD

-44.9294, 169.3995, 540 m

Silcrete boulders on Waipounamu Erosion Surface

Drive c. 1.3 km NW back down Thomsons Gorge Rd. At a right hand bend, pull off on the left.

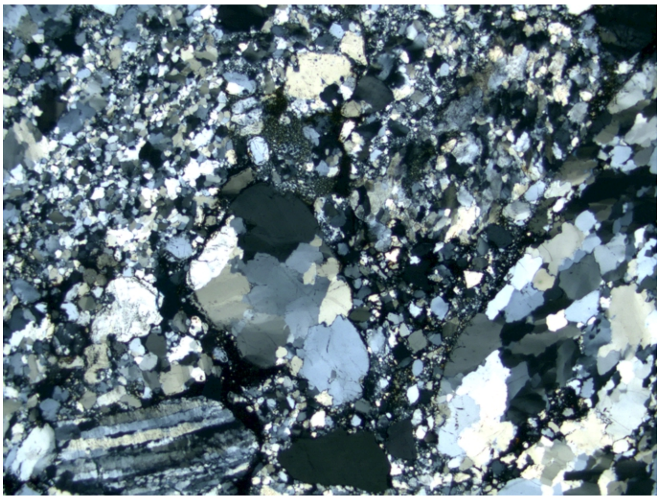


Fig. 10. Texturally revealing image of a thin section of a silcrete boulder. This one is P79891 from near Naseby. Long side of image = 9 mm.

ROCKS: Whitish siliceous boulders and cobbles are scattered above and below the road here. Outwardly they look like very thick quartz veins but they are actually silcrete (quartz cemented quartz sandstones and quartz pebble conglomerates; Fig. 10). Careful examination will reveal sedimentary structures to demonstrate this. Such silcrete boulders are common on the Otago schist landscape in the vicinity of the so-called Waipounamu Erosion Surface (WES) and are interpreted as relict features from a deflated landscape. Where seen *in situ* quartz pebble conglomerates occur in fluvial sedimentary rocks of Eocene to Miocene age.

VIEWS: All visible mountains ranges are made of schist. The WES is interpreted as a diachronous, Late Cretaceous to Miocene transgressive marine planation surface (Landis et al. 2008; other interpretations have been offered). Stop 2 offers four good views of this remarkable and distinctive landform: (1) the spur on which we are standing, (2) the gently west-dipping flank of the northern Dunstan Range, (3) the more distant flat top of the St Bathans range, (4) the convex-up crest of the Pisa Range to the west. Below us to the NW and N are prominent flat-topped, rilled terraces in the Lindis catchment. These are moderately weathered, poorly sorted, bouldery sandy gravel with silt lenses (till) assigned to marine isotope stage (MIS) 12 (478-424 ka) (Turnbull 2000). Just below us on the road are discontinuous topographically higher and till remnants assigned to MIS 16 (676-621 ka).

STOP 3. WELSHTOWN, BENDIGO HISTORICAL RESERVE

-44.9407, 169.3703, 575m

Lunch. Toilets

Drive back down Thomsons Gorge Road. Just after a gate turn sharp left onto a track that heads east to Bendigo. At the Bendigo junction, turn left (uphill) and drive to the Welshtown carpark.

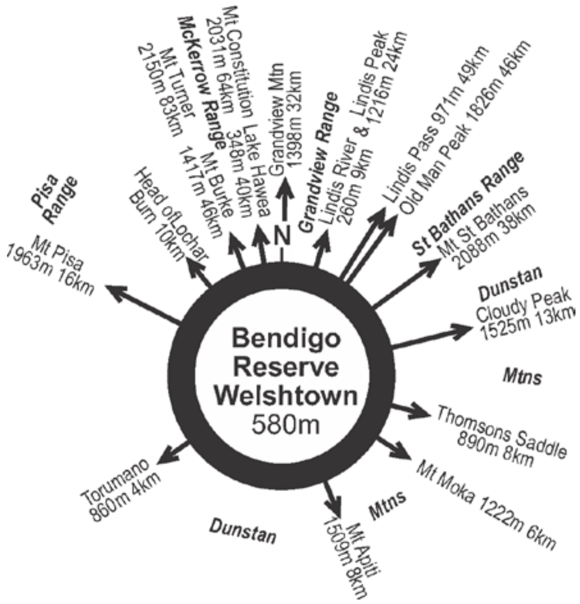


Fig. 11. Landmarks visible from Welshtown

VIEWS: Good views, mainly to the north can be obtained from Welshtown (Fig. 11). All mountains are schist, although the schist on the distant St Bathans Range is TZIIA, weakly foliated Torlesse greywacke.

ROCKS: We are mainly here for lunch and the view, but the schist here is generally similar to that seen at Stop 1b: unfaulted Torlesse TZIV schist of the Dunstan Mtns core. Instead of one simple foliation though, symmetrical, intrafolial mesoscopic folds can be observed here, the schist is less strained. Gold mineralisation here in the Bendigo field occurs in quartz lodes rather than a shear zone. If there is time, take a walk to some of the old workings below us.

STOP 4. ROARING MEG VIEWING AREA

-45.0014, 169.0716, 240 m

View of systematic joints in schist

Pull off into the carpark on the south side of SH 6 at the signed Roaring Meg Viewing Area.

Fig. 12. Looking east down the Kawarau River from the Roaring Meg lookout. S-dipping schist is cut by N-dipping systematic joints.

VIEWS: All of Lake Wakatipu drains down the Kawarau River and into the Clutha. The 4MW Roaring Meg hydro power station is just upstream. Downstream, *in situ* schist dips 110/30°SW and is cut by prominent, long joint planes dipping 100/75°N (Fig. 12). These are so-called systematic joints: planar, parallel, joints that can be traced for some distance, and occur at regularly, fairly evenly spaced distances. Systematic joints across the Otago Schist were studied by Weinberger et al. (2010). They pointed out that the systematic joint planes consistently occurred sub-perpendicular to prominent quartz rodding lineations in the schist. They explained this as a brittle release of stored Cretaceous elastic strain during exhumation. The geometry of systematic joints at this location in the Kawarau Gorge fits the regional pattern.

STOP 5. SHOTOVER RIVER, TUCKER BEACH

-44.9910, 168.7205, 340 m

Torlersse Terrane TZIV pelitic greyschist. River pebbles of different schist types.

Turn north off SH 6 at Lower Shotover along Tucker Beach Road. Drive for 4.5 km along Tucker Beach Road. At the "Quad Bike" and Stock" signs, turn right into the reserve. Continue NW for about 250 m on gravel roads. Park near some trees and walk 100 m upstream to the west end of the gravel beach.

ROCKS: A fissile, mica rich greyschist is exposed in the low bluffs at the lower end of the Shotover Gorge. Foliation has a strike and dip of 100/25°S, and a quartz lineation plunges 10° to 250. Thin quartz veins cut the schist at a high angle. The schist is cut by a fault of strike and dip 170/55°W. Adjacent to the fault, decimetre-scale kink folds have axes that plunge 10° to 180 and are overturned to the E (Fig. 13). Kink bands, some conjugate and of lesser amplitude and wavelength (lower strain), cut the schist throughout the outcrop. A slightly rusty band of schist near the river may be displaced by about 1 m across the fault, and indicates a reverse sense of motion.

Fig 13. A small, W-dipping fault and associated kink folds in grey pelitic schist at Tucker Beach (stop 5). A variety of coloured schist pebbles occur on the beach.

VIEWS: Directly downstream (east) the Crown Range (elev 1735 m) is visible, 17 km distant. Coronet Peak (1651 m, 8 km distant) is almost directly due N.

SHOTOVER RIVER ALLUVIUM: boulders and cobbles reveal a wide range of many different rock types, including minor schist lithologies. Because glacial deposits occur upstream, some pebbles may be from outside the current Shotover catchment. Here is a checklist (at least 18 different rock types, there may be more):

Otago Schist: psammitic greyschist, pelitic greyschist, chlorite greenschist, epidote greenschist, albite-porphyroblastic greenschist, magnetite-porphyroblastic greenschist, stilpnomelane greenschist, piemontite schist, spessartine quartzite (metachert), hematite quartzite (metachert), vein quartz.

Other: cataclasite, pseudotachylite (both from Moonlight Fault Zone), lamprophyre dike (Miocene), limestone, conglomerate and quartzose sandstone (fossiliferous, all from Oligocene Bobs Cove beds), red and green speckled Caples Terrane greywacke Caples Terrane (glacially transported).

QUEENSTOWN AIRPORT, FRANKTON

-45.0222, 168.7389, 340 m

Pickup/dropoff point for some fieldtrip participants. Toilets

STOP 6. CROWN RANGE ROAD, CHAIN BAY 4

-44.9957, 168.9203, 925 m

Schist landslide. Viewpoint

Chain Bay 4 is about 1.6 km from the saddle on the Crown Range Road and about 9.5 km from the junction of SH 6. Pull out at the Chain Bay 4 corner. Cross the stile to the low rock exposures.

ROCKS: The outcrops are interlayered greyschists and albite-porphyroblastic greenschists of the Torlesse Terrane. Metamorphic grade is garnet-biotite-albite zone of greenschist facies and the rocks are textural zone IV, typical of the schist core between Queenstown and Dunedin. The schist is folded. However, there's no point in measuring a strike and dip because these rocks are not *in situ*. The entire northern slopes above the Kawarau River is landslipped (note the hummocky topography).

VIEWS: On a clear day, good all-round views are obtained from this spot (Fig. 14). All visible mountains are Otago Schist. The Remarkables, Thomson Mountains and the ridge of Ben Lomond are Caples Terrane schist (on the S and W side of the schist axis. Everything else is higher grade (structurally deeper) Torlesse Terrane schist. Gently-dipping foliation (an apparent dip) can be seen on the face of Mt Larkins on the WNW horizon.

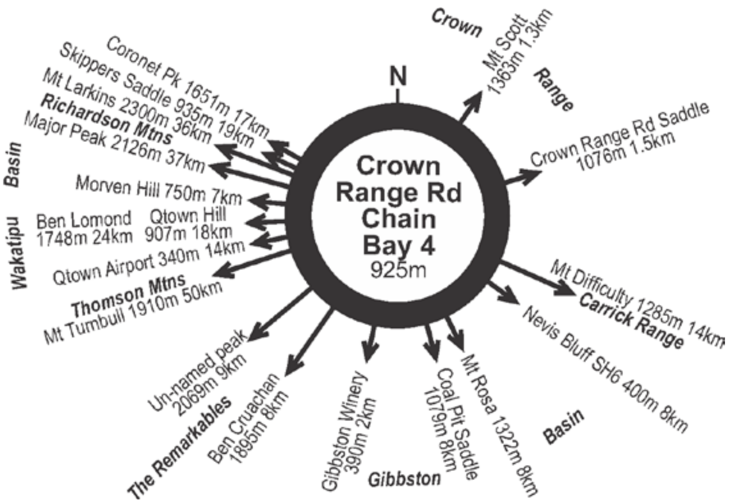


Fig. 14. Landmarks visible from Chain Bay 4 on the Crown Range Road

The landscape in the Wakatipu Basin shows many erosional and depositional glacial features. Between us and Morven Hill, the flat plateau of the Crown Terrace can be seen (although its edge it somewhat camouflaged from this angle); the terrace is underlain by Q12 fan gravels. The far terraces of the Gibbston Basin are mapped by Turnbull (2000) as Q10 fan gravels. A strand of the Nevis-Cardrona Fault, one of the major Neogene (and active) NNE-SSW striking faults in Otago, passes under the landslide near us, and thence through Coal Pit Saddle opposite, where a small sliver of Miocene Manuherikia Group is exposed.

STOP 7. CARDRONA RIVER HEADWATERS, CHAIN BAY 3.

-44.9798, 168.9435, 930 m

Psammitic and pelitic schist, TZ IV Torlesse Terrane

About 1.5 km north of the saddle on the Crown Range Road, (or, from the N, 6.7 km from Cardrona River No 2 bridge) pull out off the road at Chain Bay 3. Hop over the knoll west of the road and walk for about 150 m up the Cardrona River (now just a stream) to the first rocks at -44.9796, 168.9421.

ROCKS: This is a short stop to get among three Otago icons: snow tussock (*Chionochloa*), spaniards (*Aciphylla*) and schist. Schist has a prominent foliation 165/45W. Textural grade is IV, the segregations are thick and the micas coarse (Fig. 3). The ratio of quartz+feldspar to micas is >1 hereabouts; the schist is probably of psammitic rather than pelitic protolith. Gravel piles in the Cardrona River bed may be related to anthropogenic gold sluicing. The trace of the Nevis-Cardrona Fault is mapped as crossing the river c. 300 m upstream.

Fig. 15. Looking S from Chain Bay 3 towards the Crown Range Saddle

VIEWS are restricted but Mt Hocken (1375 m, 2 km at 135°) is at the head of Roadmans Gully on the opposite side of the Crown Range Road. Roadmans Gully is a schist dip slope so, in contrast to our side of the road, most of the slopes have collapsed in landslides (Fig. 15).

STOP 8. CARDRONA TOWNSHIP

-44.8814, 169.0042, 545 m

Views of Cardrona Valley. Toilets.

Park in the carpark opposite the Cardrona Hotel. Alternatively, park next to the Cardrona Domain, 250m N along the road, where public toilets are available.

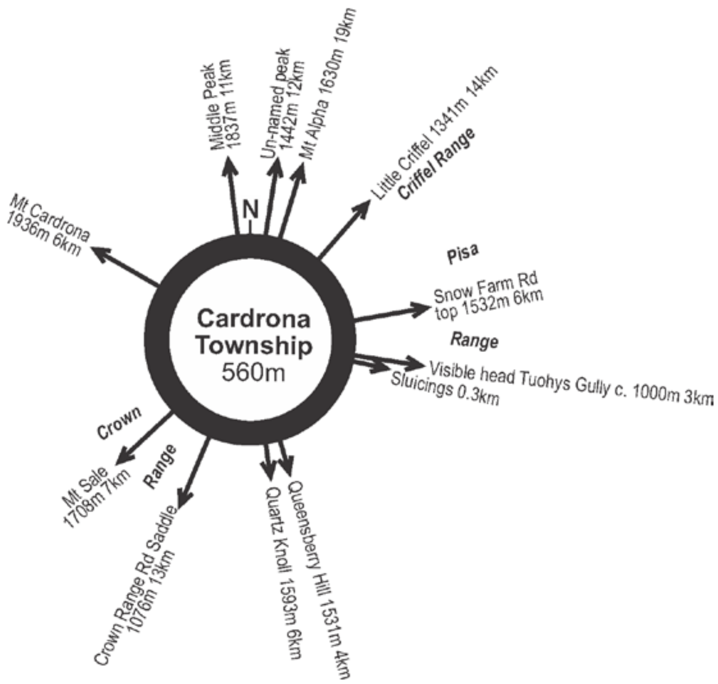


Fig. 16. Landmarks visible from the Cardrona Hotel.

VIEWS: There are good views NNE down and SSW up the fault-controlled Cardrona Valley (Fig. 16). The Cardrona Valley is the westernmost basin of the Otago Basin and Range Province. As a general rule the eastern toe of each range (western edge of each basin) is marked by the trace of a steep west-dipping reverse Neogene (23-0 Ma) fault, in this case the Nevis-Cardrona Fault.

The sluicings immediately to the east are in weathered greywacke gravels of early Quaternary age. As noted by McDonnell & Craw (2003) there is no greywacke basement in the Cardrona area, and these gravels must have been transported >60 km from the NE. Imbrication in the greywacke gravels supports this SW transport direction, as do rare lamprophyre clasts. This is opposite to the present flow direction of the Cardrona River and implies major changes in regional paleo-drainage in the last million years.

References

Corner, NG 1988. Bendigo project, Homestake exploration activity on the Rise and Shine Shear Zone prospecting licenses 31-576 and 31-1490, BHP Gold Mines NZ Ltd, New Zealand Petroleum & Minerals, Ministry of Business, Innovation and Employment, Wellington, unpublished open- le mineral report MR1996, 114 p.

Cox, L, Mackenzie, DJ, Craw, D, Norris, RJ and Frew, R 2006. Structure and geochemistry of the Rise and Shine Shear Zone mesothermal gold system, Otago Schist, New Zealand. New Zealand Journal of Geology and Geophysics, 49: 429–442.

Deckert, H, Ring, U and Mortimer, N, 2002. Tectonic significance of Cretaceous bivergent extensional shear zones in the Torlesse accretionary wedge, central Otago Schist, New Zealand, New Zealand Journal of Geology and Geophysics, 45:537–547.

Forster, MA & Lister, GS 2003. Cretaceous metamorphic core complexes in the Otago Schist, New Zealand, Australian Journal of Earth Sciences 50: 181–198.

Gray, DR & Foster, DA 2004. 40Ar/39Ar thermochronologic constraints on deformation, metamorphism and cooling/exhumation of a Mesozoic accretionary wedge, Otago Schist, New Zealand. Tectonophysics 385: 181–210.

Grieve, PL 1991. Prospecting license 31-2450, Rise and Shine – final report for this period 31 January 1991 to 6 October 1992, Macraes Mining Co Ltd. New Zealand Petroleum & Minerals, Ministry of Business, Innovation and Employment, Wellington, unpublished open- le mineral report MR3033, 49 p.

Landis, CA, Campbell, HJ, Begg, JG, Mildenhall, DC, Paterson, AM & Trewick, SA 2008. The Waipounamu erosion surface: questioning the antiquity of the New Zealand land surface and terrestrial fauna and flora. Geological Magazine 145: 1–25.

MacKenzie, D & Craw, D, 2005. Structural and lithological continuity and discontinuity in the Otago Schist, Central Otago, New Zealand. New Zealand Journal of Geology and Geophysics 48: 279–293.

MacKenzie, DJ, Corner, NG & Craw, D 2006. Rise and Shine Shear Zone, central Otago. In Geology and Exploration of New Zealand Mineral Deposits (eds. AB Christie and RL Brathwaite), AUSIMM Monograph 25: 319–323.

MacKenzie, DJ, Craw, D, Cox, L & Norris, RJ 2006. Mineralisation and structural setting of the Rise and Shine Shear Zone, Otago Schist: comparisons to the Macraes deposit, in Proceedings of the 2005 New Zealand Minerals and Mining Conference, pp 374–379 (Crown Minerals, Ministry of Commerce: Wellington).

Martin, AP & MacKenzie, D 2016. Rise and Shine orogenic gold prospect, Otago - exploration summary. AUSIMM Monograph 31: 149-156.

McDonnell, M & Craw, D 2003. Stratigraphy and provenance of Pliocene greywacke-bearing conglomerate, Cardrona Valley, Otago, New Zealand. New Zealand Journal of Geology and Geophysics 46: 425-436.

Mortimer, N 2000. Metamorphic discontinuities in orogenic belts: example of the garnet-biotite-albite zone in the Otago Schist, New Zealand. International Journal of Earth Sciences 89: 295-306.

Mortimer, N 2003. A provisional structural thickness map of the Otago Schist, New Zealand. American Journal of Science 303: 603-621.

Mortimer, N, Lee, J & Stockli, D 2015. Double dating of zircon gives new information on timing of Otago Schist deposition, metamorphism and exhumation. Geoscience Society of New Zealand Miscellaneous Publication 143A: 98.

Paterson, CJ 1971. Bendigo scheelite prospect geological reports 1 and 2, preliminary report on structure, metamorphism and mineralisation in Haast Schist group. New Zealand Petroleum & Minerals, Ministry of Business, Innovation and Employment, Wellington, unpublished open-file mineral report MR1914, 12 p.

Scott, JG 2005. Structural controls on gold-quartz vein mineralisation in the Otago schist, New Zealand. PhD thesis, University of Otago. 290 p.

Turnbull, IM 1988. Sheet S133 - Cromwell. Geological map of New Zealand 1:63 360. Wellington, New Zealand. Department of Scientific and Industrial Research.

Turnbull, IM 2000. Geology of the Wakatipu area, scale 1:250000, Geological Map 18 (GNS Science: Lower Hutt).

Turnbull, IM, Craw, D, Norris, RJ 1993. Pre-Miocene and post-Miocene deformation in the Bannockburn Basin, Central Otago, New Zealand. New Zealand Journal of Geology and Geophysics 36: 107-115.

Turnbull, IM, Mortimer, N & Craw, D 2001. Textural zones in the Haast Schist - a reappraisal. New Zealand Journal of Geology and Geophysics 44: 171-183.

Weinberger, R, Eyal, Y & Mortimer, N. 2010. Formation of systematic joints in metamorphic rocks due to release of residual elastic strain energy, Otago Schist, New Zealand. Journal of Structural Geology 32: 288-305.

Williams, GJ 1974. Economic Geology of New Zealand, Monograph 4, 490 p (The Australasian Institute of Mining and Metallurgy: Melbourne).

Winsor, CN 1991. Low-angle shear zones in Central Otago, New Zealand - their regional extent and economic significance. New Zealand Journal of Geology & Geophysics 34: 501-516.