Field Trip 8
27\textsuperscript{th} November to 3rd December 2013

The Mesozoic Accretionary Orogen of Zealandia

Leaders: Nick Mortimer & Hamish Campbell,
GNS Science

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Hokonui Hills, Southland. Lloyd Homer, GNS Science.

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GEOSCIENCES 2013 FIELD TRIP 8
The Mesozoic Accretionary Orogen of Zealandia

Wed 27 Nov to Tue 3 December 2013

LEADERS
Nick Mortimer & Hamish Campbell, GNS Science

TRIP SUMMARY
The purpose of the trip is to make a geological transect of Gondwana’s Mesozoic orogen from the accretionary wedge, across the fore-arc basin to the magmatic arc. The South Island of New Zealand is the only place between New Guinea and the Antarctic Peninsula where all three elements of this Mesozoic convergent margin can be seen. The accretionary wedge comprises the Caples Terrane, Torlesse Terrane and Haast Schist; the fore-arc basin comprises the Murihiku Terrane, structurally cradled on a basement of Permian Maitai and Brook Street Terranes. The magmatic arc is the Median Batholith.

These terranes, schists and batholiths accreted onto and intruded into the southeast Gondwana margin in the Jurassic and Early Cretaceous. On the trip we will be able to examine a variety of structural and stratigraphic levels in the wedge, fore-arc and arc. We will also get to see some of the Late Cretaceous to Holocene post-orogenic deposits.

The trip includes a boat cruise on Milford Sound in remote Fiordland. It has been costed on a share twin accommodation basis in motels and hotels. The intention is that lunches and dinners are included in the cost of the trip (please let us know of any dietary requirements e.g. vegetarian).

The fieldtrip route can be viewed in Google Earth or Google Maps by pasting or importing this link: <http://nolledge.com/GSNZ2013FT8.kmz>

A small selection of reprints and geological maps will be carried in the van.

HAZARDS
There’s nothing too strenuous. At most we will be walking a few hundred metres along rivers and beaches. However these are bouldery, uneven and slippery when wet. Light walking boots will be fine. If you are at all unsure of your balance, bring a trekking pole. On beaches, be careful of seals and large waves. Although we will avoid roadside exposures, you will still need to take care getting in and out of the van and to watch for traffic. Bring a fluorescent jacket if you have one. Always follow the instructions of your leaders.

Spring weather in New Zealand is generally warm but windy and changeable. The ultraviolet radiation is harsh so please everyone bring your own sunscreen and sunhat. Also insect repellant, wet weather gear, a windproof top and a headlight or flashlight. Hay fever can be an issue so bring appropriate medications.

Prior to the start of the trip you will be asked to provide the leaders with information on any medical conditions, and also next-of-kin contact details.
Field trip stops (http://nolledge.com/GSNZ2013FT8.kmz) on Google Earth and geological map backgrounds.

Geological legend: yellow=Cenozoic, green=Cretaceous, blue=Permian to Jurassic, purple=schist
Schematic cross sections in space and time of the major litho- and tectono-stratigraphic units of New Zealand. The Median Batholith is the main unit of the Tuhua Intrusives. Supersuccession, Superprovince, Succession and Supergroup names are proposed and not yet formalised. Note scale change at 100 Ma in lower figure.
ITINERARY

Each day we'll aim for breakfast at 0700 hrs, try and depart at 0800 hrs, allow half an hour for lunch, aim to arrive at accommodation at 1800 hrs and have dinner at 1900 hrs.

<table>
<thead>
<tr>
<th>Day</th>
<th>Time</th>
<th>Activity</th>
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<tbody>
<tr>
<td>Wed 27 Nov</td>
<td>1530 hrs</td>
<td>Depart University of Canterbury, Christchurch</td>
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<tr>
<td></td>
<td>1830 hrs</td>
<td>Arrive Tekapo. Possible Mt John visit. Drive 230 km, 3.0 hrs; Geology 0 hr</td>
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<tr>
<td>Thu 28 Nov</td>
<td>0800 hrs</td>
<td>Depart Tekapo. Ruataniwha Dam: Rakaia T21 greywacke and argillite</td>
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<td></td>
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<td>Ahuriri River: Rakaia T2A schist</td>
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<td>Lindis Pass: Rakaia T2B schist</td>
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<td></td>
<td></td>
<td>Cluden Stream: Rakaia T23 schist</td>
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<td></td>
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<td>Come in Time Mine (x3): Rise &amp; Shine Shear Zone</td>
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<td></td>
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<td>Thomsons Gorge Road: Waipounamu Erosion Surface</td>
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<td>Cromwell Old Reservoir: Rakaia T24 schist</td>
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<tr>
<td></td>
<td>1800 hrs</td>
<td>Arrive Cromwell. Drive 230 km, 3.0 hrs; Lunch 0.5 hr; Geology 6.5 hrs</td>
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<tr>
<td>Fri 29 Nov</td>
<td>0800 hrs</td>
<td>Depart Cromwell. Arthurs Point: Rakaia T24 schist, kinks, variants</td>
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<td></td>
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<td>Goldfield Heights, Frankton: Caples T3</td>
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<td>Kingston Shirttail Track: Caples T3</td>
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<td></td>
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<td>Garston Quarry: Caples T2B</td>
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<td>Mossburn Hills Road: Maitai Serpentinite Quarry</td>
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<td>West Dome: Maitai Tramway &amp; Little Ben</td>
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<td>Castle Rock (viewpoint): Oligocene limestone</td>
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<td></td>
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<td>Gerrard Road: Murihiku <em>Monotis</em> locality</td>
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<tr>
<td></td>
<td>1800 hrs</td>
<td>Arrive Te Anau (2 nights). Drive 300 km, 3.5 hrs; Lunch 0.5 hr; Geology 6 hrs</td>
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<tr>
<td>Sat 30 Nov</td>
<td>0800 hrs</td>
<td>Depart Te Anau. Eglington Valley: viewpoint stops</td>
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<td></td>
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<td>Pops Lookout (viewpoint): Hollyford Valley, Brook St</td>
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<td></td>
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<td>Hollyford River: Median Tectonic Zone</td>
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<td></td>
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<td>Homer Hut: Darran Complex</td>
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<td></td>
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<td>The Chasm: Darran Complex walk</td>
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<td></td>
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<td>Milford Sound: cruise</td>
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<td></td>
<td>Return</td>
<td>Te Anau</td>
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<tr>
<td></td>
<td></td>
<td>Drive 240 km, 3.0 hrs; Lunch 0.5 hr; Geology 6.5 hrs</td>
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<tr>
<td>Sun 1 Dec</td>
<td>0800 hrs</td>
<td>Depart Te Anau. Wairāki River Bridge: Brook Street rocks in stream</td>
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<td>Beaumont Station, Ohai: Brook St-Murihiku boundary</td>
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<td>McCrackens Rest (viewpoint) Solander Island</td>
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<td></td>
<td>High tide 1230 hrs</td>
<td>Cosy Nook: Median Batholith granite beach sculpture</td>
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<td></td>
<td>Low tide 1845 hrs</td>
<td>Kawakaputa Point: Median Batholith enclaves</td>
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<tr>
<td></td>
<td>1800 hrs</td>
<td>Arrive Invercargill. Drive 180 km, 2.5 hrs; Lunch 0.5 hr; Geology 7 hrs</td>
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<tr>
<td>Mon 2 Dec</td>
<td>0800 hrs</td>
<td>Depart Invercargill. Curio Bay: fossil forest</td>
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<td>Roaring Bay: Triassic conglomerates</td>
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Geosciences 2013

Low tide 0700 hrs
Nugget Point lighthouse: Triassic

High tide 1400 hrs
Kaka Point
Watsons Beach
Reid Stream
Bruce Rocks

1800 hrs
Arrive Dunedin
Drive 320 km, 4.5 hrs; Lunch 0.5 hr; Geology 5 hrs

Tue 3 Dec
0800 hrs
Depart Dunedin
Palmerston: Zealandia statue
Horse Range Road drive by: conglomerate

Low tide 1000 hrs
Shag Point: Taratu, Coal Seams

High tide 1600 hrs
Moeraki Boulders
Oamaru Boatmans Harbour: Eocene limestone, pillows

1500 hrs
Arrive Christchurch airport
Drive 350 km, 4.5 hrs; Lunch 0.5 hr; Geology 2 hrs
# STRATIGRAPHIC UNIT CHECKLIST

## Eastern Province

### Mesozoic Accretionary Wedge

Torlesse Composite Terrane
- Pahau Terrane (Early Cretaceous)
- Kaweka Terrane (Jurassic)
- Rakaia Terrane (Permian and Triassic)
  - TZI greywacke and argillite
  - TZIIA schist
  - TZIIB schist
  - TZIII schist
  - TZIV schist
  - greenschist and metachert
- Caples Terrane (Permian and Triassic)
  - TZIII schist
  - TZIIIA schist
  - TZIIIB schist
  - TZI greywacke and argillite

### Mesozoic Fore-arc Basin

Maitai Terrane
- Triassic Willsher Group
- Permian-Triassic Maitai Group
- Permian Dun Mountain Ultramafics

Murihiku Terrane
- Middle Jurassic Ferndale Group
- Late Triassic Taringatura Group
- Middle Triassic North Range Group

Brook Street Terrane
- Early Permian Takitimu Group

## Western Province

### Mesozoic Arc

Median Batholith
- Austin Quartz Monzodiorite (230 Ma)
- Mistake Diorite (225 Ma)
- Boat Harbour Diorite (203 Ma)
- Darran Complex (140 Ma)
- Milford Gneiss (Carb. & Cret.)

### Cover rocks

- Aoraki supergroup
- Maui supergroup
- Waitomo supergroup
- Kahurangi supergroup
- Kawatiri supergroup
- Ruaumoko Volcanic province

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Stops
**Day 0. Wednesday 27 November 2013**

Leave Christchurch as soon as possible after the close of conference. No geology stops.
It is about a 3 hour drive to Lake Tekapo where we will eat dinner and spend the night.

*Possible evening side trip to the Mt John Astronomical Observatory.*

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**Day 1. Thursday, 28 November**

Today we will be exclusively in the Rakaia Terrane, New Zealand’s largest terrane by onland area (and arguably the most lithologically monotonous and geologically challenging). Furthermore the depositional age of most of the rocks we will see to the horizon at all times is probably Triassic.

We start by driving south across the steeply-dipping imbricated Permian-Triassic greywacke and argillite, that is generally interpreted as the low grade part of a Mesozoic accretionary prism. For a long time the Rakaia (Older Torlesse) Terrane has been regarded as allochthonous, or exotic, to the New Zealand part of the Gondwanaland margin (MacKinnon 1983).

There is now good evidence, from detrital zircon and mica ages, that the detritus forming the greywackes was derived from northern Queensland (Adams & Kelley 1998; Adams et al. 2002). We will examine the Rakaia rocks as they get progressively metamorphosed and deformed into Otago Schist which represents deeper exhumed parts of the accretionary prism.

**STOP 1. LAKE PUKAKI VISITOR CENTRE. WGS84 lat/long -44.1903, 170.1409**

**BRIEFING STOP. VIEWS OF MT COOK**

*About half an hour drive from Tekapo, pull off on the right at the signposted Pukaki Visitor Centre, just before the turnoff to Mt Cook.*

All the mountain ranges in view here are formed of (Permian-) Triassic Rakaia Terrane greywacke and argillite sequences, part of the imbricated Mesozoic accretionary prism. Looking up Lake Pukaki, Mt Cook (Aoraki) may be visible, depending on the weather. This is the highest peak in New Zealand (3754 m). Lake Pukaki is dammed by a terminal moraine, and many Quaternary fluvioglacial terraces and features can be seen around us.

Drive south on State Highway 8 past Twizel.
STOP 2. RUATANIWHA DAM, SOUTH ABUTMENT. Lat/long -44.2870, 170.0883
RAKAIA TERRANE TZI BEDDED GREYWACKE & ARGILLITE

Drive over the dam, turning left just after the small carpark. Follow the access road down to the river back towards the dam. Climb around the fence to examine the exposures on the south abutment.

View of Stop 2, looking south.

The Ruataniwha Dam was constructed in 1980 as part of the extensive scheme of hydroelectric generation on the Waitaki River.

Here we see typical dm-m bedded sandstone and mudstone (commonly referred to as "greywacke and argillite" by New Zealand geologists) of the Rakaia (Older Torlesse) Terrane. No fossils have been found here, but a Late Triassic age is inferred. Most of the Southern Alps are made up of these rocks in varying proportions. Bedding dips 75°/030 (the convention used in this guide is dip/dip direction) and is overturned, facing west. Dark brown phosphatic nodules are present in siltstone beds, these commonly yield well-preserved radiolarian faunas. Tool marks can be observed on some bedding planes about 2/3 of the way up the face (towards the car park), and graded beds can also be seen throughout the outcrop.

Metamorphic grade is prehnite-pumpellyite facies. There are a few mesoscopic folds in the finer bedded parts of the outcrop but these do not significantly disrupt the largely homoclinal dips. Quartz fibre lineations can be seen on some microfaults.

Back on State Highway 8, a roadcut some 50 m south of the carpark exposes a 1m thick red argillite band. The band appears concordant within the grey clastic sequence. These are distinctive local marker beds in the Rakaia Terrane, but can rarely be traced more than a couple of km.

Continue south through Omarama (pop. 650)
TEXTURAL ZONES

Cross-polarised microscope images showing progressive destruction of detrital textures and development of coarser metamorphic textures from TZI (prehnite-pumpellyite facies, unfoliated greywacke) through TZ IIA-IIA (pumpellyite-actinolite facies semischist & phyllite) to TZIII and IV (greenschist facies schist). Scale bar is 1mm.

As a means to map fine-grained, low metamorphic grade schist in southern New Zealand, Hutton & Turner (1936) came up with their Chlorite1-4 textural zones. Amendments to the way in which textural zones were defined were made by Bishop (1972) and Turnbull et al. (2001). Textural zones remain the most reliable way to map monotonous greyschist in the field and are still shown on the modern New Zealand geological maps (e.g. Forsyth 2001).
STOP 3. AHURIRI RIVER, BIRCHWOOD ROAD. -44.8062, 169.5060
RAKAIA TERRANE TZIIA SCHISTOSE GREYWACKE AND ARGILLITE

Drive through Omarama on State Highway 8 towards the Lindis Pass. Just after the Longslip Creek bridge, and before a major left hand bend, turn off right along a dirt road signposted to Birchwood Station. This road follows the true right bank of the Ahuriri River. After about 5 minutes on this road a Flying Fox is passed. Park near the green gauging tower and fence, reached shortly afterwards. We will look at the riverside outcrops between here and the Flying Fox.

Like Stop 2, this exposure consists of greywacke and argillite, this time interlayered on a cm-m scale. However here, the main fabric is not bedding, but a weakly penetrative S1 foliation (dipping 80°/140). Both sedimentary and metamorphic rocks names could be used at this outcrop. The incipient foliation is best seen under a hand lens. Field indicators of textural grade TZIIA are that the greywacke, when hit with a hammer, splits preferentially along the foliation; argillite has a phyllitic sheen. Graded bedding can still be seen, particularly in the pelitic downstream exposures. Psammitic-rich portions are less foliated than pelitic rocks. Metamorphic grade is pumpellyite-actinolite facies.

A weak stretching lineation, L1, marked by elongated lithic grains and grain overgrowths, plunges 68° northerly. Note that quartz veins are more common than in TZI Rakaia rocks; their abundance generally increases with increasing metamorphic & textural grade.

*Drive back to S.H. 8 and drive up to Lindis Pass.*

STOP 4. LINDIS PASS, STATE HWY 8. Lat/long -44.5864, 169.6397
SCENIC VIEWPOINT AND RAKAIA TERRANE TZIIB SCHIST

Pull over at crest of Lindis Pass to admire the scenery, and make another brief stop about 500m on the Otago (south) side of the pass to examine the higher textural grade of the rocks.

Weathered roadcuts just below the stopping place are TZIIB black phyllite with minor psammitic schist. Note the almost perfect foliation, it is difficult to split the rocks into any shape other than parallel sided slabs – this is distinctive of textural zone IIB. Even without the textural zone nomenclature scheme, it should be clear that the Rakaia Terrane rocks are becoming more deformed and recrystallised as we have driven south this morning. S1 foliation is 50°/010 and the L1 stretching lineation plunges almost downdip at 48° to 030.

*Continue south along State Highway 8. This schist section was once thought to be essentially structurally continuous (Mortimer 1993a) but is now known to be cut by many faults, some with demonstrable Quaternary displacement (Turnbull 2000). See isopach map on next page.*
Structural thickness map of the Otago Schist from Mortimer (2003). The schist is a two-sided arch (antiform) with metamorphic grade lower on the northeast and southwest flanks than along the axis. Increasing Neogene exhumation to the northwest means that deeper structural levels are exposed to the northwest.
STOP 5. CLUDEN VALLEY STATION (HANGERS) ROAD. -44.8029, 169.5119
RAKAIA TERRANE TZIII SCHIST
After a few km, a straightish segment of the Lindis River (now on the left) follows one of these fault zones. The road then curves left over Black Bridge into a gorge past Ram Hill. Pull out at the end of the gorge where it trends east-west, just before Georges Flat.

The schist here is interlayered psammitic and pelitic. We have progressed down-structure in the schist pile from Lindis Pass; here textural grade is ill and metamorphic grade is chlorite zone, greenschist facies. The dominant S1 foliation dips 15°/350 and has been injected by thicker quartz veins. Nearby, mesoscopic cm-m scale F2 folds have axes plunging 5° to 070 and are overturned to the north. We can discuss here whether the foliation we see in an S1 or an S2. A lineation is visible; across Otago there is controversy as to whether such lineations are fundamentally "a" or "b" lineations (Mortimer 1993b).

Photo of thin section of P50653, veined and folded greyschist from Lindis Pass highway close to stop 5. Tightly folded veins and S1 foliation define an incipient S2 strain slip cleavage. Scale bar 5mm.

Continue driving south through the small settlement of Tarras down State Highway 8. The Dunstan Range is to the east and Pisa Range and Lake Dunstan are to the west.

STOP 6. COME IN TIME BATTERY, THOMSON GORGE ROAD -44.9351, 169.4126
RISE AND SHINE MINERALISED SHEAR ZONE
Drive south on State Highway 8 through the small township of Tarras. Continue on to cross the Lindis River then immediately turn right into Ardgour Road. Thomson Gorge Road (gravel) forks right off Ardgour Road at a bend about 2.5 km from the main highway. Follow Thomson Gorge Road uphill until the green Dept of Conservation signs at the Come in Time Battery carpark are reached.

The Rise and Shine Shear Zone (Cox et al. 2006) is a gently north-dipping syn-metamorphic mineralised shear zone that developed under mixed brittle and ductile conditions. Metallic minerals include pyrite, arsenopyrite and gold, and there is a strong ankeritic alteration associated with mineralisation. The upper part of the mineralised shear zone is truncated by a low angle fault, the Thomsons Gorge Fault. Mortimer (2000, 2003) and Deckert et al. (2002) identified the gently north-dipping Thomsons Gorge Fault as a major discontinuity - a post-metamorphic fault zone - in the Otago Schist, across which there had been a net-normal dip-slip displacement of up to 10 km. Metamorphic and textural grade, and apparent argon ages of schist all change abruptly across the Thomsons Gorge Fault. As such the fault is one of the few major brittle structures in the Otago Schist that we can identify as having played a role in the exhumation of the schist. Forster & Lister (2003) proposed a metamorphic core complex model for
the schist of the Dunstan Range to the south of here, but it is a puzzle why they did not use the Thomsons Gorge Fault as supporting evidence for a low angle brittle detachment.

![Map of the Rise and Shine Shear Zone](image)

*Rise and Shine Shear Zone setting from Cox et al. (2006)*

There are a few things to look at in the vicinity and we will spend more than an hour here.

- **6A:** Weathered surface outcrops to the northeast of the road are Rakaia Terrane TZIII schist, as seen at the previous stop
- **6B:** Prospecting Pit. Strongly sheared TZIV schist with prominent orange ankeritic alteration. Some small normal fault displacements, but structurally very complex.
- **6C:** Red Tunnel Mine Adit. This is 60 m long and trends 062. The end is right beneath the road near the Prospecting Pit. Foliation dips 40/100 in most of the adit. Halfway along the adit, a normal fault trends 55/350 and has brecciated schist in its footwall.
- **6D:** Come in Time Battery, Restored quartz stamper battery. Schist here is unmineralised and unsheared TZ4 greyschist. We are below (and in the footwall block of) the Rise and Shine Shear Zone. So, the lower plate of the metamorphic core complex, if you prefer. Foliation is 50/040. Isoclinally folded quartz veins can be seen in layered pelitic and psammitic greyschist.

*Drive back down Thomsons Gorge Road about 1 km towards the main highway.*
STOP 7. THOMSONS GORGE ROAD -44.9292, 169.3994
SILCRETE BOULDERS ON WAIPOUNAMU EROSION SURFACE
Stop to examine silcrete boulders to left of road on low ridge.

The conspicuous Waipounamu Erosion Surface is cut into the Otago Schist and flanking greywackes between the Otago Coast and the Pisa Range. The crest of the Pisa Range to the west of us is the WES. It is overlain by fluvial strata of Late Cretaceous age in the east and of Miocene age in the west and is interpreted as a diachronous, transgressive marine planation surface. In most places there are either no cover strata or, at this stop, just scattered silcrete boulders, on the WES.

The silcretes are quartz-cemented quartz pebble conglomerates and occur as isolated blocks (sometimes in moderate concentration) throughout Central Otago and northern Southland. Where seen in situ they occur in Cenozoic quartzose sedimentary rocks of Eocene to Miocene age. They represent fluvial deposits.

The interpretation and significance of the WES has been controversial and we will discuss some of the issues on the outcrop.

STOP 8. CROMWELL LOOKOUT & OLD RESERVOIR (walk) -45.0639, 169.2191
RAKAIA TERRANE TZIV PSAMMITIC & PELITIC SCHIST; F3 FOLDS

Drive straight past Cromwell township (pop. 3000) and the bridge over Lake Dunstan. About 1km towards Dunedin, park on the lake side of State Highway 8 at the (signposted) Cromwell lookout.

The Clyde Dam was completed in 1989 and Lake Dunstan was filled in the early 1990s for hydroelectric power generation. We are above the former confluence of the Clutha and Kawarau Rivers. Most of the old Cromwell town buildings are now underwater. The roadcut opposite the lookout (under the large power lines) is a landslide deposit.

8A: BLUFFS ON S.H. 8 SOUTH OF CROMWELL LOOKOUT.
Walk 100m south to the bluffs just past the start of the track to the Old Cromwell Reservoir.

The rocks here are TZIV psammatic and (minor) interlayered pelitic schist of the Rakaia Terrane. Mineral assemblage is qtz-albite-white mica-chlorite-titanite. Biotite and “grossalspite” (Ca, Fe, Mn) garnet have been identified in rocks nearby, so we are in the greenschist facies, garnet-biotite-albite zone, at still deeper structural levels than the last stop, and very close to the schist antiformal culmination.

Note the larger mica grain size, less distinct psammitic-pelitic boundaries, and totally penetrative and pervasive S2 as compared with the previous stop (S1 is completely transposed). S2 foliation dips 15°/005. Good three-dimensional views of the prominent L2 quartz rodding (stretching) lineation that plunges 12° to 000 can be obtained in the cavernous overhangs. Note also the mm-scale F3 crenulations of mica segregations that plunge 1° to 079. As is usual in TZIV, the schist is criss-crossed by numerous multigenerational quartz veins, the youngest being an en enchelon set; note also the conjugate joint planes.
8B: RIDGE EAST OF OLD CROMWELL RESERVOIR.

Walk up the wooden-stepped track in the briar-, thyme- and scabweed-infested gully signposted to the Old Cromwell Reservoir.

The north side of the gully is a landslide. Halfway up, the track crosses a fluvioglacial terrace containing a variety of rounded and transported Caples and Rakaia schist lithologies and Miocene lamprophyres; good views of Quaternary terraces can be seen across Lake Dunstan a few km to the north.

Cross the stile and continue on the track across the old dam and under some small power lines. We will look at the schist tors on the broad ridge above here.

F3 folds fold S2 at stop 8B. Quartz lineations, L2, are parallel to the hammer handle

The lithologies and many structural elements are the same as on the road below, but we have now walked up-structure into the base of a zone of dm-scale, open, mesoscopic F3 folds that fold S2 and L2. Background S2 foliation is 20°/355 and the F3 fold axes plunge 5° to 250. F3 folds are consistently overturned to the south. These folds may be parasitic on the upper limb of the macroscopic Northburn Isocline fold of Turnbull (1981). Millimetre-scale F3 crenulations are widespread on S2 planes along the schist culmination, but only amplify to mesoscopic scale in some zones, such as this one.

This is a good place to consider the age of metamorphism and exhumation of the Otago Schist. Is foliation related to "prograde" crustal thickening or "retrograde" crustal thinning?

Night in Cromwell

Optional evening trip to Bannockburn to examine Miocene Manuherikia lake beds (leaf fossils).
Day 2: Friday, 29 November
A four terrane day. Initially we drive west along the axis of the Otago Schist to examine more greenschist facies Rakaia Terrane schist. Then we start moving southwest across the Otago Schist accretionary prism, looking at Caples Terrane rocks of progressively lower textural grade in three places. We then have two stops in the Maitai Terrane which we regard as the backstop to the accretionary wedge: serpentinite melange of the Permian Dun Mountain Ophiolite Belt, a Permian-Triassic boundary sedimentary section. We finish with a quick look at fossiliferous Late Triassic Murihiku Terrane rocks of the Mesozoic forearc basin.

Drive west up State Highway 6, the Kawarau Gorge. Exposures in the gorge are of segregated pelitic schist with S2 foliation. This lithology is highly susceptible to landsliding and most of the scrub-covered northern (dip) slopes of the gorge are underlain by landslides. Turn right to Arrowtown at Arrow Junction and continue to Arthurs Point.

Aerial view looking east over Queenstown. Lake Wakatipu is in the foreground. The Remarkables Mountains and Peninsula Hill, made of Caples Terrane TZIII schists, are on the right. The other ranges are structurally lower than The Remarkables and are composed of Rakaia Terrane TZIV schists.

STOP 9. SHOTOVER RIVER, ARTHURS POINT. -45.0459, 169.1955
RAKAIA TERRANE TZIV GREYSCHIST, GREENSCHISTS, METACHERTS

At Arthurs Point, park in the public carpark area and walk down to the upstream end of the gravel bar of the Shotover River, away from the jetboat launching area.

Some 95% of the nonschistose Rakaia Terrane consists of a greywacke-argillite lithologic association as seen at yesterday’s stops 2 and 3. Metamorphic equivalents (greyschists) make up a correspondingly large proportion of the Otago Schist (e.g. stops 4, 5 and 6 and 8). A subordinate (< 5%) lithologic association in the Rakaia Terrane comprises basalt-chert-limestone and (extremely rare) serpentinite. Outside the schist this association is typically fault-bounded and marks the structural base of imbricated accretionary prism sequences. Metamorphosed equivalents of these rocks occur as in the Otago Schist thin bands of greenschist, quartzite, marble and talc schist. At this stop (stop 9) we will examine greenschists and quartzites.

Here at Arthurs Point we are in a pelitic schist and greenschist rich part of the Rakaia Terrane called the Aspiring Lithologic Association. A prominent S2 foliation and L2 stretching lineation can be seen. Thin, 1-5cm thick greenschist bands are present within the grey pelitic schist. These are either subtle or obvious depending on sun/cloud and wet/dry conditions.

Late kink folds cut the schist here. They are spatially associated with Cenozoic (mainly Miocene) reverse faults.
The river gravels here contain excellent examples of minor schist and other lithologies. Here is a checklist (at least 18 different rock types, there may be more):

**Otago Schist:**
- psammitic greyschist;
- pelitic greyschist,
- spessartine metachert,
- piemontite schist,
- epidote greenschist,
- chlorite greenschist,
- stilpnomelane greenschist,
- albite-porphyroblastic greenschist,
- magnetite-porphyroblastic greenschist,
- fuchsite schist (very rare),
- vein quartz

**Other:**
- cataclasite:
- pseudotachylite (both from Moonlight Fault Zone);
- Miocene lamprophyre;
- Oligocene limestone;
- Oligocene conglomerate;
- red and green speckled greywacke Caples Terrane, (glacially transported).

*Drive over the bridge and along Gorge Road into Queenstown.*

*We may stretch our legs with a short walk along the Lake Wakatipu waterfront.*

*Drive out along Highway 6A towards Frankton.*
TELLING TERRANES APART

New Zealand terranes, like all others, are "fault-bounded geological entities having a geological history that differs from other terranes". Geological history is established and compared on the basis of lithology, stratigraphy, biogeographic interpretations, petrology, structure and metamorphism. In the case of the Caples and Rakaia Terranes, petrochemistry, detrital zircons and isotopic composition enable their discrimination in the Otago Schist where primary sedimentary features have been destroyed.

Thin section images of P55886, a Rakaia Terrane feldsarenite greywacke from Mt Cook (left), and P61636, a Caples Terrane volcanic litharenite greywacke from Mt Bee (right). Detrital modes (e.g. % quartz, % lithics) readily discriminate between the two terranes in unfoliated rocks. Image height 3mm.

The mineralogical differences between Rakaia and Caples greywackes are mirrored in chemical differences. This diagram shows matching of greywacke and schist clasts in a Pliocene Westland conglomerate with a Rakaia Terrane source. Geochemical differences have been used to map Caples and Rakaia protoliths in the Otago Schist.
This diagram, from Adams (1997) shows the evolution paths (different Rb/Sr ratios) of whole rock isochrons based on many sample suites from different terranes. Sr isotopes can be used to discriminate between terrane protoliths.

Detrital zircon patterns for Rakaia Terrane schist (top) and Caples Terrane schist (below). Both have a classic Permo-Triassic Eastern Province peak but the Caples pattern contains no pre-Permian zircons. From Adams et al. (2009)
STOP 10. GOLDFIELD HEIGHTS. -45.9856, 168.6983
CAPLES TERRANE TZIII SCHIST: BOUNDARY WITH RAKAIA TERRANE.

About halfway between Frankton and Queenstown, turn off State Highway 6A turn off into the signposted road called Goldfield Heights. Park off the road at the first bend and walk uphill to the roadcuts.

Up until now, the entire trip has been in the Rakaia Terrane, the Permian-Triassic unit of the Torlesse Composite Terrane. As we cross the schist axis and move towards the back of the Mesozoic Accretionary wedge, things change and we come into the Caples Terrane. It is still metamorphosed like the Rakaia Terrane, the terrane boundary being mostly a pre-metamorphic feature. How, then do we tell the two apart?

At least in the Queenstown area there can be a pronounced lithologic contrast between schist of the Caples and Rakaia Terranes, a difference first mapped by Park (1909) as a contact between Maniototo and Te Anau Series. Schist to the northeast and east of here (towards Frankton and Arrowtown) is pelitic Rakaia schist that forms low, landslide-prone hills. Schist to the south and west of here (towards Queenstown and The Remarkables) is composed of structurally overlying dominantly psammitic Caples Terrane that forms craggy hills and ranges. The position of the Caples-Rakaia boundary was established on The Remarkables by Cox (1991), and across Otago by Mortimer & Roser (1992). Some revisions have been made by Turnbull (2000) (see colour schist thickness map for stop 4: the '0 km' reference line is the Caples-Rakaia contact).

The schist at the northwest (uphill) end of the roadcut is mainly micaceous (pelitic) schist; this grades into mainly psammitic schist at the southeast (lakeward) end. Petrochemistry and Sr isotopic composition indicate that the psammitic schist is metamorphosed Caples Terrane, not Rakaia Terrane. We are very close to the terrane boundary which has been overprinted by the metamorphism and S2 foliation. Textural grade is III (note slightly finer metamorphic mica grain size and a hint of relict detrital grains as compared with Cromwell and Arthurs Point schist stops). S2 foliation dips 15°/180. L2 stretching lineation plunges 12° to 240 and is defined by elongated argillite chips, fibrous streaks on foliation planes and linear ornaments on deformed quartz veins. The quartz veins are not exactly parallel segregations but cut foliation at very slight angles. A prominent joint set has developed perpendicular to lineation at 80°/050.

Drive through Frankton and take the road south towards Kingston. Pass the Remakables skifield road on the left. Continue driving south down the shores of Lake Wakatipu.

STOP 11. SHIRT-TAIL TRACK, KINGSTON. -45.3278, 168.7123
CAPLES TZIII SCHIST: QUARTZ VEINS AND F2 FOLDS

Turn off the main highway at Kingston (signposted). Drive along the waterfront past the railway station and past the steam engines. Park at foot of bush just short of the wharf. Follow easy grade on the switch-back Shirt-tail track to the first bench and lookout, about 15 minutes.

The schist here is Caples Terrane psammitic and pelitic schist. Outwardly, the schist resembles the TZIIIO exposures seen at Goldfield Heights (stop 10) with psammitic and pelitic layering transposed into a single pervasive foliation with layer-subparallel quartz veins. However, the dominant foliation here is regarded as S1, not S2 - because of time demands we have had to “jump” the zone of penetrative and isoclinal F2 mesoscopic folds between Kingston and Queenstown (we will see these at stop 36). Structural level is slightly higher, and metamorphic grade slightly lower than the Caples schist we saw at the last stop. Isoclinally folded quartz veins show that the fabric here is S1, and not bedding.
In the in situ exposures just before the seat at the overlook, S1 foliation dips 30°/190 and west-verging F2 mesoscopic folds have axes that plunge 25 to 184. Some quartz veins are folded, some quartz veins show pinch-and-swell structures. Metamorphic grade is still chlorite zone, greenschist facies.

Looking out over Kingston, “tide marks” of high lake levels behind terminal moraine can be seen. Also the schist tor-studded Hector Range on the horizon.

*Continue driving south down State Highway 6. Prior to damming of the south end of the lake by terminal moraines, the entire Wakatipu catchment used to be debouch down this valley Now, the Mataura River headwaters are grossly underfit with respect to the size of the valley.*

STOP 12. GARSTON QUARRY. -45.4649, 168.6846  
**CAPLES TZIIA-B SCHIST, S1 UNFOLDED, FEW QUARTZ VEINS**  
Eventually turn round a left hand bend into the small town of Garston. Here, we are as far from the sea as it is possible to get anywhere in New Zealand. Park on the gravel at the north end of the town and walk back to the quarry on the inside of the left hand bend, previously passed.

The Caples TZIIB rocks here, though indifferently exposed, are noticeably much less quartz-veined than at Kingston. Most of the rock in the quarry is a black slaty argillite, though a few thin bands of psammitic (sandy) schist can also be seen. Recall stop 4, Lindis Pass, where we saw Rakaia Terrane TZIIB slaty phyllites. We are in an exactly equivalent structural and metamorphic position but on the rear side of the Otago Schist arch and accretionary wedge.

Foliation is 35°/260, there are no obvious lineations. Rare post-foliation quartz veins trend 30°/040 in en echelon arrays defining steep low-displacement reverse shear zones. We are very close to the pumpellyite-out isograd.

*Continue south on S.H. 6. Cross over the drainage divide between the Mataura and Oreti Rivers. Turn right at Five Forks (signposted to Milford). Turn right down Hillas Road to the quarry at the foot of Black Ridge.*

STOP 13. BLACK RIDGE QUARRY. -45.6250, 168.2891  
**MAITAI TERRANE (DUN MOUNTAIN OPHIOLITE): PERMIAN SERPENTINITE AND RODINGITE**

This is the southeasternmost known exposure of serpentinite in the 265-285 Ma (Permian) Dun Mountain Ophiolite Belt and is very close to the map trace of the Livingstone Fault, a major terrane boundary that separates the Caples and Maitai Terranes. Recent work indicates that most of the deformation associated with the Livingstone Fault probably occurs within the ophiolite, thus the tectonic fabrics we see in Black Ridge Quarry can be attributed to terrane boundary movement. In a Mesozoic convergent margin context, this Permian ophiolite represents the backstop to the Caples-schist-Rakaia Terrae accretionary wedge.

Most serpentinites in the quarry consist of massive green-black lizardite with a dark, hackly fracture.
Numerous large blocks of resistant rodingitised (Ca metasomatised) microgabbro, average size 3x3x6 m, are present and show the characteristic mineral zoning developed at their margins (Coleman 1966). Original igneous textures are generally well preserved in the centres of the blocks but nearly all plagioclase has been replaced by albite and prehnite, and nearly all brown igneous hornblende by a pale tremolite. Prehnite veins, many perpendicular to the margins, extend into the blocks. Monomineralic veins and segregations of tough, dense, greenish-white semi-nephrite (tremolitic amphibole) are present along the edges of some inclusions. Small dolerite blocks (<0.6 m in size) are almost completely altered to a dense rodingite consisting of hydrogrossular and chlorite. Numerous accumulations of hydromagnesite are present within shear planes. Late fractures cutting across all pre-existing structures are filled with massive white stevensite.

Over the years, serpentinite extracted from this quarry has been mixed with superphosphate to give the non-caking aerial top dressing agricultural fertiliser “Serpentine Super”.

**STOP 14. SOUTH SLOPES OF WEST DOME. -45.6064, 168.2351**

MAITAI TERRANE PERMIAN-TRIASSIC BOUNDARY SECTION

Continue along Hillas Road up Acton Stream. At a road junction a Rayonier (logging company) sign is seen; keep driving straight on the logging road (Forestry Road) that traverses the north side of West Dome towards the Windley River. Hopefully this can be negotiated by our two wheel drive vehicle. The exact fieldtrip stop is difficult to identify but is on a right hand curve before a culvert approximately 1.8 km beyond the Rayonier sign junction. Park in the wide space on the left of the road.
The Mesozoic Accretionary Orogen of Zealandia

The clastic and carbonate Maitai Group overlies the igneous rocks of the Dun Mountain ophiolite.

At this stop we see the conformable, transitional contact between the top of the Tramway Formation and the bottom of the Little Ben Sandstone. Bedding here dips steeply at 85°/200 and faces south (i.e. is upright). Tramway Formation to the north consists of interbedded very fine grained black quartzofeldspathic greywacke and argillite. About 10 m of Tramway Formation can be seen in the stream above the culvert just west along the road. Little Ben Sandstone consists of fine grained green volcaniclastic sandstone and siltstone. The wooden post, if it is still there, marks the lowest green sandstone bed and can be considered the base of the Little Ben Formation. Krull et al. (2000), on the basis of a $^{13}$C anomaly, have provisionally identified the Permian-Triassic boundary within this conformable marine sequence as some 20 m above the base of the Little Ben Sandstone.

The view from here is of the North Range and the Hokonui Hills across the Five Rivers Plain and the Oreti River. The fronts of these ranges are part of the Murihiku escarpment which marks the northern edge of the Murihiku Terrane on their steep north limb of the Southland Syncline. South-dipping strata can be seen outlined on the faces. Further to the west rise the craggy Takitimu Mountains, part of the Brook Street Terrane. Behind us is West Dome, underlain by Dun Mountain Ophiolite Belt.

Drive back down Hillas Road to Mossburn-Five Rivers Road. At Mossburn, dog-leg right then left onto Wreys Bush-Mossburn Road. Follow this for about 9 km and turn left onto Dipton-Mossburn Road. The main road winds around a little. After about 11 km the prominent castellated Castle Rock is seen. Pull over at a safe place.
STOP 15. CASTLE ROCK. -45.8081, 168.2812
LATE OLIGOCENE-EARLY MIocene LIMESTONE, CORE OF SOUTHLAND SYNCLINE

Viewpoint only. The outlier of Forest Hill Limestone at Castle Rock lies in the axis of the Southland Syncline, defined regionally by Murihiku strata. Steep north limb Murihiku strata will have been noted on the drive to here, and shallow-dipping, south limb Murihiku strata lie ahead of us in the tablelands to the south.

The Oligocene beds are also folded into a syncline, but not as tight a one as that defined by the underlying Mesozoic strata. The folding of the syncline was principally Cretaceous, with some tightening during orocline bending in the Cenozoic (probably in the Neogene).

The Forest Hill limestone is part of a nationally extensive condensed sequence of limestones and greensands of Late Oligocene to earliest Miocene age. This was the time of maximum flooding (marine inundation) of the Zealandia continent.

At the far end of the limestone ridge turn left onto Gerrard Road.

STOP 16. GERRARD ROAD, NORTH RANGE. -45.8255, 168.3240
MURIHIKU TERRANE, NORIAN FOSSIL LOCALITY

Drive from Mossburn east on S.H. 94 to Castlerock saleyards. Turn right on Castlerock-Dipton Road. Pass Sutherland Road, Honeywood Road and Glencairn Road. About 1 km into the range, just before the road crosses the stream, go through the wooden gate directly to S side of Gerrard Road. Private property: permission required for access.

Monotis on the former Geological Society of New Zealand logo

The Murihiku Terrane consists of Early Triassic to Late Jurassic marine sandstones and mudstones. It is New Zealand's least deformed basement terrane - by a country mile. The only significant structure is the regional asymmetric Southland Syncline. Maximum metamorphic grade is zeolite facies. In contrast to the coeval Rakaia and Caples rocks, bedding is well preserved, structure is simple and fossils are relatively abundant.

We place the Murihiku in a Mesozoic fore-arc basin setting. The arc that supplied detritus may well have been the (coeval) Median Batholith immediately to the west; provenance studies are currently underway to test this. As yet there are no proven detrital links across the Dun Mountain Ophiolite, to the Triassic rocks of the accretionary wedge. The Murihiku Terrane has impressive correlatives in the Permian-Triassic rocks of New Caledonia.

Blocks of Monotis shellbed are seen at this stop. There are poor in situ exposures further up farm track. The blocks are rewarding. This is a surprisingly rich locality with much more than just Monotis: other molluscs, including small ammonoids (as yet undescribed and poorly determined, but important), brachiopods etc. Apart from the faunal assemblage aspect, the special point about this locality is the superb preservation of Monotis, and its tendency to split relatively nicely along bedding planes. It is a good collecting spot. Monotis is a Middle-Late Norian indicator fossil, cosmopolitan and widely represented globally. Described by Bronn in 1830 from the European Alps. It is the Warepan Stage (205-212 Ma) indicator fossil in NZ and New Caledonia.
Continue east on Gerrard Road. At the junction, turn right then left onto Dipton-Mossburn Road. Continue back into Mossburn then on to Te Anau where we spend two nights. Brook Street Terrane underlies the jagged Takitimu Mountains to the south of the main road. Clastic Eocene-Oligocene mudstones are exposed at the broad saddle between Mossburn and Te Anau.

Day 3: Saturday, 30 November

Te Anau is in the centre of a small Eocene-Pliocene sedimentary basin that has undergone spectacular Neogene shortening. Fiordland (to the west) is regarded as a semi-rigid structural block that has undergone significant Plio-Pleistocene exhumation near a bend in the Pacific-Australia plate boundary. The first part of our drive north is in the basin. After some viewpoints, we spend almost the entire day in the Median Batholith.

We will examine cataclastic Triassic diorite, and intact Early Cretaceous diorite and gabbro. From the boat on Milford Sound we will cruise past Cretaceous amphibolite and granulite facies orthogneisses, the most deeply exhumed part of the batholith. From the outermost part of the cruise we may glimpse the Alpine Fault trace. This is mainly a day for cameras, not hammers.

For ease of description, the geological stops are listed in east to west order, as we progress from Te Anau to Milford. Which ones we visit, and in what order, will depend on progress of the trip, weather conditions, snow avalanche hazard and boat departure time. In addition to the geological stops, we can make picture stops on demand.

STOP 17. EGLINTON VALLEY -45.0623, 167.9942
VIEWPOINT
Earl Mountains to the west and Livingstone Mountains to the east. The Earl Mountains are underlain by Eocene flysch unconformably overlying Median Batholith. The Livingstone Mountains are underlain by Eastern Province Brook Street Terrane. The Eglinton Valley itself is fault controlled.

STOP 18. POP’S LOOKOUT. -44.8092, 168.1051
BRIEFING STOP, BROOK ST TERRANE & NORTHERN FIORDLAND PANORAMA
Drive towards Milford, past The Divide. If the weather is clear we have excellent views down the Hollyford River and into the Darran Mountains of Fiordland.

In the fern and moss-covered roadcuts opposite the lookout, green siltstone and minor sandstone of the Consolation Formation of the Brook Street Terrane are poorly exposed. Bedding dips steeply west but faces east. This is our first glimpse of the Brook Street Terrane close-up. As new slips are quite common, we may also see it elsewhere along the road and, if it is safe, we will make an opportunistic stop; we will see Brook Street rocks at their best on the coast at Riverton tomorrow.
To this point on the fieldtrip, we have seen largely sedimentary and metasedimentary rocks (except for the Dun Mountain serpentinite). Fiordland, to the west, is composed of plutonic and metaplutonic rocks. This profound east-west "medial" change in NZ basement geology has long been recognised, but the interpretations of what it represents have changed over the decades.

**The "Median Tectonic Phenomenon"**

New Zealand's Median Tectonic Line was proposed by Landis & Coombs (1967) as a regional structure separating the two halves of a paired metamorphic belt: lawsonite-bearing rocks in the Eastern Province (Caples & Maitai terranes) and amphibolite facies rocks intruded by abundant granitoids in the Western Province.

Subsequent work identified that metamorphism of rocks either side of the MTL was highly time transgressive such that the "paired" nature of the belt was inapplicable. An emphasis on terranes in the 1980s led to the concept of the Median Tectonic Zone as a zone of exotic terrane shards and dismembered plutonic complexes of uncertain tectonic affinity between the EP & WP (Kimbrough et al. 1993; Bradshaw 1993).

More recent work in the MTZ has led to (1) the recognition that 90% of the rocks in the MTZ are plutonic or metaplutonic (2) the proposition of the MTZ as part of a long-lived, composite, Cordilleran batholith: the Median Batholith (Mortimer et al. 1999a). This is the interpretation that is given in this field guide.

**Stop 19. Hollyford River. -44.8145, 168.0898**

**Glade-Darran Fault (Median Tectonic Line).**

*Park at Hollyford Junction. Carefully walk in single file along the Milford Road for a few hundred metres until the road sweeps left adjacent to the Hollyford River. Walk carefully out on the slippery rock platforms. Do not get too close to the river!*

Hopefully the rock platform will have been scoured by recent floods. Any impression of "horriblised" and "fubaritic" rocks is entirely correct.

We are in the epidotised crush zone of the Glade-Darran Fault. This is New Zealand's "Median Tectonic Line" (Landis & Coombs 1967). Back in the day it was regarded as a major fault, separating New Zealand's Eastern and Western Provinces. Later it became a fault in the Median Tectonic Zone. Today the GNS team regard it as as a local Neogene fault with no Mesozoic significance whatsoever. It separates Permian volcanoclastic sedimentary rocks of the Brook Street Terrane from Triassic Mistake Diorite of the Median Batholith. The fault strikes obliquely across the road.
Until the GNS Science team starting studying the Median Tectonic Line and Zone away from the Alpine Fault, it was not fully appreciated that the “T” in fact represents only Neogene, not Mesozoic tectonics. It is hard to find a geological contact in the Eglinton-Hollyford and Nelson areas that is not a fault: the entire forearc Murihiku Terrane and Maitai Terranes are faulted out and the batholith lies within 3 km of the accretionary wedge.

Carefully retrace steps to van and resume drive along road to Milford. Carry on along State Highway 94 up the Hollyford Valley. The surrounding rocks are recently deglaciated Cretaceous Darran Complex. Note the lack of trees in the valley, even though the road is below bush line. This is due to snow avalanches.
STOP 20. HOLLYFORD RIVER NEAR HOMER HUT -44.7674, 168.0023
MEDIAN BATHOLITH: EARLY CRETACEOUS DARRAN COMPLEX
Before the Homer Tunnel Portal, turn right onto a dirt road marked with the yellow and green DOC sign to “Gertrude Valley”. Park in the car park. We will look at transported boulders (partly reworked glacial deposits) in the stream between here and the Alpine Club Hut in the trees. Larger boulders can be observed upstream towards the hut.

The Darran Complex is a major plutonic unit in northern Fiordland. It lends its name to the Triassic to Early Cretaceous (230-135 Ma) I-type, low Sr/Y calc-alkaline Darran Suite of the Median Batholith. It has been mapped and studied by Blattner (1991 and references therein). Varieties of gabbro, of pyroxene and hornblende diorite and of hornblende pegmatite can be observed. Some epidotised cataclasites are present. A number of samples give U-Pb zircon ages of c. 140 Ma (Kimbrough et al. 1993; Muir et al. 1998).

Recent work (Tulloch in progress) indicates that the Darran Diorite is the exact same age and composition as the Noosa Diorite of coastal SE Queensland. The two are correlated as the same Gondwana margin Mesozoic arc.

Drive through Homer Tunnel and descend the road in the Cleddau Valley.

STOP 21. THE CHASM. -44.7215, 167.9508
MEDIAN BATHOLITH: CRETACEOUS DARRAN COMPLEX
Pull over into the carpark on the south side of the highway at the Dept. of Conservation signposted short walk to The Chasm. Keas (native parrots) often hang out here and peck at windscreen wipers.

No hammers! This is a 20 minute round trip walk through native New Zealand bush, mainly beech forest. The Cleddau River has cut a slot gorge in Darran Complex gabbro-diorite. This is not a safe place to examine the rocks, but the power of this short river is spectacular.

Continue to the road end at Milford Sound.
STOP 22. MILFORD SOUND CRUISE. -44.6683, 167.9268
MEDIAN BATHOLITH GRANULITE FACIES ORTHOGNEISSES; ALPINE FAULT
Park in the car park. Walk along the covered track to the main boat terminal.

Geological sketch map of the Darran Mountains–Milford Sound area (Blattner 1991). Anita Ultramafics shown in black. Fieldtrip stops 20–22 are shown. Darran Complex (Cretaceous) and Mackay Intrusives (Triassic) are largely unfoliated whereas amphibolite and granulite facies orthogneisses occur to the west. Mortimer et al. (1999) regard all rocks between the Glade–Darran Fault and the Pembroke Fault as part of the Median Batholith.

No hammers needed. Doing fieldwork in Fiordland is difficult and time-consuming. The moss and lichen mean that it is usually very hard to see any geological detail in outcrop, despite the near vertical cliffs and general abundance of rock. The steep to vertical topography means much rock is inaccessible; extensive helicopter and boat support is necessary. High rainfall (c. 6m annual here, up to 12m in parts of the West Coast–Southern Alps) also hinders productivity and the sandflies also make outdoor work miserable. Let’s go on a cruise instead.
The Mesozoic Accretionary Orogen of Zealandia

View looking northwest down Milford Sound, Fiordland. Mitre Peak is in the far distance.

P10604. Two pyroxene garnet granulite (Pembroke Gneiss) from Milford Sound. Height of photo 3mm. Clarke et al. (2000) have established that garnet symplectite reaction zones, widespread throughout western Fiordland, record conditions of c. 14 kb and T>750C. Age of metamorphism is only a few m.y. younger than the 119-126 Ma protolith age of the Western Fiordland Orthogneiss. Exhumation of these rocks also occurred soon after metamorphism, possibly in a mid-crustal metamorphic core complex setting (Gibson et al. 1988)

The glacially-carved steep-walled cliffs of Milford Sound do not give much away when viewed from a distance but the scenery is stunning. Work by Blattner (1991 and references therein; see map p. 25) and Clarke et al. (2000) has emphasised the regional occurrence of granulite facies mafic orthogneisses. If the boat travels far enough, we will be able to see the trace of the Alpine Fault at the foot of the Southern Alps where it heads out to sea.

We return to Te Anau, picking up missed stops on the way if we have time.
**Day 4: Sunday, 1 December**

We drive south from Te Anau to the Southland Coast. Today we mostly will be in Late Triassic to Late Jurassic Median Batholith and Permian Brook Street Terrane. Bad weather alternatives are to go down Clifden Caves (Oligocene-Miocene limestone) and visit the Riverton Museum.

**STOP 23. LAKE MANAPOURI, FRASERS BEACH. -45.5562, 167.6211**

**CENTRAL FIORLAND PANORAMA**

*On entering Manapouri township, take Frasers Beach Road (signposted to right). Do not drive down to the beach straight away but continue to the 2nd “Access Beach” sign. Walk down to the beach to the large glacial erratics.*

A wide variety of glacially transported plutonic and metasedimentary rocks can be seen here, all brought to us from across the lake. The Median Batholith rocks we saw yesterday and will see later today are mainly gabbros and diorites, but this stop shows that granodiorites and granites are also important rock types in this Cordilleran batholith.

*We leave Manapouri and drive south down the Waiau River valley which drains Lakes Te Anau and Manapouri. The Waiau Valley is floored by Tertiary sedimentary rocks and Quaternary gravels. To the west are the high, bush-covered mountains of Fiordland (Median Batholith). To the east are the talus- and scrub-draped Takitimu Mountains underlain by the Brook Street Terrane.*

**STOP 24. WAIRAKI RIVER BRIDGE -45.9348, 167.7049**

**BROOK ST TERRANE LITHOLOGIES IN RIVER**

*Pull off next to the water treatment building on the south side of the bridge. Walk down to the river.*

Cross section through the Takitimu Group (Brook Street Terrane). Stop 24 is at ‘X’.

Typical basaltic composition Brook Street Terrane lithologies can be seen in the river. These include volcanic breccia, sandstone, siltstone, various lavas including plagioclase and augite porphyritic. Also hypabyssal fine-medium grained pyroxene gabbros.

*Do not continue south on the Southern Scenic Route but turn left on Otahu-Eastern Bush Road. Follow signs to Birchwood and Ohai, taking Run 47 Road and Struan Flat Road. After passing through the Cretaceous coal mining town of Ohai, turn left along Gorge Road then right onto Beaumont Station Road.*
STOP 25. BEAUMONT STATION, OHAI.
BROOK STREET TERRANE-MURIHIKU TERRANE BOUNDARY
Permission required from Struan and Lynn Minty, Beaumont Station.

The accompanying map shows the main geological features. Prior to the detailed mapping in the 1980s by Chuck Landis and students, no structural break was recognised and the area was interpreted as an unfaulted Permian-Triassic section. Today it is a major terrane boundary.

We will drive in along the farm track from the south on stratigraphically basal Murihiku Terrane, across the Letham Fault and into stratigraphically upper Brook Street Terrane. Exactly what we are able to examine close-up will depend on exposure, time and weather. Unfortunately we will not have time to examine the Brook Street Terrane stratigraphy (northern end of area) in detail. We will at least get a good general overview of the stratigraphy and structure in this scenic part of the eastern Takitimu Mountains.

Local geological map of part of Beaumont Station showing Letham Fault Zone, the boundary between the Brook Street and Murihiku Terranes.

Brook Street Terrane consists of east-dipping Middle Permian Caravan Volcanics overlain by Late Permian Mangarewa Formation and Glendale Limestone, in turn overlain by Early to Middle Jurassic Barretts boulder Conglomerate. The iconic Permian Gondwana leaf fossil Glossopteris has been found in Mangarewa Formation.

Murihiku Terrane consists of Middle Triassic interbedded sandstones and mudstones.

Map from Landis (1987).

Drive back through Ohai and continue on the Ohai-Clifden Highway to Tuatapere. We may make a brief stop at the historic Clifden Bridge. Continue south through Tuatapere (pop. 700, self-proclaimed sausage capital of New Zealand) through to the south coast.
STOP 26. McCracken’s Rest Lookout. -46.2280, 167.6692
SOUTHLAND COAST and SOLANDER ISLAND
Pull out on right at the prominently signposted McCracken’s Rest.

Median Batholith rocks are exposed in the Longwood Range (inland, behind us), and along the coast to
the east at Pahia Point. Far to the west on the other side of Te Waewae Bay is Fiordland, also Median
Batholith. Stewart Island is largely obscured behind Pahia Point.

If the weather is clear, Solander Island can also be seen. Solander Island was named in 1770 by Captain
Cook for Daniel Solander, a Swedish botanist, who accompanied Cook on his first Pacific voyage. In
contrast to the well-developed Tonga-Kermadec-Taupo volcanic arc, Solander is the only known
subduction-related volcano on this south part of the Pacific-Australian plate boundary. A GNS-
Macquarie University Expedition in 2010 was only the third time geologists had visited the island.

The island is the highly eroded 1km² remnant of an andesite volcano. The expedition found that the
coalesced domes and pyroclastic flows were preserved, and established an age range of 125-400 ka for
eruption. The adakitic nature of the andesites was confirmed but an origin by extensive amphibole
fractionation rather than slab melting was indicated.

The flat terrace here is a Q5 (125 ka) or older Pleistocene marine terrace surface. It rises in altitude to the
west and falls in altitude to the east: a long baseline spirit level. The tilting is due to uplift of Fiordland
along the present day plate boundary.

Continue east along State Highway 99 a few kilometres to just before Orepuki.

OPTIONAL STOP 26A. GEMSTONE BEACH, OREPUKI.
PlioCene Cover
Turn right at Mullans Road West to the signposted Gemstone Beach. Park in carpark.

Gemstone Beach is so named because of the pebbles of hard, rounded waxy green hydrogrossular-
idocrase that can be found here. The sand:pebble ratio and height of the sand beach changes month to
month. As well as the hydrogrossular (which is rare), a range of epidotite, silicic porphyry, granitic and
quartz vein pebbles can be found. Most of these have their origins in the catchment of the Eglington
Valley where we were yesterday. The hydrogrossulars are derived from rodingites of the Dun Mountain
Ophiolite Belt.

Just like we have been, the pebbles were transported down the Waiau River valley, but as fluvo-glacial
bedload in the Pleistocene. Longshore drift in Te Waewae Bay then further sorted the pebbles.

The cliffs at Orepuki are eroding a section of shallow marine sandstone of the Plio-Pleistocene Orepuki
Formation. About midway up the cliff, carbonaceous and pebbly horizons are present and can be traced
south for a few km. In places, the carbonaceous horizon becomes thicker and pieces of fossil wood and
 lignite are found. The rocks themeselves are poorly dated and have not been studied as intensely as the
marine Pleistocene of Wanganui and Canterbury Basins.
Sketch geological map of the Longwood Range and coast (stops 26-29). From McCoy-West et al. (in press).

If the weather is good and the tide is right, the party can optionally walk 1.5 km south along the beach and be picked up at the carpark near the cliffs at Dudley Road. Tree stumps and wood can often be seen in slumped blocks that have fallen down the cliff.

Continue driving east through Orepuki, to where the main road takes a right angle left hand bend. Turn right here at Pahia-Wakapatu Road. Drive down for 1.5km then turn right on Mullet Road. Arrive at the inappropriately-named fishing settlement of Cosy Nook.
STOP 27. COSY NOOK, EASTERN BEACH
MEDIAN BATHOLITH: AUSTIN QUARTZ MONZODIORITE

Do not continue round to the cottages but park at the toilets. Walk south and then east round the pont for a few hundred metres.

High tide 1230 hrs, Low tide 1845 hrs.

The Median Batholith is well exposed around the Longwoods Coast; additional but poorer exposures occur within the low, forested Longwood Range. Overall, a variety of I-type plutons ranging in age from 261 to 144 Ma and represent the lower and middle crustal levels of an evolving, long-lived Cordilleran batholith.

We will look at exposures of Boat Harbour Diorite, dated at 203±3 Ma by U-Pb zircon SHRIMP methods (Price et al. 2006), although cobbles of other Longwoods plutonic lithologies can also be seen, along with more red garnet sand.

We will also discuss how the smooth-fluted shape of the in-situ rock came about. And the concave shapes to some of the boulders.

Return along Mullins Road and turn right on Pahia-Wakapatu Road. Follow this to the coast at Kawakaputa Bay and turn right (Austin Road). Park near the cabbage trees at the beach end, before the road turns up to a farm driveway.

STOP 28. SW END KAWAKAPUTA BAY. -46.3823, 167.8069
MEDIAN BATHOLITH: TRIASSIC COMPOSITE INTRUSION

Walk along the shore below/past the caravan site. To/past a slipway and a promontory, but no further than a small bay.

The first rocks encountered are "clean", orange-weathering Austin Quartz Monzodiorite, dated at 230±2 Ma by U-Pb TIMS methods (Kimbrough et al 1994). As we walk south towards the slipway, blobby dioritic mafic enclaves become more abundant. On the point, up to 50% is the rock consists of this dark diorite. Many of the mafic blobs have the appearance of disrupted dikes. One interpretation is that the dark diorite magma was injected into the partially consolidated orange monzodiorite magma. The diorite "chilled" to form plutonic pillows. Reactivation of the monzodiorite magma by heating led to still further structural disruption.

Trace element data preclude a simple mixing relation between the enclaves and the quartz monzodiorite to produce the host quartz diorite (Palin et al. 2003; Price et al. 2011).

Return to State Highway 99 and continue eastthrough Colac Bay and to Riverton. Just before the main bridge in Riverton, turn right and follow the coast road round past Howells' Point, into a reserve.
STOP 29. HOWELLS POINT, RIVERTON. -46.3842, 168.0381
BROOK STREET PILLOWS AND VOLCANICLASTICS, DIKES.

Turn off State Highway 99 in Riverton just before the main Aparima River bridge. Follow the main road, signposted to Riverton Rocs. It heads inland and uphill but eventually comes out at the coast again. Pass over the stock grid at the entrance to the Reseve. Park in one of the pullouts on the left.

We are back in the Brook Street Terrane again (see stop 24). The rocks here are a sequence of gently south-dipping pillow lavas, pillow breccias and sandstones of the Early Permian Takitimu Group. Several basaltic dikes cut the volcano-sedimentary section. This is classic Brook Street Terrane and the three-dimensional coast exposures offer the best place in the country to examine these rocks.

Despite careful examination, no body fossils have been recorded from here, only trace fossils.

It is probably easier to walk upsection (south and west) but this will depend on the tide and weather.

The lavas in the Brook Street Terrane are low-K arc tholeiites. For all its reputation as an intra-oceanic island arc, at least 50% of the Brook Street Terrane is sedimentary (volcaniclastic) and it appears that most of the arc was a submarine one.

Drive back to the main Riverton township. Turn right on State Highway 99 and drive to Invercargill for the night.

Sunset is 9.20 pm. Possible evening drive to Bluff, Omaui or Greenhills.
**Day 5: Monday 2 December**

Today we leave the Median Batholith behind us. We traverse back across the forearc basin and into the Caples Terrane Otago Schist accretionary wedge again. We end up in Dunedin, at the same structural depth and position in the wedge as we reached in Queenstown.

On the way we examine Triassic and Jurassic sedimentary sections in the Murihiku and Maitai Terrane. We contrast the vastly different structural and metamorphic character of Triassic strata in the Murihiku, Maitai and Caples terranes on the Otago Coast.

Low tide 0700 hrs, High tide 1400 hrs (the tide is not in our favour).

To get on Southern Scenic Route drive east out of Invercargill on the Main State Highway 1 towards Dunedin. At Rockdale Road intersection turn right (south) and drive 3 km south until Gorge Road-Invercargill Highway is reached. Turn left onto Gorge Road-Invercargill Highway. Follow this east across Southland alluvial plains to Fortrose. Follow signs to Curio Bay.

**STOP 30. CURIO BAY. -46.6618, 169.0981**

MURIHIKU TERRANE JURASSIC FOSSIL FOREST

Turn off the main Southern Scenic Route (S.H. 92) at Fortrose (follow signs to “Curio Bay via Coast Road”). About 1 km later turn right along Boat Harbour Road towards the golf course. Park in a large basin in the grassed over sand dunes below the Club House. Walk through the dunes (5 minutes) to the rocks at the harbour entrance.

Strictly no hammers!

After the high temperature rigours of the Median Batholith, we are back in zeolite facies and little deformed Murihiku Terrane fore-arc basin. At Curio Bay, and for many kilometres east and west along the coast, subhorizontal, cross-bedded fluvial to shallow marine sandstones, pebbly sandstones and grits of Temaikan (Middle Jurassic) Ferndale Group are exposed. These are the youngest Murihiku rocks in Southland although Late Jurassic nonmarine beds are exposed in the North Island.

According to Pole (2001), the Middle Jurassic paleoenvironment of Curio Bay was a fluvial plain adjacent to volcanic uplands. Intermittent flood events successively buried conifer forests. After each flood, soils developed and vegetation was reestablished. In about 40 metres of vertical section, 10 fossil forest horizons can be recognised. At the end of each flood soils developed and vegetation was reestablished.

The prominent flat platform is both the principal and the lowest fossil forest horizon exposed and reveals silicified stumps in growth positions and silicified logs in untransported positions. Higher forest and log horizons can be seen in the cliffs. Some smaller coalified wood and leaf fragments are present in sandstones.
Curio Bay stratigraphic section from Pole (2001). The main bench exposed at Curio Bay is in the CBF1 horizon. CBF=Curio Bay Forest horizon, CBL=Curio Bay log horizon.

The tide is high during the middle part of the day. Drive north on the Catlins Highway, making a few photo stops. Keep going through Papatowai and Owaka.

We cross the Southland Syncline axis again just north of Owaka (refer stop 15). Up to this point today, the landforms have been tablelands and plateaus reflecting the subhorizontal dip of Murihiku strata on the syncline's south limb. North from here prominent strike ridges can be seen in the surrounding hills, a results of the steep southerly dip of bedding on the north limb.
Turn right on Ahuriri Flat Road, Karoro Road and The Nugget Road, signposted to Roaring Bay and The Nuggets.

STOP 31. ROARING BAY. -46.4449, 169.8028

MURIHIKU LATE TRIASSIC SECTION

Walk down the track to the beach, halfway down turn right down the narrow track to the beach (not left to the penguin hide). Because of returning yellow-eyed penguins we have to be off the beach by 3pm. When on the beach, turn right (west) and walk to the first rock outcrops at the west end of the sand. Mid- to low-tide is essential to get beyond the first conglomerate.

Triassic Murihiku on the Catlins Coast (from Campbell 1980). We will examine the Roaring Bay section which starts at the conglomerate marked "N. end of bay". The top of the section in Roaring Bay is marked by an impassable cliff. See p.46 for international timescale correlations.

The section we are about to examine is of steeply dipping and southward facing Late Triassic North Range Group rocks. We are on the steep north limb of the Southland Syncline, below the stratigraphic level of the Warepan Monotis we saw at stop 16. Metamorphic grade is zeolite facies, laumontite zone.

The first exposure encountered on the beach is a conspicuous 19 m thick conglomerate band with abundant granitoid pebbles. Overlying siltstones and fine sandstones are fossiliferous with Oretian (217-227 Ma) bivalve fossils (notably Maoritrigonia nuggetensis, Oretia coxi), ammonoids (Pinacoceras), nautiloids, (Proclydonautilus), brachiopods (especially Spiriferina novoseelandica) and trace fossils.

About 250 m of Oretian rocks are exposed in this section. They are overlain by a conspicuous shellbed with the bivalve Manticula problematica; this marks the base of the Otamitan Stage. The shellbed has some intriguing sedimentological features and has been variously interpreted as a debris flow and tempestite. Other fossils include ammonoids (e.g. Rhacophyllites) and nautiloids (e.g. Proclydonautilus), brachiopods (Oxycopella), bivalves (Halobia, Hokonuiia), gastropods and abundant microfossils. Strong (1984) recorded 65 species of foraminifera. Radiolaria, ostracods and fish teeth are also present.
Plant beds with vertebrate fossils (including ichthyosaur bones) occur about 30m above the Manticula horizon within a 300m thick section of dominantly medium to coarse sandstones. *Return to the van and continue in the same direction along The Nuggets Road to to the carpark.*

**STOP 32. NUGGET POINT LIGHTHOUSE -46.4481, 169.8169**

**MURIHIKU TERRANE & VIEWPOINT**

*It is a 2 km round trip from the carpark to the Nuggets Point lighthouse.*

This is a scenic walk out to the lighthouse to make while the tide is high on the coast. Along the track weathered, steeply south-dipping (72/210) Early to Middle Triassic beds of the North Range Group Murihiku Supergroup are seen. Recall the subhorizontal bedding at Curio Bay: the asymmetry of the Southland Syncline is obvious.

Seals are usually seen on the rocks below. Signs describe the history of the lighthouse.

On a clear day, there are views to the north to the rounded hills around Dunedin, 90 km distant.

**STOP 33. KAKA POINT. -46.3845, 169.7859**

**WILLSHER GROUP (MAITAI TERRANE?) TRIASSIC**

*Park in car park opposite Kaka Point Store. Walk north along sandy beach to rocks. We will pick our way across the rocks as far as the north side of Kaka Point. Do not go beyond the concrete chimney on the beach. Watch for seals – give them a wide berth!*  

The Willsher Group is a reasonably simple, folded but generally NNE facing succession about 2 km thick, of probable Oleneian to Ladinian age (late Early to late Middle Triassic). It appears to have a different source direction (from ESE) and to be of distinctly lower metamorphic grade again than the Murihiku rocks just seen by us at Nugget Point and Roaring Bay. Its terrane status is uncertain; its position between Murihiku and Caples Terranes suggests a Maitai correlation but metamorphic grade of these coastal rocks is much lower than those seen inland and individual formations cannot be correlated (e.g. at stop 14).

The first shore platforms near Kaka Point Store consist of well bedded steeply N-dipping and N-facing thin bedded siltstones, thin fine grained sandstones and tuffs. This is the top part of the Bates Siltstone (165m stratigraphic thickness). There are abundant sedimentary structures, numerous bentonitic or zeolitised ash beds, and many horizons are rich with concretionary nodules. Sparse macrofossils (ammonoids, brachiopods, bivalves and gastropods) indicate an Etalian age (Anisian, Middle Triassic).

At the headland of Kaka Point the Bates Siltstone is conformably overlain by the more resistant Kaka Point Sandstone (100m), a heulanditised coarse grained epiclastic lithic volcanic sandstone with a prominent crystal-vitric tuff member. Channel fills of granule conglomerate, some offset by faults, are present on the north side of the point.

The Kaka Point Sandstone is overlain by the Tilson Siltstone (820m thick). Like the Bates Siltstone, this is a well-bedded sequence of NNE facing and younging siltstones, thin sandstones and tuffs.

*Drive north back through the South Otago farming town of Balclutha (pop. 4000). Drive north on State Highway 1 to Milton. Follow the Milton-Taieri Mouth Road until Watson Road is reached. Turn down Watson Road (ignore Russell Road) to the beach.*
STOP 34. WATSONS BEACH. -46.1641, 170.1504
CAPLES TERRANE: LATE TRIASSIC TUBE FOSSILS, TZIIA MELANGE

Park as soon as the beach is reached. Walk south for about 0.5 km along the rocks.

The coastal exposures here are within TZ II A, and medium sandstones show crude foliation
development. Metamorphic grade is pumpellyite-actinolite facies. Early brittle and semi-ductile fabrics
are clearly visible, with broken formation to melange structure and phacoidal boudinage of sandstone
beds in mudstone (eg. Nelson 1982). Of particular note are the extensively developed shear surfaces
with N-trending quartz fibre stretching lineations. A slaty cleavage is locally developed axial planar to
folds in a second generation of folding, refolding the early soft-sediment deformation. The metamorphic
grade is transitional between prehnite-pumpellyite and pumpellyite-actinolite facies.

Small black phosphatic nodules have yielded well preserved Late Triassic radiolarian faunas (Ito et al.
2000), but the cherts are too recrystallised. Manganiferous cherts and metabasites occur at several
nearby localities in this coast section. The trace fossil *Torlessia* can also be found on sandstone bedding
planes (Campbell & Campbell 1970). In the Rakaia Terrane these are found in association with Late
Triassic body fossils.

Although referred to as Caples Terrane, the petrochemistry of the sandstones show more affinity with
Rakaia Terrane than with classic Caples (Coombs et al. 2000). The tectonic implications of this have yet
to be fully worked out.

It is also of interest to contrast the sedimentary and tectonic style of these well dated Triassic rocks at
Watsons Beach with the Triassic forearc rocks of the previous two stops.

*Drive back along Watsons Road and turn right on Akatore Road. Drive all the way to, and through, the
coastal settlement of Taieri Mouth.*

Some possible brief photo stops of interest to view the Akatore Fault trace:

1. Akatore Stream, partly dammed and swamp created by uplift of the coastal range along the Akatore
Fault.

2. In paddocks opposite Taieri Mouth School where a Pleistocene marine terrace has a 2 m vertical
offset.

The Akatore Fault is a southeast dipping reverse fault that has a rupture recurrence interval of between
2000 and 3000 years. The most recent surface rupture is estimated to have occurred between AD 1350-
1370, generating a vertical change in the order of 2-4 m. In April 1974, a Magnitude 4.9 earthquake
struck approximately 10 km off the coast of Dunedin, at a depth of 12km. This was probbaly on the
Akatore Fault. The net offset of the Waipiunamu Erosion Surface by the Akatore Fault is 75 m, up to the
east.
STOP 35. BEACH AT REIDS STREAM. -46.1641, 170.1504
CAPLES TZII B DEFORMED CONGLOMERATES

Watch for farm buildings and a moderate sized pond coming up on the left. Try and park on the beach side of the road just before Reids Stream culvert (which drains the pond) is crossed. Walk north on the beach across Reids Stream to the first rock outcrops.

Metamorphic and textural grade are noticeably higher here than at Reid Stream and the S1 foliation has a noticeable southerly dip (25°/220°). Protoliths here are pebbly sandstones on which Norris & Bishop (1990) have done strain studies that indicate up to 80% flattening with a plane strain ellipsoid. Clasts include argillites, sandstones and rare granitoids. A prominent L1 stretching lineation plunges towards 170 on S1 surfaces. In addition, mm-scale F2 crenulations (common) and broad, m-scale F2 warps are present; fold axes trend 140 and verge NE. Brittle structures here include quartz tension gash arrays and steep faults.

One prominent fault (095/88°S) has a dextral motion based on associated quartz vein geometry. Steep, straight quartz vein arrays strike 045. Although thin and low volume, these are prominent.

Continue north towards Dunedin. Watch for a long gorse hedge on the left of the road. At the end of this there is a gentle left-hand bend. Pull out on the right hand side of the road immediately after the Hall’s letterbox (rapid no. 232). Drive to the north end of the pullout and and walk down to the beach.

STOP 36. BRUCE ROCKS. -45.9708, 170.2859
CAPLES SCHIST TZIII, F2 FOLDS, S2 FOLIATION, BRITTLE FAULTS
Scramble down to the beach

The rare mesoscopic F2 folds seen at Reid Stream now dominate the outcrops and have a distinct and consistent asymmetry, verging NE. This asymmetry is seen in mesoscopic folds throughout the lower levels of the Caples Terrane. This is the ‘missing section’ of tight to isoclinal F2 folds that we did not see between Kingston and Queenstown a few days ago.

Sandstone and mudstone protoliths can still be readily distinguished as TZIII psammitic and pelitic schists. Thick quartz veins are refolded with fold axial planes parallel to the penetrative foliation. The problematic issue of distinguishing between S1 and S2 will be discussed here and at the final stop at Brighton. The relatively abundant thick quartz veins seen here appear to have no counterparts at Reid Stream and Taieri Mouth where early-formed quartz veins are much thinner and rarer.

The schist here has many deformed late-stage quartz veins, and is also strongly lineated with intense quartz roding. Nevertheless, original sandstone and mudstone layers are clearly visible and younging directions may be inferred by the bold or foolish. Refolded L1 stretching lineations may be seen wrapping around F2 fold hinges.

Late faults are abundant here. One particularly prominent fault zone with a calcite-cemented gouge zone dips 052/45°NW; ancillary faults dip up to 60°. Possibly these are structures that were conjugate to the Akatore Fault during its inferred former extensional phase.

Blocks of rusty, cemented sandstone have fallen from the loess capped cliffs. They are Quaternary terrace deposits.

Drive into Dunedin. Optional night trip to Nichols Creek to see Glow Worms.
Day 6: Tuesday 3 December

This is basically a transit day back to Christchurch up State Highway 1. Along the east coast, an extensive sequence of Late Cretaceous to Neogene strata (including intraplate volcanics) covers the older basement rocks. Exactly where we stop, and for how long, we will determine at the time. Low tide is at 1000 hrs (in our favour).

*Simplified Late Cretaceous-Miocene stratigraphy of the Dunedin area (Bishop & Turnbull 1996)*

About an hour's drive north of Dunedin we will make a brief stop in Palmerston, to admire a marble statue of Zealandia. This is one of only three in the entire continent.
STOP 37. TROTTERS GORGE -45.4047, 170.7878
MATAKEA GROUP, HORSE RANGE FORMATION

At the north end of Palmerston, keep straight on Horse Range Road instead of veering right over the rail bridge on State Highway 1. Keep on this road. Follow signs to Trotters Gorge and start looking for rocks a few hundred metres over the pass (marked with a yellow road sign).

We may just admire the rocks from the van, or we may make time for a 30 minute hike in the scenic reserve.

Horse Range Formation is a 400 thick sequence of alluvial pebble-cobble conglomerate, sandstone, siltstone and carbonaceous mudstone with rare thin coaly lenses. It was deposited in a northwest-south east trending half graben associated with normal movement (north side down) on Waihemo Fault. Three lithologic associations are recognised: quartz conglomerate, quartz sandstone, and roundstone greywacke pebble conglomerate in the Trotters Gorge succession. The roundstone greywacke pebble conglomerates were deposited by an axial braided river system, whilst subangular quartzose schist pebble conglomerates were derived from Otago Schist forming the uplifted southwestern shoulder of the Waihemo Rift. Schist and greywacke clasts in the Trotters Gorge area are locally partially replaced with calcite (Lee et al. 1996).

Igminbrite associated with conglomerate south of Trotters Gorge has been dated at 112 Ma (U-Pb zircon). The ignimbrite is restricted to an infaulted strip of Horse Range Formation lying between subparallel branches of the Waihemo Fault. This is one of the oldest "cover rocks"

Continue driving north to rejoin State Highway 1.

STOP 38. SHAG POINT.
TARATU FORMATION SANDSTONES AND COAL SEAMS
Turn right off State Highway 1 to Shag Point (signposted). Drive right to the end of Shag Point Road and park in the carpark. Either continue on the track through the gate and drop into one of the first two bays to the south, or scramble down to the rocks southeast of the carpark

Alluvial sedimentary rocks at Shag Point are of Piripauan to Haumurian age (Late Cretaceous). Inland, they depositionally overlie Horse Range Formation.

Taratu Formation consists of conglomerate-sandstone-mudstone-coal cycles. Immediately east of the road-end vehicle park, muddy sandstone overlying quartzose conglomerate displays large-scale inclined bedding characteristic of meandering channel point-bar accretion (Figs 3 & 4).

Bituminous coals from the Shag Point area contain c. 2% sulphur and 5-10% ash. There are six significant seams or seam groups. Coal production from Shag Point mines started in 1848 and amounted to approximately 2 million tonnes.

Return to State Highway 1 and continue north.
STOP 39. MOERAKI BOULDERS -45.4769, 170.8259
UPPER ONEKAKARA GROUP CONCRETIONS

Drive past the right hand turnoff to Moeraki township. About 2 km north of here take the clearly signposted right hand turn to the Moeraki Boulders. However, after crossing the railway line do not turn left to the restaurant but continue straight on the dirt road to the beach. Park, and walk north along the beach about 1km to the boulders.

No hammers! The spectacular septarian concretions have been studied by Boles et al. (1985) from which the following information is taken. The Moeraki boulders are large (up to 2 m) calcite concretions with septarian veins of calcite and rare quartz and ferrous dolomite. The concretions are enclosed by gently-dipping Paleocene marine mudstones with vitrinite reflectance values of 0.29% R suggesting maximum burial temperatures of 25-30°C. Maximum depth of burial, based on stratigraphy, is estimated at 600-700m. The growth time of the larger concretions is estimated at about 4 m.y. based on published diffusion growth models.

Moeraki Boulders

Continue north on State Highway 1

STOP 40. BOATMANS HARBOUR, OAMARU. J42/642512
LATE EOCENE PILLOW LAVAS

On approaching Oamaru town centre, turn right into the historic district and follow the road and railway around to the penguin centre. Park, and walk along the track to Boatmans Harbour.

This locality provides an excellent section through a 30m thick sequence of Late Eocene intraplate basaltic pillow lavas, the interstices of which are infilled with bryozoan - brachiopod limestone. The pillows vary from football-size to 5x2m and larger pillows may be transitional to lava tubes. The bryozoans between the pillows are not in life position, but even delicate forms are well preserved.

Beneath the pillow lavas are 150m+ of thinly-bedded tuffs which are thought to have formed from a Surtseyan-type eruption on a shallow continental shelf. At a few places in the section, thin beds of fossiliferous and pebbly limestones mark localised unconformities in the tuff beds. These beds contain rich faunas of delicate bryozoans, small brachiopods, foraminifera, echinoids and occasional molluscs, and are thought to have colonised platforms cut in unconsolidated tuff by wave and current action. The pillows and limestones are all Runangan (Late Eocene) in age, and the entire life of the Oamaru submarine volcano may, like Surtsey, have been quite brief (Lee et al. 1996).

Mid-pm, arrive Christchurch
End of trip.
REFERENCES & BIBLIOGRAPHY


The Mesozoic Accretionary Orogen of Zealandia

Geosciences 2013

Interim New Zealand Geological time scale from Crampton, et. al. 1995
GEOCHRONOLOGICAL SUMMARIES: OTAGO SCHIST & MEDIAN BATHOLITH

Argon and fission track radiometric age profiles through the Otago Schist (from summary by Mortimer, submitted). $Sp$ isopach thickness corresponds broadly to structural depth in the schist; 0km is level of the Caples-Rakaia Terrane boundary (TZI-II IV isotect). Progressively younger Jura-Cretaceous metamorphic ages are found at deeper levels in the schist pile; very low grade schists and greywackes are "contaminated" by ages of Triassic and older detrital minerals.

U-Pb ages of plutonic rocks in the Median and other New Zealand batholiths (from Mortimer et al. 1999). Magmatic pulses and lulls can be interpreted as periods of convergent and strike-slip movement between Gondwana and Panthalassa plates. Current work is aimed at trying to reconcile the Jura-Cretaceous history of the Median Batholith with that of the Otago Schist. Do they represent different parts of the same the same arc-subduction complex?