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Field Trip 3
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Fossils and Strata of Central and North Otago Waitaki Valley

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Photo: Searching for vertebrates in the fossiliferous Oligocene marine package in the upper Swin Burn catchment, Maniototo, with the volcanic plateau of Swinburn Peak in the distance. Photograph: Marcus Richards.

Photos in text by R Ewan Fordyce, except for Fig. 8 which is mostly by MD Richards.

Departs Dunedin by 9 am, Sunday 27 November

Arrives Wanaka late afternoon Monday 28 November.

Introduction

Our first field localities are in Central Otago's Maniototo district near Ranfurly and Naseby, with later stops on the southern side of the Waitaki Valley, North Otago. The Maniototo and adjacent Central Otago have had a rich history of geological study: schist basement, Cretaceous syn-rift strata, Neogene basaltic volcanics, the Miocene Manuherikia Group, and young auriferous strata. The Waihemo Fault and other geologically young structures all command ongoing study.

The marine rocks of the Maniototo have been rather neglected, however, in spite of their potential contribution to the history of Zealandia; these strata have been simplified under the name of Naseby Greensand. This field trip will introduce Oligocene rocks of the Swinburn-Kyeburn areas, showing that the name Naseby Greensand (sensu Bishop 1974) covers a stack of several marine formations (Richards et al. 2014) that can be correlated northwards to the Waitaki region and south Canterbury. Canterbury Basin names can now be used in Central Otago: the Wharekuri Greensand, Earthquakes Marl, Kokoamu Greensand, and Otekaike Limestone. We will see these formations in the Maniototo and in North Otago.

Health and safety

Refer to the Geosciences Society pdf document on field safety, circulated by email; we are committed to follow this, and we may also follow additional H&S policy of landowners. We will provide hard hats and hi-viz vests. For this trip, you must be at least of medium fitness and ability. We will not stop at roadside localities. We will visit private and public lands, walking up to 1 km from the vehicle. Hazard warning: there are high scarps at Swinburn; while we do not know of major slips in the last year, there is risk of falling debris. At Wharekuri Creek, steep-sided walls are capped by alluvium which, along with the little-cemented marine strata, have risk of collapse, with some debris fallen within the last year.

There will be rough or uneven ground, and we will cross shallow streams. A Leki stick or similar may help. We will get wet feet at stops 1, 2 and 3 on Sunday up to calf-deep, and at stop 8 on Monday morning, up to calf-deep.

There will be toilet stops on Sunday at Palmerson, and at Danseys Pass pub and at Duntroon, and on Monday at Kurow, Fishermens Bend-Lake Waitaki, Otematata Benmore, and Omarama.

Summary of logistics

Day 1, Sunday

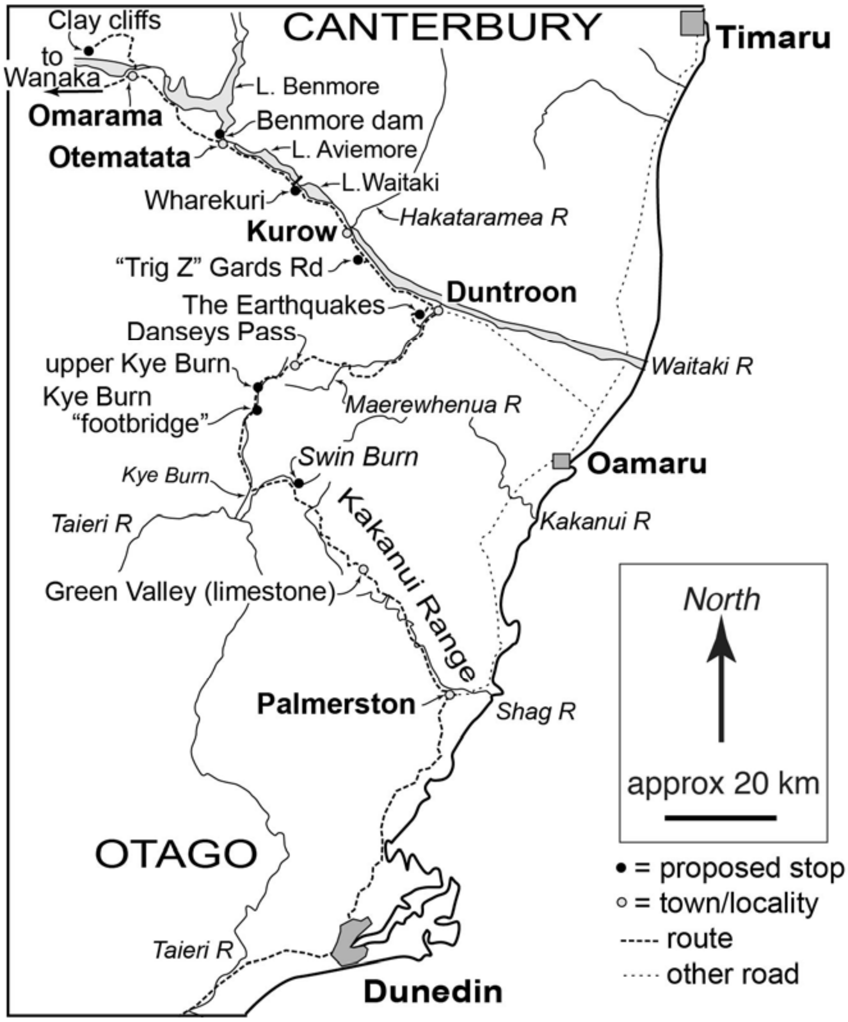
- By 9 am, depart from north end of the Geology Bulding, University of Otago, Dunedin, travelling north to Palmerston.
- **Dunedin Volcanic group** basaltic rocks occur in road outcrops, and form skylines, from Dunedin to Waitati. Volcanic-capped peaks are prominent as far north as Palmerston.
- After Evansdale, the road over the Kilmog has cuttings in **Abbotsford Mudstone** (Paleocene/ Eocene) with, in places, large clastic dykes. Mass movement features can be seen, and encountered on subsiding bits of the road.
- To the west, the Silverpeaks area is developed on the **Haast Schist.** The surface of the schist, the "Otago peneplain" of old literature, dips gently to the northeast, and is overlain by the coastal east and north Otago Cretaceous-Cenozoic sequences.
- North of the Kilmog, near Cherry Farm, views to the northeast reveal thick yellow-brown mid-shelf marine **Caversham Sandstone** (early Miocene) at Karitane and Matanaka.
- Near Palmerston, there are views of the Kakanui Range to the north, uplifted along the northwest **Waihemo Fault** - a Cretaceous normal fault on which reverse movement occurred in the late Cenozoic, as noted by Alexander McKay.
- From Palmerston, travel northwest toward the head of the Shag Valley, following the Waihemo fault beyond the Pigroot. Glimpses of Cenozoic strata include **Otekaike Limestone** at Green Valley.
- Stops 1 and 2, Swinburn, on the margin of the Maniototo basin: nonmarine-marine transition, thick massive greensand/glauconitic sandstone – Eocene?, and Oligocene shelf strata.
- Stop 3, Kyeburn "old footbridge" site: thin steeply dipping equivalent of stop 1 - fossiliferous Oligocene shelf strata.
- Lunch, Danseys Pass Hotel.
- Stop 4, upper Kyeburn: nonmarine-marine transition, late Eocene fossiliferous greensand.
- Stop 5, top of Danseys Pass. If clear, view toward Livingstone, in Maerewhenua valley.
- Stop 6, The Earthquakes: peak-transgressive greensand, limestone, "mid" Oligocene unconformity.
- Stop 7, time permitting (alternatively, Monday), Trig Z-Gards Road: type locality for Waitakian stage.
- Overnight, Kurow

Day 2, Monday

- Stop 8, Wharekuri Creek: Oligocene near-basin margin - a shoreline nearby in "drowned" NZ peak-transgressive greensand, limestone.
- Stop 9, time permitting, Fishermans Bend, Aviemore: fossiliferous greensand.
- Stop 10, Waitaki river outcrops below Benmore dam: Torlesse Spillway Formation, shallow marine with possible bathysiphonid foraminifera.
- Stop 11, Omarama-Quailburn, Hawkdun Group clay cliffs badlands.

- Omarama west to Lindis Pass, Tarras, and Wanaka by late afternoon.

Fig. 1 - map



Further reading - key literature beyond this guide

North Otago stratigraphy: Gage 1957

Canterbury Basin stratigraphy: Field & Browne 1986, Field et al. 1989

Geological map of Waitaki region: Forsyth 2001

Carbonate stratigraphy of Waitaki region: Thompson et al. 2014

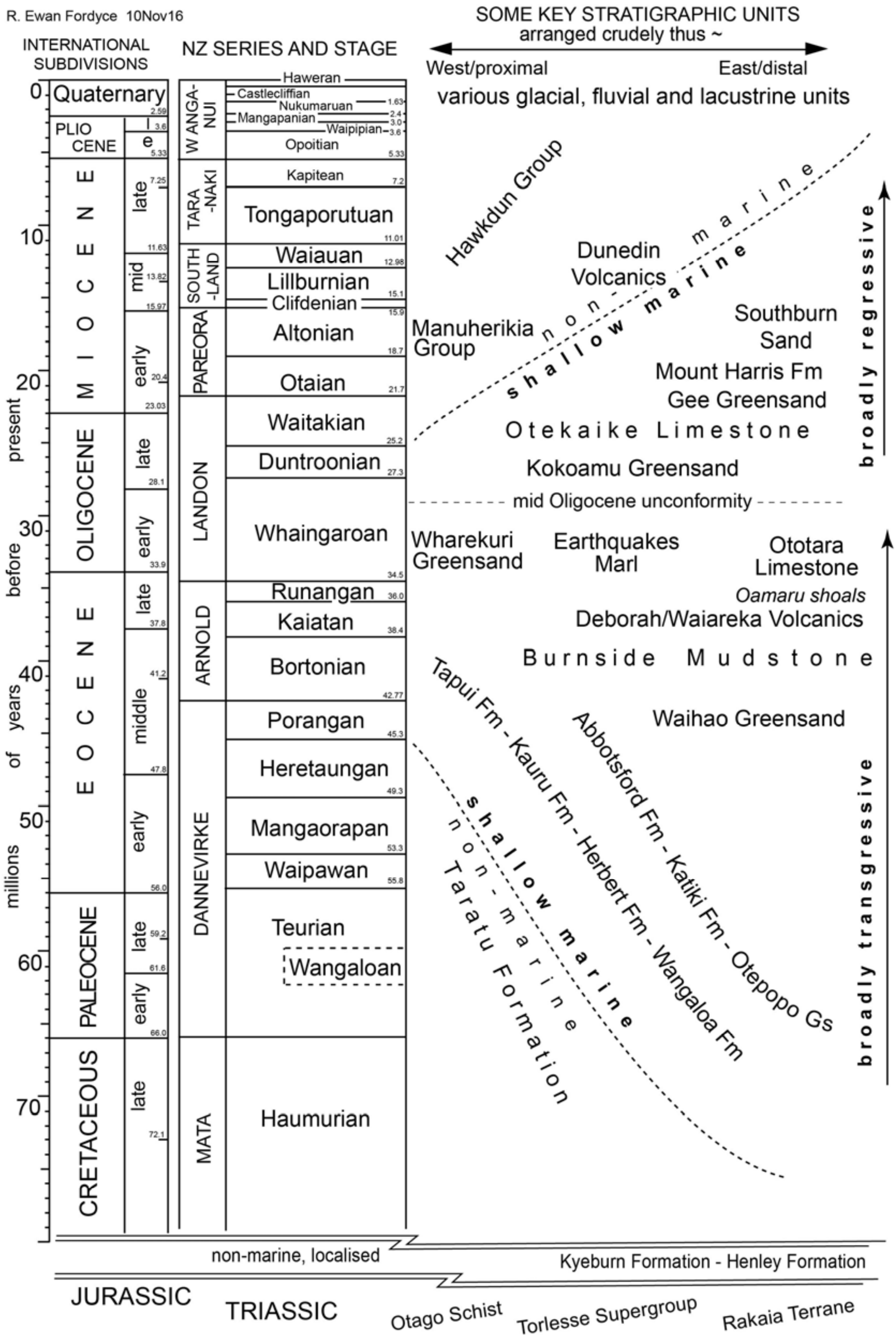
Geology of Maniototo-Naseby: Bishop 1974, 1979

Naseby Greensand as a composite: Richards et al. 2014

Torlesse basement: Retallack 1983

Fig. 2 - stratigraphy

General succession of Cretaceous-Cenozoic sedimentary rocks in southern Canterbury Basin. There is no consensus for the names for the basal marine strata.



Stop 1 – Fig. 3 - Swinburn Creek: thick subhorizontal Oligocene "Naseby Greensand" correlating with Canterbury Basin units: Earthquakes Marl/Wharekuri Greensand; Kokoamu Greensand; Otekaike Limestone (Richards 2014 and unpublished data). This site uniquely exposes the entire Oligocene sequence in one outcrop 60 m high. Calcareous fossils provide biostratigraphic control. The south-facing outcrop in Fig. 3 below is 280 m across. The sequence youngs upstream.

The **Wharekuri Greensand** is a green-blue, micaceous, sparsely glauconitic (>5%) silty sandstone, calcareous in the upper 10 m, but decalcified below. The base of the unit is seen near Stop 2 (below). A disconformity at the top is heavily burrowed with *Thalassinoide*s; the horizon is presumed to be the Marshall Unconformity.

The overlying silty **Kokoamu Greensand** is richly glauconitic in its lower 0.5 m, containing mud pellets, abraded *Serripecten* shells, rare phosphatic nodules, quartz granules and bones. Rare associations of cetacean bones in about the middle of the greensand are consistent with quiet deposition.

Otekaike Limestone – Fig. 4 below - yields crinoid and mollusc fossils. The uppermost horizon is the youngest Oligocene marine sediment from Central Otago (*Globigerina woodi woodi* zone, mid Waitakian Stage, ~23 Ma), concurrent with the Foulden volcano eruption near Middlemarch (40 km south) in an inland forested setting (Lindqvist & Lee 2009). Nearby is the **Kokonga Limestone**, a lithic-rich coquina of apparent shoal setting, possibly representing a topographic high in the late Oligocene only 5 km southwest of Site 1 (Scott et al. 2014).

Locally-derived river gravels and sands of overlying **Maniototo Conglomerate** is associated with local coastal uplift (D. Craw pers. comm. 2014), and not genetically related to later 'true' Maniototo Conglomerate found downstream of Swin Burn bridge (see below). The age of the unit is constrained by the **Waipiata Volcanics** basalt flow overlying the river deposit, This flow event is dated to 13.4 ± 0.3 Ma (K-Ar dating in Youngson et al. 1998; J. White pers. comm. 2014).

Table 1 – summary of stratigraphy at Swinburn stops 1 and 2.

Name	Lithology	Depositional setting	Age
Waipiata Volcanics	Flow basalt; vesicular flow with lherzolite mantle xenoliths. Baked basal unconformity with…	Terrestrial; basalt flowed over unconsolidated river gravels	K-Ar 13.4 Ma = Lillburnian, Middle Miocene
Maniototo Conglomerate	7 m sandy conglomerate with quartz and schistose lithics; undulose, erosional contact overlying . . .	Fluvial (riverine)	Syndepositional with basalt, Lillburnian, Middle Miocene
Otekaike Limestone	34 m massive sparsely macro-fossiliferous muddy limestone; calcite cemented horizons. Grades down to . . .	Marine, sheltered and/or below storm wave base. Deeper than Kokoamu Gsd?	Duntroonian-mid-Waitakian Late Oligocene
Kokoamu Greensand	24 m massive calcareous greensand with scattered fossils: *Lentipecten*, other molluscs, brachiopods, echinoderms, fish and shark teeth, Cetacea. Disconformity over . . .	Marine, sheltered and/or below storm wave base. Presumed sediment-starved.	upper Whaingaroan-Duntroonian, Late Oligocene
Wharekuri Greensand = Earthquakes Marl-Nessing Greensand	>60 m massive sparsely glauconitic silty sandstone, calcareous toward top; heavily bioturbated; scattered plant debris. Gradational contact with inner shelf sands of…	Marine, sheltered and/or below storm wave base, in a deepening shelf setting. Plant debris and terrigenous clastics suggest proximity to land especially at base	Arnold?-lower Whaingaroan, latest Eocene-Early Oligocene
Kauru Formation = Tapui Formation	>30 m glauconitic and/or carbonaceous sandstone-mudstone; mollusc shells and moulds, fish teeth, plant debris, lignite; bioturbated, ripples and hummocky cross-stratification. Base not seen.	Estuarine, shoreface and shallow/inner shelf settings, with fluctuating sea levels.	Bortonian or younger/Arnold series, Middle-Late Eocene
Taratu Formation **=** Hogburn	Soft carbonaceous siltstone-mudstone. Poorly exposed; base not seen.	Nonmarine paralic	uncertain

Holocene deposits on the Swin Burn valley floor produced a well preserved partial stout-legged moa (*Euryapteryx curtus)* near Stop 1. This species grazed on low-lying vegetation in dry regions of New Zealand prior to human-induced extinction ~700 years ago (Szabo 2013).

Summary

The Swinburn Oligocene marine sequence is fossiliferous but less carbonate-rich than the Waitaki sequences. The formations are thick, with matrix dominated by mica and quartz silt, contrasting with large authigenic glaucony and sandy carbonate bioclasts in the thinner equivalent strata in the Waitaki region. This background sedimentation may indicate that Swinburn was a depocentre for terrigenous material derived from a schistose Central Otago landmass. The upper Wharekuri Gsd (Earthquakes Marl equivalent) may be the deepest period of basin history, judging from patterns in the adjacent Waitaki region. Foraminifera indicate open marine circulation. Increased glauconite and carbonate levels above the mid-Oligocene unconformity may indicate deeper water deposition.

Stop 2 Swinburn cattle yards 2 km northwest of Swinburn Creek outcrops.

Fig. 5 left below looks upstream, with presumed Taratu coal measures in foreground; **Fig. 5 right** looks downstream with Taratu in the foreground, distant “up” arrow at the Kauru Formation with *Ophiomorpha* (Fig. 6, below), and “down” arrow at coarse greensand of Kauru Formation. Schist forms the distant skyline ridge.

Fig. 6, below. Left, nonmarine to shallow marine Kauru Formation. Grey silts with burrowed carbonaceous siltsone; right, detail of pebble lag and *Ophiomorpha* burrow.

Summary

Local basement is **Haast Schist** (metamorphosed Permian-Triassic **Rakaia Terrane**). Rakaia **Torlesse** strata will be seen at the Benmore Dam later in the trip.

Taratu Formation (coal measures, = **Hogburn Formation** of Bishop 1974) is presumed to be the basal Cenozoic unit; it is poorly exposed at the cattle yards. Elsewhere, ferrigenous sandstone unconformably overlies a thin weathered-schist veneer on Haast Schist on the western Swinburn Plateau margin. There is no evidence for coal measures older than Bortonian in the Maniototo. Basal shallow marine strata at Swinburn are hard to correlate with the Waitaki region (Gage 1957) because of poor exposure and uncertain dates, so formational names are provisional. The sequence is further complicated by the nearby Hyde and Waihemo Faults, which have deformed and faulted basal beds.

At Stop 2, paralic to shallow marine facies may represent the **Kauru Formation**, of uncertain relation to the **Tapui Sandstone**. Basal shoreface sands and muddy greensand pass up into variably-carbonaceous shale and claystone with marine molluscs and vertebrates, and plant debris, inferred to be estuarine. These strata are truncated by a burrowed unconformity with quartz pebble lag grading into sandstone with *Ophiomorpha* burrows commonly taken to signal shallow sublittoral settings. A Bortonian age is inferred by *Hedecardium ?brunneri* from a road cutting near Stop 2. Upstream, well sorted medium sands grade up into the silty very fine sandstone of presumed **Wharekuri Greensand**. This Kauru-Wharekuri sequence contains *Teredo*-bored logs and amber fragments in heavily bioturbated, sparsely glauconitic sandstone.

Fig. 7, below. En route on the road near Swinburn-Longlands, on the left note a prominent outcrop of dipping, tan-weathered, fluviolacustrine conglomerate and associated sedimentary rocks. These strata came from uplifted and eroding basement, probably the Hawkdun and Kakanui Ranges. This is the **Maniototo Conglomerate** (Forsyth 2001) of the Hawkdun Group. The age based on palynology is reportedly Late Miocene to Pliocene (Youngson et al. 1998).

Stop 3, Fig. 8 - Kyeburn "old footbridge" locality: steeply dipping fossiliferous Oligocene shelf strata exposed on the true right (southwest) bank of the Kye Burn. The sequence is interpreted as similar to Swinburn Stop 1: Wharekuri Greensand/ Earthquakes Marl, Kokoamu Greensand, and Otekaike Limestone.

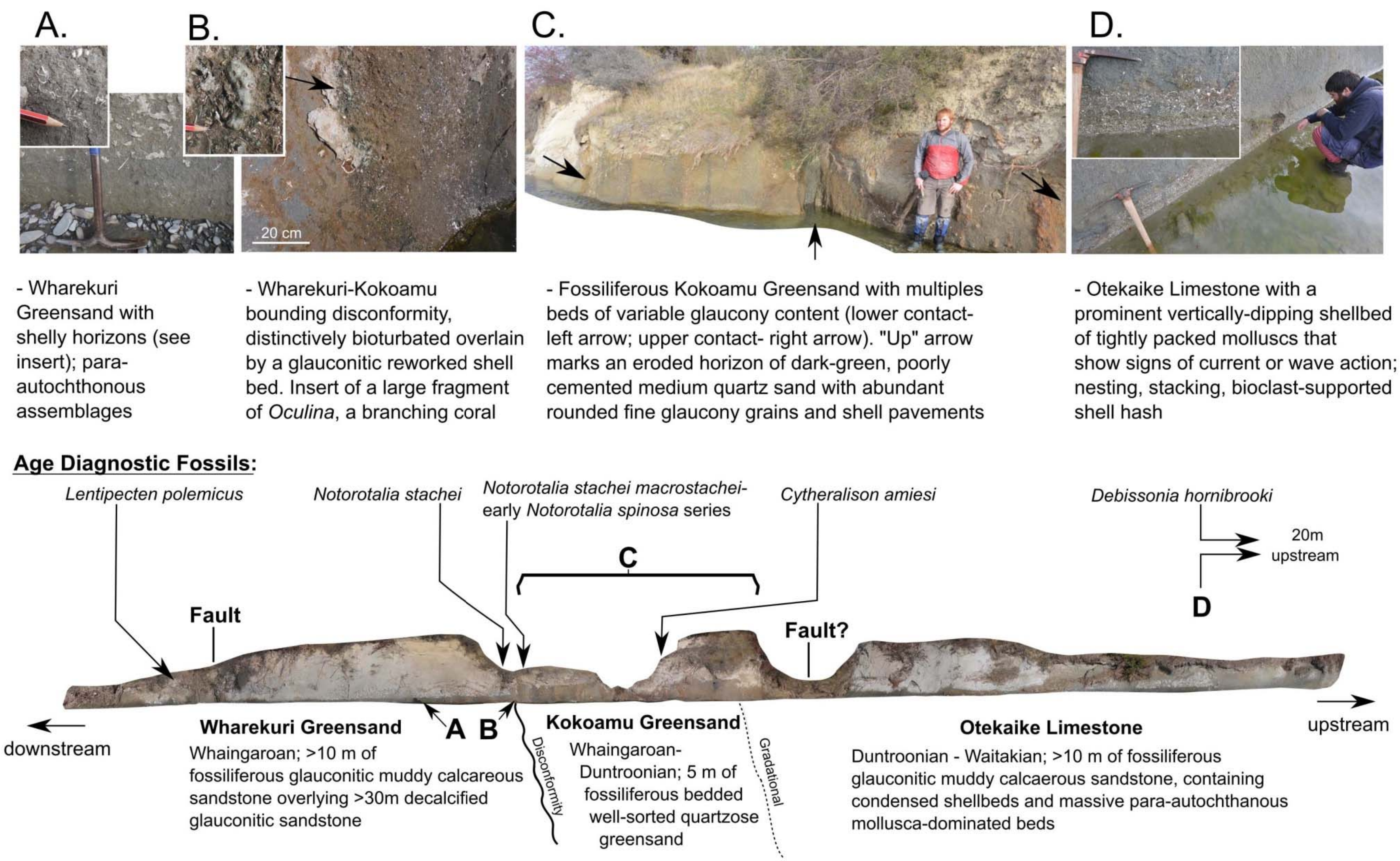


Figure 8. Annotated orthophoto of the Oligocene sequence at the "Old Footbridge" locality, facing SW towards true right bank of the Kye Burn. Field of view is 80 m across with vertically-dipping strata of a thickness of ~25 m.

Lower **Wharekuri Greensand** is sparsely-fossiliferous, with *Lentipecten polemicus* in life position. The unit grades up to fossiliferous grey sparsely-glauconitic sandstone. The fossiliferous character of the upper beds is reminiscent of Wharekuri Greensand at Wharekuri Creek Stop 8, but there is no Earthquakes Marl correlative.

The **Kokoamu Greensand** has a basal disconformity with infilled fissures and bioturbation. The lowest 10 cm is a densely-packed shellbed with rounded and phosphatised shells, shark teeth and other bones. Common *Oculina* stems may indicate coral thickets on the unconformity. The setting is inferred to be a shallow marine current-swept firm-ground. Up-sequence the greensand is bedded, without a fully overprinting biofabric. Upper Kokoamu Greensand has a 1 m thick bed of highly glauconitc medium quartz sand containing single-valved pavements of *Cyclocardia* and *Lentipecten hochstetteri*.

The moderately-glauconitic muddy **Otekaike Limestone** has abundant life and death assemblages of molluscs. One para-autochonous assemblage includes articulated mussels and an unworn, polychaete-encrusted, large *Echinophora* (helmet shell). Terebratellid brachiopods are absent, possibly because of turbidity. RM Carter suggested a shallow marine setting below wave base on a soft sandy substrate for the formation at this site (Carter cited by Bishop 1974).

This outcrop is a condensed Oligocene sequence, thinner than at Swinburn stop 1. Inferred bottom currents and/or wave action may indicate a shallow setting, both above and below wave base, and shallower than usual in the Late Oligocene of the southern Canterbury Basin. Carter (in Bishop 1974) inferred deposition “near the edge of a shallow sea”. Landis et al. (2008) argued for full marine transgression across Otago at this time, contrary to the implication of abundant terrigenous clasts in these Oligocene units.

Lunch stop, Danseys Pass Hotel.

Stop 4 – upper Kye Burn: nonmarine-marine transition, late Eocene terrestrial and marine shelf strata. Note old gold-workings: tailings, water-races.

The sequence youngs upstream. The basal **Haast Schist is** overlain unconformably by sub-vertical coal beds, cross- and planar-bedded sandy conglomerates and carbonaceous muds of the **Taratu Formation**, a likely fluvial or deltaic setting.

The **Kauru Formation** (see Swinburn Stop 2) comprises well sorted, planar laminated, quartz sandstone, truncated surfaces, and traces (*Planolites*, *Skolithos*), grading up into *Ophiomorpha*-burrowed sands with *Hedecardium* and *Panopea*. A bioturbated unconformity marks the top. The strata represent intertidal-shoreface-shallow (inner) shelf succession, perhaps Bortonian (cf. *Hedecardium brunneri*).

Fig. 9 - terrestrial and shoreface sediments. **Below, left**:Taratu cross-bedded sandy quartz conglomerates with occasional mud drapes. Insert; rare schist fragment. **Below, right**: Kauru Formation steeply-dipping shoreface sands. Insert; *Planolites* burrows in finely laminated siltstone – pencil shows younging up.

Up-sequence, an unconformity-bound bioturbated pale-cream siltstone may be the **Burnside Mudstone** of Kaiatan-Runangan age. Above a faulted stratigraphic gap is a thick Eocene greensand, bioturbated in the base. From here, a *Palaeeudyptes*-like penguin has been dinoflagellate-dated as Runangan-lowermost Whaingaroan (late Eocene-earliest Oligocene) (Richards & Fordyce 2015). Further up-sequence (upstream), above another gap, is a fossiliferous calcareous greensand (Fig. 10) presumably the **Wharekuri Greensand**. The adjacent leached hillside bears lithologies seen in the Wharekuri greensand at Wharekuri Creek stop 8 (below); deeply weathered bioturbated glauconitic siltstone grading down to a granule-rich greensand.

Fig. 10 – presumed Wharekuri Greensand/Nessing Greensand. **Below, left**: massive fossiliferous calcareous greensand (glauconitic quartzarenite), younging upstream (toward the upper left). *Notorotalia uttleyi* suggests upper Runangan-early Whaingaroan (Late Eocene - early Oligocene). **Below, right:** fossil-rich horizon with solitary corals *Flabellum* and *Stephanocyathus*; *Cucullaea, Panopea*, crassatellids, cardiids and other molluscs. The articulated bivalves, and preservation of fine detail in the corals, suggest a para-autochthonous assemblage, almost in life position.

Stop 5 - Fig. 11 - top of Danseys Pass. If clear, good views toward Livingstone, in Maerewhenua valley. Above, see Haast schist in foreground, in the headwaters of the Maerewhenua River. The gently left-dipping surface of the basaltic Tokarahi Sill is marked by pine trees arounds its margins (right arrow). The mesa and scarps of Otekaike Limestone between Awamoko and Maerewhenua catchments are further distant, beyond the sill (left arrow).

Stop 6, The Earthquakes, peak-transgressive greensand, limestone.

This locality shows 3 Oligocene formations deposited during the peak transgression onto Zealandia:

Name	Lithology	Depositional setting	Age
Otekaike Lst	~25 m of massive bioclastic limestone with glauconitic horizons and sparse macrofossils including penguins and cetaceans, grading down into macrofossil-rich . . .	Marine shelf below storm wave base but shallower than Kokoamu Greensand	Duntroonian-Waitakian, Late Oligocene
Kokoamu Greensand	5-6 m massive bioturbated calcareous greensand, occasional phosphorite, richly fossiliferous and dm bedded in upper; overlies burrowed disconformity	Marine shelf, sheltered and/or below storm wave base	upper Whaingaroan-lower Duntroonian, Late Oligocene
Earthquakes Marl	<5 m, comprising 0.5 m of relict marl over ~1 m of bioturbated massive calcareous mudstone, grading down to glauconitic base (= Nessing Greensand? = Wharekuri Greensand?)	Marine distal, probably outer shelf	Lower Whaingaroan, Early Oligocene

Fig. 12, below - the Earthquakes Marl (base of outcrop, on right) is truncated by the “mid” Oligocene Marshall Unconformity, overlain by the late Oligocene Kokoamu Greensand (upper Whaingaroan in base, to Duntroonian; forms lower part of cliff), and resistant Otekaike Limestone (Duntroonian-Waitakian; upper 20+ m of cliff). The massive, foraminiferal-rich Earthquakes Marl reflects deep waters, while the Kokoamu Greensand and Otekaike Limestone mark shallower settings, probably of mid-shelf depths below storm wave base.

The sequence here is well exposed, and accessible for the public. The skull and other remains of a *Mauicetus*-like fossil baleen whale have been prepared and partly exposed for public view in a fallen block of transitional Kokoamu Greensand-Otekaike Limestone. A poster explains the site. This is one of 20 sites on the Vanished World Trail. The locality has recently been acquired by DoC.

Stop 7, Fig. 13 below - “Trig Z” - Gards Road, type locality for Waitakian stage (time permitting, probably Monday). (Slightly modified from Fordyce 2009.) "Trig Z", Gards Road, Otiake is the type locality for the Waitakian Stage, and the type locality for the Otekaike Limestone.

The sequence dips gently to the west, to right in the figure. The Waitakian stage was proposed originally by Park in 1918 but has been much modified to meet modern standards. Gage established lithostratigraphic names used here. Most of the outcrop comprises the massive Maerewhenua Member, Otekaike Limestone. The upper, honeycombed strata with low-angle crossbeds – presumed to signal shallowing - represent the Miller Member.

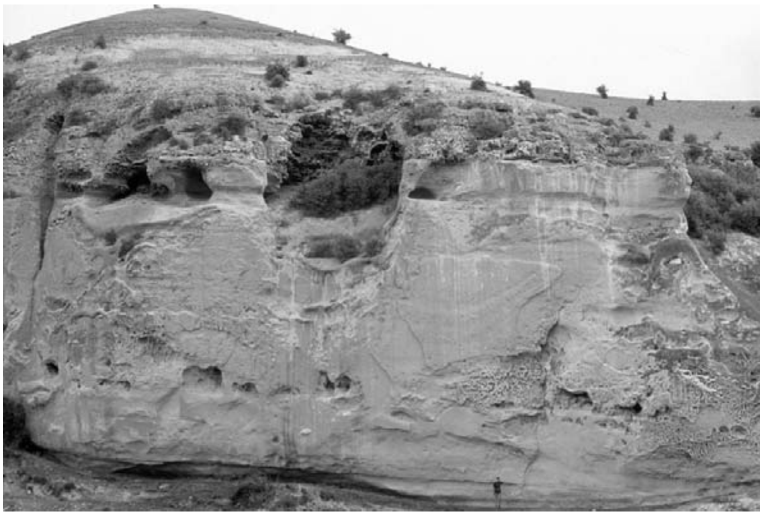


Fig. 14 - The person at the base of the outcrop, slightly right of middle, is close to the base of the Waitakian Stage, roughly at a prominent bedding plane, and indicated by the incoming of the planktic *Globoquadrina dehiscens*.

The top of the Maerewhenua Member has a prominent shellbed, the lower or “main” shellbed, with well-preserved macroinvertebrates. Another shellbed is higher, about the top of the Miller Member. Not shown here is the Waitoura Marl, exposed in patches to the west (right of the figure), marking the start of the Mount Harris Formation.

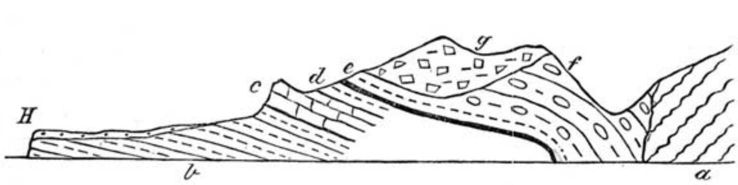
The outcrop has recently been acquired by DoC and has been or will be accorded reserve status. No collecting. Past research has recovered important fossil vertebrates including bony fish, penguins (*Platydyptes*), dolphins (*Otekaikea marplesi*) and baleen whales.

Overnight, Kurow

Stop 8, Wharekuri Creek (reprinted with edits from Fordyce's 2009 field guide to this locality). Peak-transgressive greensand, limestone, younging upstream.

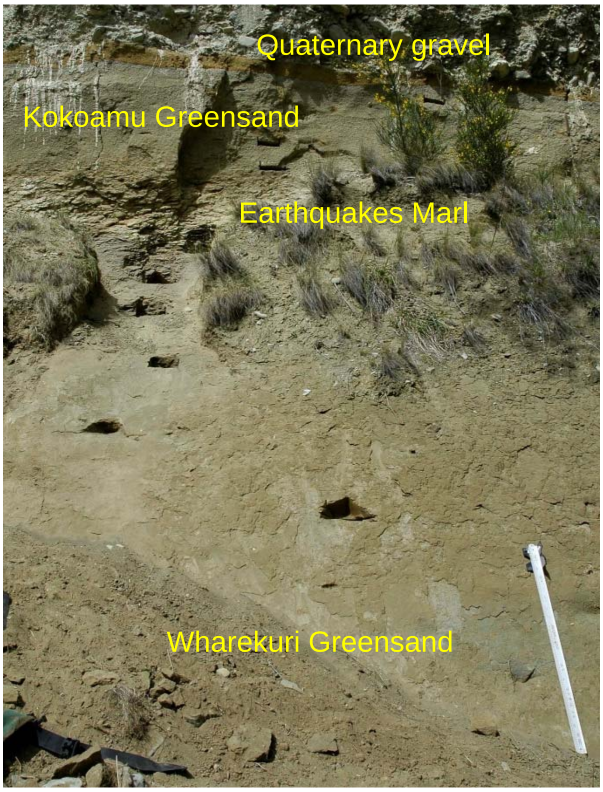
Hazard warning: the steep-sided creek walls are capped by loose alluvium; both the little-cemented marine strata and gravels are at risk of collapse. The going may also be rough.

Fig. 15 - Section of Wharekuri Creek, from McKay 1882.



Section across Tertiary Basin at Wharekauri from the Waitaki River westward. *a* represents the subschistose rocks of the Kurow Mountains. *b.* The Kekenodon beds. *c.* The Otakaika limestone, including Hutchinson's Quarry beds. *d.* Grits and sandstones associated with the Wharekauri coal-seam. *e.* The coal-seam as seen on the west side of the hill. *e′.* Its supposed outcrop on the eastern slope of the hill. *f.* The Pareora gravels overlying the coal-seam. *g.* Glacier drifts. *H.* The point whence the fossil remains of *Kekenodon onamata* were obtained.

Wharekuri Creek preserves the most inland notable occurrence of Cenozoic marine strata in the Waitaki Valley. The locality was visited by Alexander McKay (1880, 1881; see McKay 1882a, b), as part of field work on the widely-cited fossil whale *Kekenodon onamata*. The oldest marine Cenozoic unit here is the Whaingaroan Wharekuri Greensand (**Fig. 16 - right**) - one of the earliest named units in the Waitaki Valley. Older rocks (Taratu-like quartz pebble conglomerate with *Flabellum* corals - Kauru or Tapui Formation?) occur a few km to the north, on the flat topped basement mesa beyond the Aviemore dam across the Waitaki River.



The Wharekuri sequence is disrupted by faulting, with access hampered by scrub. Access beyond the Wharekuri Greensand-basal Kokoamu Greensand is difficult, and we will not visit it on this trip.

The creek bed for 200+ m upstream of the highway is cut in the **Wharekuri Greensand**: massive brown-weathered glauconitic siltstone with distinctive brown quartz granules (lower Whaingaroan; *Subbotina angiporoides*-zone). Macroinvertebrates are present, more common in the base. Fossils include the scallop *Janupecten*, terebratulid brachiopods, *Flabellum* corals, and the crab *Tumidocarcinus*. Vascular plants include *Teredo*-bored logs and rare *Cocos*-like coconuts. Two archaic whales have been collected. The abundance of terrigenous debris and land-derived plants is consistent with a more-proximal setting for the Greensand than most other Whaingaroan rocks of the Canterbury Basin. The setting could have been sheltered inner shelf, or deeper and below storm wave base.

The Wharekuri Greensand passes up into <1m of **Earthquakes Marl**. The Marl is thicker 30+ km to the east near Duntroon, where – as at Wharekuri - it is glauconitic in the base. At Wharekuri, the Marl is overlain by **Kokoamu Greensand** at a bioturbated disconformity: presumed to be the **Marshall Unconformity**.

Further upstream, not visited, the Kokoamu Greensand has macrofossil-rich shellbeds – the ***Kekenodon* beds** in the sense of McKay. Of historic note, the archaic toothed whale *Kekenodon onamata* and other fossil whales were collected by McKay in 1881 from outcrops at the junction of Wharekuri Creek and the Waitaki River, now covered by Lake Waitaki (on history, see Fordyce & Watson 1998). The single specimen of *Kekenodon onamata* provides the name for the **Kekenodon Group** of Canterbury Basin regional stratigraphy.

Glauconitic **Otekaike Limestone** crops out some 10s of m above the creek; its lower contact with the Kokoamu is not exposed. McDermid (1998) reported up to 40 m of Kokoamu Greensand and 20 m of Otekaike Limestone.

Name	Lithology	Depositional setting	Age
Otekaike Lst	Up to ~20 m of massive glauconitic bioclastic lst with; lower contact not seen at Wharekuri	Marine shelf below storm wave base but shallower than Kokoamu Greensand	Duntroonian-Waitakian, Late Oligocene
Kokoamu Greensand = *Kekenodon* beds	Up to ~40 m of massive bioturbated calcareous greensand, occasional phosphorite, macrofossil shellbeds in upper; overlies burrowed disconformity with …	Marine shelf, sheltered and/or below storm wave base	upper Whaingaroan-Duntroonian, Late Oligocene
Earthquakes Marl	~0.75 m of massive calcareous mst grading down over short distance into . . .	Marine distal, probably outer shelf	Lower Whaingaroan, Early Oligocene
Wharekuri Greensand	~12 m brown (weathered) to grey-green sandy siltstone, burrowed; towards base, quartz granules, invertebrates, wood, and phosphatised burrows.	Marine, sheltered shelf and/or below storm wave base, presumably deepening upwards.	Lower Whaingaroan, Early Oligocene

Stop 9, Fishermans Bend, Aviemore - time permitting - toilet stop. Depending on lake level we may see richly fossiliferous Kokoamu Greensand.

Stop 10, Fig. 17 - Waitaki River Torlesse outcrops below Benmore dam.

Torlesse, or Rakaia Terrane, strata in this middle part of the Waitaki catchment, include Triassic shelly marine fossils and nonmarine plant beds (Retallack 1983, Retallack & Ryburn 1982). Also nearby, not seen today, are Permian fusulinid limestones of the Te Akatarawa Lithologic Association, comprising melange-turbidite strata (Cawood et al. 2002). Because of limited time, we will stop only at the outcrops immediately downstream of Benmore dam (**Fig. 16** - below), to see tens of metres of overturned steeply (southeast) dipping, bedded dark siltstones and massive to cross-bedded lighter gray sandstones. These facies represent the Spillway Formation, of Retallack (1983a). Retallack cited a probable Kaihikuan age (early Late Triassic), and a shallow marine setting.

A single specimen of an agglutinated tube seen here in dark siltstone (but not collectable) is presumed to represent a benthic foraminiferan in the family Bathysiphonidae. Whether *Bathysiphon*, or *Torlessia*, or some other genus (Hannah & Campbell 1996) is uncertain. *Torlessia* was thought to have possible value as a zone fossil (Campbell and Warren 1965), but like the long-ranging foraminiferan *Bathysiphon* it is probably a facies indicator. These fossils occur as elongate tubes 2-3 mm in diameter, commonly formed of white silt grains. **Fig. 18**, left, shows a bathysiphonid specimen from Torlesse strata of Mount Hutt.

Stop 11, Fig. 19 - Omarama-Quailburn, clay cliffs badlands.

http://www.openspace.org.nz/Site/Places_to_visit/South_Island_public/Clay_Cliffs.aspx

The location is west of Omarama, on the north (true left) bank of the Ahuriri River. This site is protected under a Queen Elizabeth II Open Space Covenant (url above).

Fig. 19 – below: Outcrops form a prominent dissected scarp of northwest-dipping fluviolacustrine conglomerate, sandstone and siltstone variously identified as Kurow Group or **Hawkdun Group** (Forsyth 2001, Ghisetti et al. 2007). The upper part of the section includes bedded clast-supported quartz conglomerate. Exposures are associated with the Ostler Fault, a N to NE striking reverse fault which has surface expression for ~40 km, cutting young glacial features <200 ka (Ghisetti et al. 2007).

The Clay Cliffs, along with other New Zealand geological features, recently figured in an article on geology and postage stamps (Dove 2016).

End of stops. Travel to Wanaka.

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