GEOSCIENCES 09

Annual Conference
Oamaru, NZ

FIELD TRIP 11

WAITAKI/CANTERBURY BASIN

Sunday 22 November to Monday 23 November

Leader: Ewan Fordyce

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Introduction, **Trip 11: Waitaki/Canterbury Basin**

Day 1: short stop at Vanished World Centre [see also mid-conference trip #7]; Wharekuri Creek (Oligocene near-basin margin = a shoreline nearby in "drowned" NZ); Corbies Creek/Backyards (basement - Kaihikuan fossiliferous Triassic marine); Hakataramea Valley (Paleogene nonmarine to marine, including richly fossiliferous Oligocene, and Quaternary block faulting); Waihao Valley (if time permits - Eocene large forams and other warm-water fossils and/or Oligocene unconformities). Night in Waimate.

Day 2: Otaio Gorge (Paleogene-early Miocene nonmarine-marine sequence); Squires Farm (Oligocene unconformity); Makikihi (Plio-Pleistocene shallow marine to nonmarine fossiliferous strata); Elephant Hill Stream (Early Miocene; start of Neogene basin infill).

Which localities are visited will depend on weather, time taken at early stops, and farm/quarry activities which normally don't prevent access - but may occasionally.

The guide draws on some material from earlier guides (Fordyce & Maxwell 2003, and others cited). Graphics, photos, and field observations, are by Ewan Fordyce unless indicated.

FIG. 1: ROUTE MAP

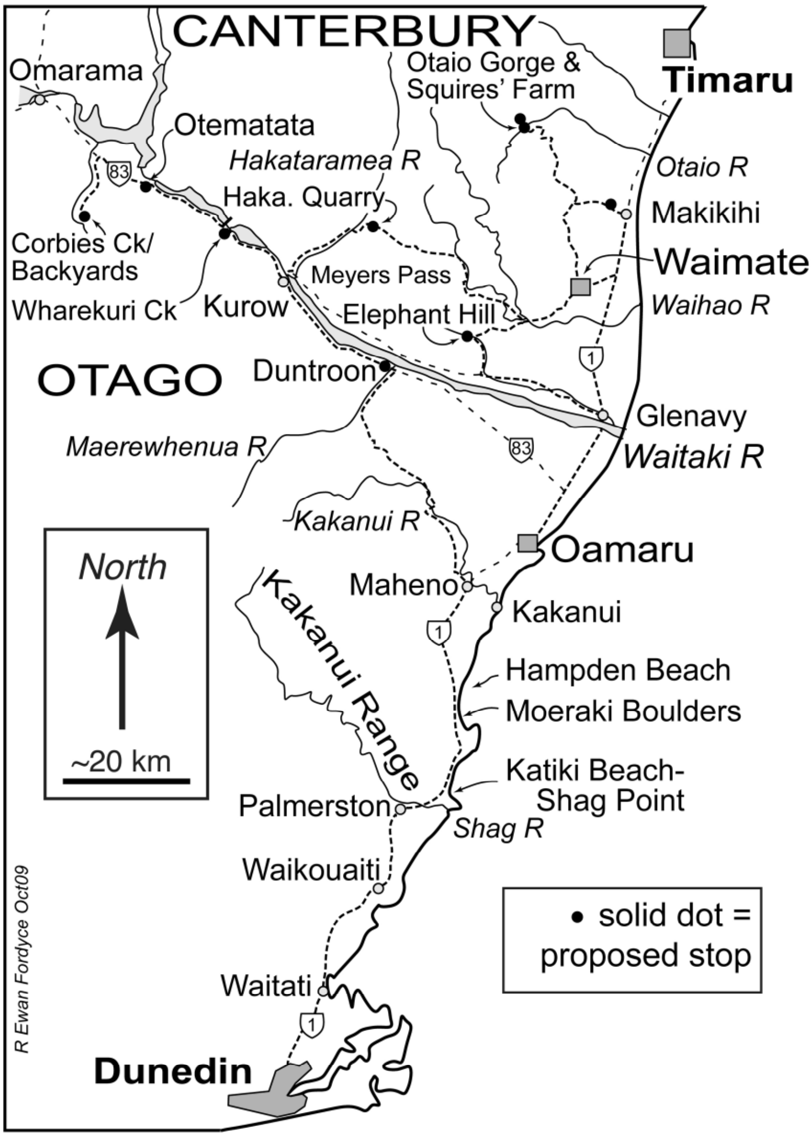
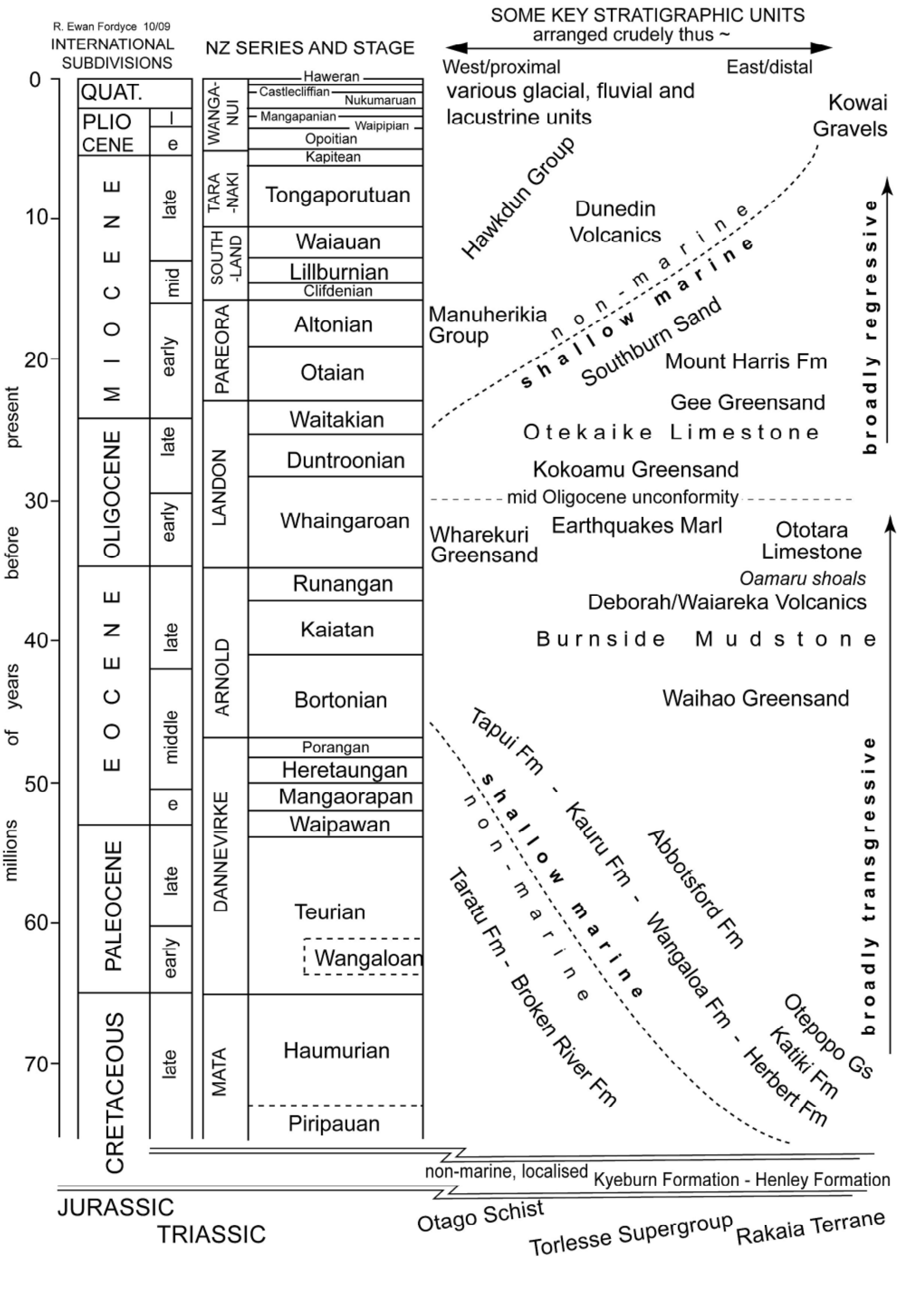


FIG. 2:GENERALISED STRATIGRAPHY, DUNEDIN-NORTH OTAGO-SOUTH CANTERBURY



INTRODUCTION TO STRATIGRAPHY

This summary is based on, but expands, that of Field Trip 7 (Vanished World Trail). The geology of the Waitaki Valley and regions immediately north and south is renowned for several reasons inlcuding: 1, accessible, thin, superposed ("layer-cake") cover sequences, sometimes with abundant and spectacular fossils of middle Eocene to early Miocene age; 2, basaltic volcanics and intrusives, in places with significant upper mantle minerals; 3, basement rocks with associated fossils that elucidate terrane origins; 4, landforms, related particularly to faulting, unconformities

(Fig. 3, below) and karsting; 5, economically important geological materials – mainly the Oamaru "whitestone", Ototara Limestone.

Fig. 3: Gently dipping top of St Mary's Range, south bank, Waitaki River, as seen from northeast near Homestead Stream, Hakataramea Valley. Elsewhere in the southern Canterbury Basin, a similar surface is unconformably overlain by Cretaceous-Cenozoic cover strata.

The broader Waitaki region has received attention from many notable geologists, starting with Mantell in the late 1840s (Mantell 1850), and then-Otago provincial geologist Hector in the early 1860s. Later, from the Geological Survey, Hector directed McKay's work in the region. The early 1900s saw a succession of locally based geologists active in the district: Park, Thomson, Uttley, Allan, Finlay, and Marwick – all originating from or based in Dunedin or Oamaru. All worked with Cenozoic (and sometimes Cretaceous) fossils and strata from the Waitaki region, and all were involved variously in early proposals of New Zealand stages (Bortonian, Tahuian, Duntroonian, Waitakian, Awamoan, Hutchinsonian). North Otago and nearby regions were thus important in early studies of New Zealand's Cretaceous-Cenozoic stratigraphy, biostratigraphy, and paleontology. Problems of local stratigraphy and correlation in the early days involved contentious debate about, for example, regional correlations of volcanics, limestones and greensands near Oamaru. Thus, Park (1918) and Uttley (1920) disagreed on the number and relationships of limestone formations.

By 1947, Finlay and Marwick had produced a workable chronostratigraphy (Fig. 2, opposite), with stages recognised by biostratigraphy. This allowed Gage (1957) to map much of North Otago and, with help of biostratigraphy by Hornibrook, to resolve the issues debated by Park, Uttley and others. Gage produced most of the stratigraphic names that are used today for the Waitaki region and beyond. He worked at a time when local formational names were still in common use for regionally widespread facies; some of his names can now be applied more-widely than in 1957 (e.g. Kokoamu Greensand, Otekaike Limestone), while others are synonyms of earlier-proposed names. Formational names proposed for South Canterbury by Gair (1959) and Riddolls (1968) have also mostly been synonymised. Amongst examples, Papakaio Formation and Pentland Formation = Taratu Formation; and Rifle Butts Formation, Waitoura Marl in part, Bluecliffs Silt, and Tokama Siltstone = Mount Harris Formation. Coombs et al. (1986) and Edwards (1991) clarified the nomenclature for volcanics and associated limestones of the Oamaru coast.

Reports on the Canterbury Basin (Field and Browne 1986, 1989) usefully place the Waitaki rocks in a broader setting. Beyond the maps of Gage, see also Mutch (1964) and Forsyth (2002).

THE COVER SEQUENCE

In North Otago and South Canterbury, the cover strata span mainly late Cretaceous to early Miocene, and Quaternary. The Paleogene units are typically thin, and may be condensed, with terrigenous-rich rocks passing up into bioclastic limestones and greensands of Oligocene age. The field trip area has only a few Neogene formations other than Quaternary, but as further north in the Canterbury Basin, Neogene strata are much thicker and reflect substantial sediment input.

It is useful to think of the cover sequence as having 3 phases: 1, broadly transgressive, representing a Cretaceous-Paleogene passive margin; 2, quiescent, with thin terrigenous-poor Oligocene limestone and greensands representing peak submergence; 3, a rapid regressive Neogene, with substantial inputs of terrigenous material from sources uplifted on an increasingly active plate boundary.

Wellman (1953) produced an inspired clear summary of this pattern showing broad patterns for the Cenozoic of the southern Canterbury basin. The vertical axis is time, not rock thickness (and the Hutchinsonian and Awamoan Stages - Ph, Pa - are no longer used).

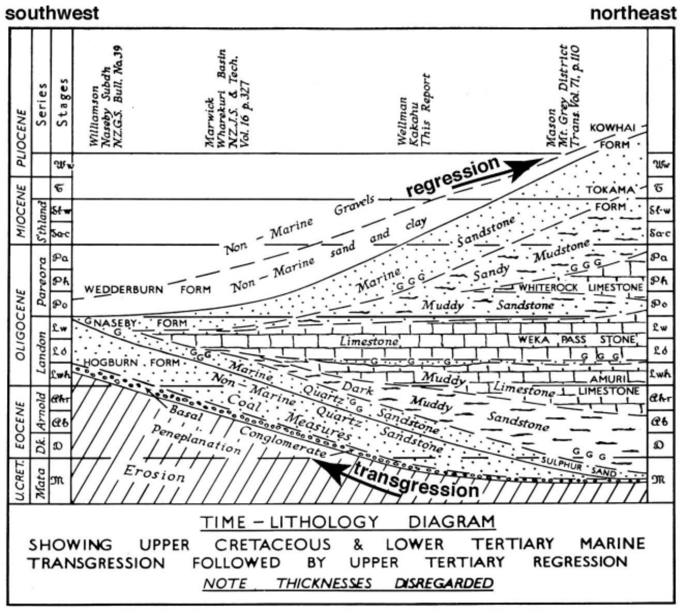
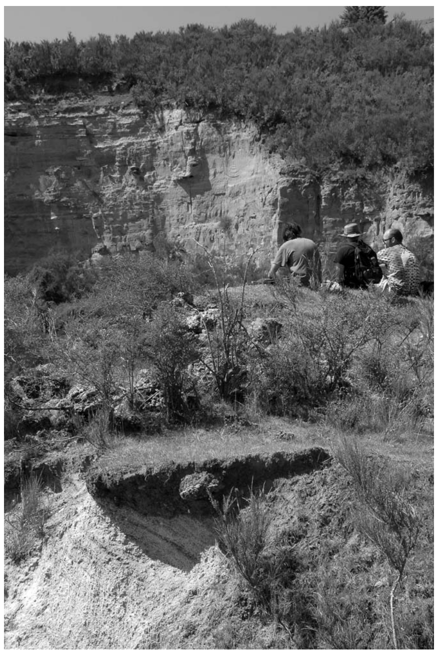


Fig. 4: above, Wellman's 1953 cross section of transgression/regression in the southern Canterbury basin.

Fig. 5, below: Livingstone gold sluicings, showing dipping Taratu Formation, lower left, and overlying subhorizontal Tapui Formation beyond the people.

In the Waitaki region, the basement of either Otago Schist or Torlesse rocks is everywhere overlain unconformably by the cover strata, most of which were deposited in a passive-margin setting. The basal cover rocks are commonly nonmarine, particularly quartz-dominated conglomerates and sometimes coal measures of the Taratu Formation, or clay-dominated Broken River Formation; the coal measures are late Cretaceous to ?middle Eocene (Haumurian- ?Bortonian). In places, there may be some m of kaolinitic claystone above basement rocks. Elsewhere, shallow marine Kauru Formation (Paleocene – Wangaloan and younger) and Tapui Formation (middle Eocene - Bortonian) mark the base of the cover rocks. Nonmarine Taratu strata, if present, are overlain by shallow marine sandstones of the Kauru and Tapui Formations.



The Kauru and Tapui formations both include strata with shallow-water fossils and/or sedimentary structures, and perhaps only one formational name could be used. The overlying strata, and lateral equivalents to the east, become terrigenous-poor, glauconitic, calcareous, and more massive, commonly with open water fossil assemblages indicating a deeper, or at least distal, marine origin. Thus, Waihao Greensand in South Canterbury is a deep water lateral equivalent of Tapui Formation; intriguingly, in places the Waihao Greensand just above an unconformity with basement includes the large foraminiferan *Asterocyclina* (see Riddolls 1966), an indicator of warm shallow conditions. The patchily exposed Burnside Mudstone/Hampden Formation, better exposed in South Canterbury than in much of North Otago, has been interpreted as marking outer shelf to upper bathyal settings.

From Oamaru to Kakanui and beyond, and inland to Weston-Enfield, the basaltic Deborah-Waiareka volcanics and associated bryozoan-bioclastic Ototara Limestone are significant (Eo-Oligocene, Kaiatan-Runangan-Whaingaroan). Further west, the basaltic rocks occur as the Tokarahi Sill (middle Eocene – Bortonian), while the Earthquakes Marl (lower Whaingaroan) is laterally equivalent to the Ototara Limestone of coastal localities. In South Canterbury, the basaltic Kapua Tuff (Riddolls 1968) lies within the Burnside Mudstone (Kaiatan-Runangan, late Eocene).

Widely across the field trip area, the Earthquakes Marl is truncated by a “mid” Oligocene unconformity (the Marshall unconformity; see figure showing N de B Hornibrook at a representative outcrop) which is followed by variably-developed Kokoamu Greensand (sometimes upper Whaingaroan in base, to Duntroonian), and resistant Otekaike Limestone (Duntroonian-Waitakian). Whereas the massive, foraminiferal-rich Earthquakes Marl and Amuri Limestone reflect deep waters, the overlying Kokoamu Greensand (bedded and macrofossil-rich in places) and Otekaike Limestone mark shallower settings, probably of mid-shelf depths below storm wave base. Otekaike Limestone produces prominent landforms in the Awamoko-Maerewhenua area and the Waihao Valley, but in North Otago both the Limestone and underlying Greensand thin eastwards, and are thin or absent from modern coastal localities near Oamaru.

Fig. 6. Micropaleontologist N de B Hornibrook at the contact of Kokamu Greensand (above) with Earthquakes Marl (below); eastern end of Kokoamu Cliffs.

Commonly, inland outcrops of Otekaike Limestone are capped by loess and other Quaternary sediments, but the Limestone may grade conformably up into basal Mount Harris Formation (Waitakian, Otaian and Altonian – mainly Early Miocene); the Mount Harris – Tokama Siltstone of Field and Browne (1989) is significant north of the Waitaki, for example, at Mt Harris, Elephant Hill Stream, and Bluecliffs (below). Occasionally, the Otekaike is truncated by an unconformity, and overlain by Gee Greensand and in turn Mount Harris Formation; such contacts are seen at the modern coast, and at a few inland localities including Brothers Stream, Hakataramea Valley. Mount Harris strata are often succeeded by shallow-water strata of the Southburn Sand.

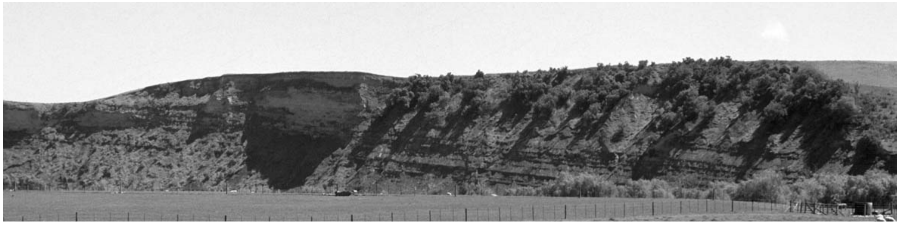


Fig. 7: Bluecliffs Silt (= Mount Harris Formation), type locality of Otaian Stage (Early Miocene), Bluecliffs section, Otaio River.

Within the limits of the field trip, no younger marine rocks are seen immediately over the Southburn Sand Formation; rather, coal measures are often overlying, and there is little marine record until the Quaternary. The exception is the marine base to the Kowai Formation, as seen at Makikihi, where a shallow-water Nukumaruan (latest Pliocene) asssemblage is reported.

DAY 1 ITINERARY

Travel from **Dunedin** to Maheno, northwards.
En route, note:

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 **Otago 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.

To the north of Shag Point is Katiki Beach, with a sequence of marine **Katiki Formation** (with belemnites, mosasaurs and plesiosaurs) and **Otepopo Greensand** (both Late Cretaceous). Katiki Formation overlies coal measures of the nonmarine to paralic **Taratu Formation**, seen later on this field trip. The north end of Katiki Beach is formed by Moeraki peninsula, with basaltic volcanics, and associated sedimentary rocks. Moeraki is the locality for the famous Moeraki Boulders, concretions derived from the distal marine mudstones of the **Moeraki Formation**. Alas, we have no time to visit these or to view north along the coast to the **Hampden Formation** (Bortonian reference section) and beyond. At Waianakarua, the skyline east of the road is dominated by the **Mt Charles Sill** (Eocene); to the left/ west, there may be a glimpse of the **Otepopo Greensand** (Cretaceous).

At Maheno, where shallow marine **Ototara Limestone** (latest Eocene) forms a distant skyline beyond the Kakanui River, we turn west toward Duntroon and initially travel on the floodplain of the Kakanui River. Kauru Hill – with a volcanic cap - will lie on our left as we approach Five Forks. The Kakanui River exits a gorge in the **Otago Schist**, which can be seen in roadside outcrops including some that show the unconformable contact with overlying **Taratu Formation** (Fig. 8).

Fig. 8. Unconformable contact of highly altered Otago Schist, below, with quartz pebble conglomerate of Taratu Formation, Five Forks-Tapui-Tokarahi Road, near Raki's Table.

To the north/right is Raki's Table, with a flat top formed by a thin resistant cap of **Otekaike Limestone**; the latter become progressively more significant in land-forms toward Duntroon. Roadside outcrops of brown **Tapui Formation** (Eocene) occur towards Awamoko Valley, where we will see prominent scarps of **Otekaike Limestone**. The basaltic **Tokarahi Sill** (Eocene) is visible between Tokarahi and Dansey's Pass road, and thick outcrops of Otekaike Limestone form cliffs on the north side (left) of the Maerewhenua River close to Duntroon.

VANISHED WORLD CENTRE, DUNTROON

The Vanished World Trail comprises a self-guided 80 km tour around some 20 geological sites in North Otago, on the coast from Waianakarua (south) to Oamaru (north), and inland to Duntroon in the Waitaki Valley. Sites are on public and private land; access to sites is free, but conditions may be imposed by some landowners. Some sites are close to or on roads, but others require a short walk. The trail is a community initiative developed by locals since 2000, in partnership with the University of Otago, to foster conservation, education and scientific study. The concept of Vanished World arose from local interest in, particularly, research on fossils from the district, but aims to take geology in the broadest sense to the public.

The **Vanished World Trail** sites - key outcrops, fossil localities, and landforms - are signposted, and most have explanatory plaques. A trail map, outcrop photographs and details of particular sites are given in the **Vanished World trail brochure –** an A3 folded colour document (Fordyce 2002) which is sold to raise funds to maintain the Trail and Centre. Copies of the brochure will be provided to field trip participants. Two sites show prepared fossil whales in the rock. There are large information boards with maps at key points on the trail, but the Trail Brochure provides the best guide to localities.

The **Vanished World Centre** in Duntroon (Fig. 9, right) contains a free-to-public foyer and sales area, and pay-to-view displays to complement the Trail; we will visit the latter as part of the trip. The displays mainly comprise fossils and other specimens loaned from the Geology Museum, University of Otago, with some items added by interested volunteers. While the Centre emphasises fossils, there is scope to expand to include more on significant rocks, minerals and landforms. Some subjects are covered on large graphics panels (by Ewan Fordyce and Martin Fisher), for example, on geological time, geological maps, the Ototara Limestone, and the penguin *Platydptes*. Also displayed are some original artworks by Chris Gaskin, showing reconstructions of ancient New Zealand organisms; these are on loan from the Geology Museum, University of Otago.

Display specimens, which are from the district, include original specimens and casts of fossil whales, dolphins, penguins, sharks. The replicas were produced by Andrew Grebneff, Rick Morcom, and Ewan Fordyce, using polyester resin and silicone moulds. Diverse invertebrates on display include well-preserved assemblages in blocks cut from the Otekaike Limestone, and prepared by students at University of Otago as part of a paleoecology exercise. A small room allows visiting school groups to work to uncover fossils in blocks of Otekaike Limestone cut from a local quarry. This is a popular activity for children.

Fig. 10, left: replica of *Squalodon*-like shark-toothed dolphin skull, Vanished World Centre.

Information on the Trail and Centre is also on the web. An earlier Geological Society field guide, produced for geologists rather than lay visitors, reviewed the development and promotion of the Trail and Vanished World Centre (Fordyce 2003). Since their opening, the Vanished World Trail and Centre have attracted many New Zealand and international visitors. The Trail and Centre are run by Vanished World **Incorporated**: a society for policy and administration, including fundraising and logistics (site and trail maintenance). A complementary group, **Friends** of Vanished World, provides support through membership subscriptions.

The route from **Duntroon** to **Kurow** affords views of fault-bounded basement blocks on the distant north bank of the Waitaki. The Takiroa Maori rock art site is developed at an overhang of Otekaike Limestone, a few km beyond which schist basement forms roadside outcrops. After Otekaike River, the "**Trig Z**" outcrop of Otekaike Limestone appears to the left, south; this is the type-locality for the Waitakian Stage.

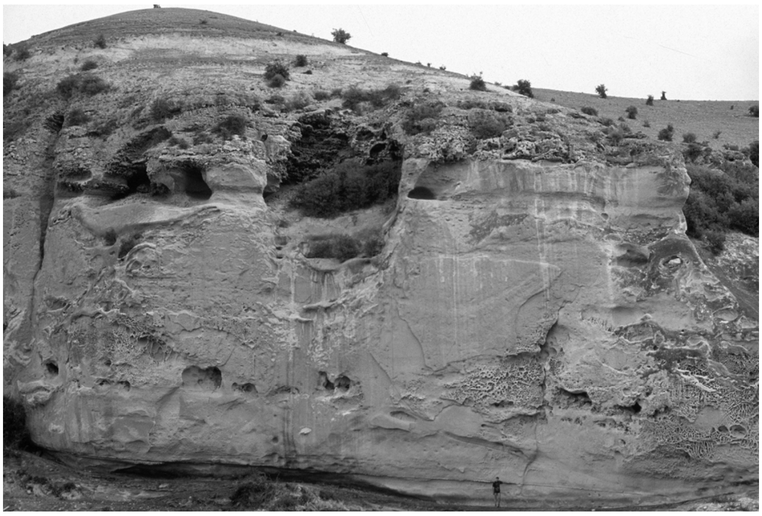
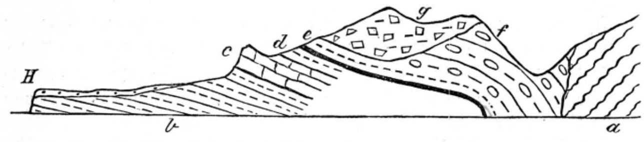


Fig. 11: Trig Z, Otiake. Most of the outcrop comprises massive Maerewhenua Member, Otekaike Limestone. The upper, honeycombed strata with low-angle crossbeds, represent the Miller Member, at the base of which is a prominent shellbed. The person at the base of the outcrop, slighlty right of middle, is close to the base of the Waitakian Stage.

Kurow – brief stop.

Travel from Kurow westwards up the Waitaki Valley to head of **Lake Waitaki** near **Aviemore Dam**. Note fault-bounded blocks.

WHAREKURI CREEK



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.

Fig. 12: Section of Wharekuri Creek, from McKay 1882. Surprisingly, McKay did not recognise the thrust shown below in Fig. 13.

Wharekuri Creek preserves the most inland substantial occurrence of Cenozoic marine strata in the Waitaki Valley. The locality was visited at least twice by Alexander McKay in his earlier years (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 Wharekuri Greensand (Whaingaroan) - one of the earliest named units in the Waitaki Valley, but 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 gorse, and access beyond the Wharekuri Greensand is slow going. ***Hazard warning: the steep-sided creek walls are capped by loose alluvium which regularly collapse.*** Where the creek steepens near the range front, there is an excellent exposure of basement semischist thrust over late Cenozoic gravels (alas, we won't have time to visit this top part of the sequence).

Fig. 13. Range front fault, Wharekuri Creek; Basement semischist, upper left, is thrust over conglomerate of the ?Kurow Group, lower right. View faces northwest; creek flows left to right.

The creek bed close to 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, but sparse; of note are 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 here. To the east, equivalent strata are the deep marine **Earthquakes Marl**, sometimes with a basal Nessing Greensand. Upstream, the Wharekuri Greensand passes up into a few m of what is interpreted as Earthquakes Marl. 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.

Fig. 14: Section in east bank, Wharekuri Creek about 100 m upstream of old 1800s bridge site; from the base, Wharekuri Greensand, ~3 m, overlain by ~1 m of Earthquakes Marl; truncated by a burrowed unconformity; in turn overlain by 1.3 m of Kokoamu Greensand and Quaternary gravels. Thicknesses here are distorted by wide-angle view from below.

The top of the Wharekuri Greensand/Earthquakes Marl is truncated by the presumed **Marshall Unconformity** (Disconformity) which is better seen elsewhere, for example, at Squires Farm. **Kokoamu Greensand** (upper Whaingaroan-Duntroonian, late Oligocene) overlies the unconformity; in the poorly-exposed base, macrofossils are rare, but they become more common up-section, and in places form diffuse shellbeds – in 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.

Otekaike Limestone is present, but not seen in contact with the Kokoamu; it occurs as an isolated outcrop well above and east of creek level. **Gee Greensand** has been reported (by McKay and others) as overlying Otekaike Limestone near Wharekuri, but is not seen in the creek. Rather, the Kokoamu Greensand is faulted against jarositic sandstone of the **Southburn Sand**, here undated but presumably Otaian-Altonian, early Miocene. The sands coarsen upwards into quartz granule conglomerate with well developed bidirectional crossbeds, consistent with a shoreface setting. The marine sequence is overlain, with uncertain contact, by carbonaceous mudstone with plant remains, sandstone (in places with coaly and sometimes silicified logs), green clays, and freshwater limestone.

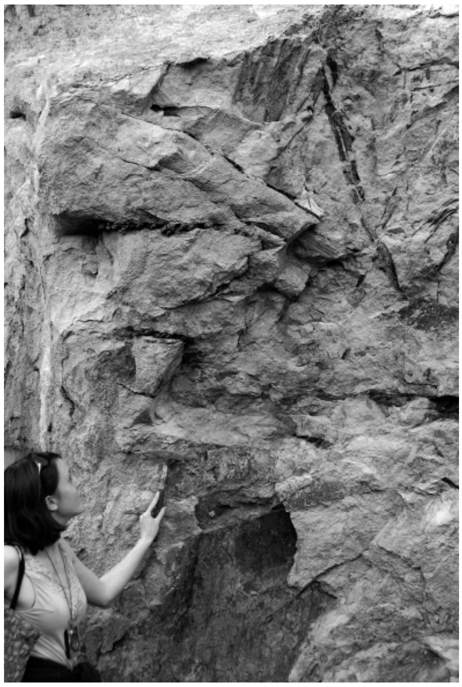


Fig. 15: Section in east bank, Wharekuri Creek: logs and stems in a vertical bed base of carbonaceous sandstone, Waitangi Coal Measures/ Manuherikia Group.

Quartz-dominated gravels further up-section (upstream) are probably part of the same section. The sequence includes, or comprises, the **Waitangi Coal Measures** (?early Miocene). A landowner reports that coal from nearby was mined for local use in the 1930s. More broadly, these strata are presumed equivalent to the **Manuherikia Group**, well documented from Central Otago localities 40-50 km to the southwest. **Kurow Group** conglomerate (of uncertain later Neogene age) contains abundant clasts of semischists and Torlesse rocks, which differentiate it from the underlying quartz-dominated conglomerates

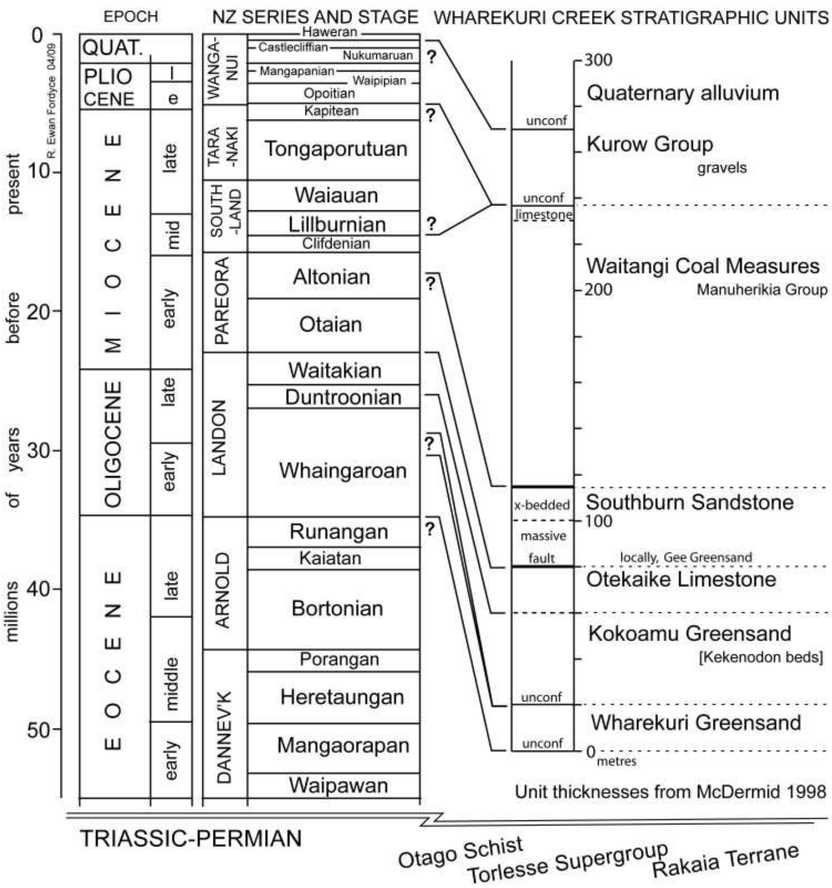


Fig. 16: Stratigraphy of Wharekuri Creek. Unit thicknesses are from McDermid (1998).

Travel northwest via **Otematata**, with Benmore Dam on the right. Torlesse basement rocks are exposed in the river bed below the dam (Retallack 1983), and the Akatarawa miniterrane sequence, with late Permian fusulinid limestones occurs a little downstream (Hada & Landis 1995). Turn south at Otamatapaio River; drive 5 km to Backyards Station.

CORBIES CREEK-BACKYARDS, OTEMATATA STATION

Torlesse rocks on the south side of the Waitaki Valley from Awakino (near Kurow) to Otematata region include noted localities for middle Triassic invertebrates and plants from the Kaihikuan Stage (Gair et al 1962, Campbell & Warren 1965). Retallack & Ryburn (1982) documented of 9 sedimentary formations spanning 1200 m in an area east of Backyards Station. The rocks, now metamorphosed to prehnite-pumpellyite grade, were inferred to represent settings including shallow marine, bar, shoreface, lagoon, delta and flat coastal plain.

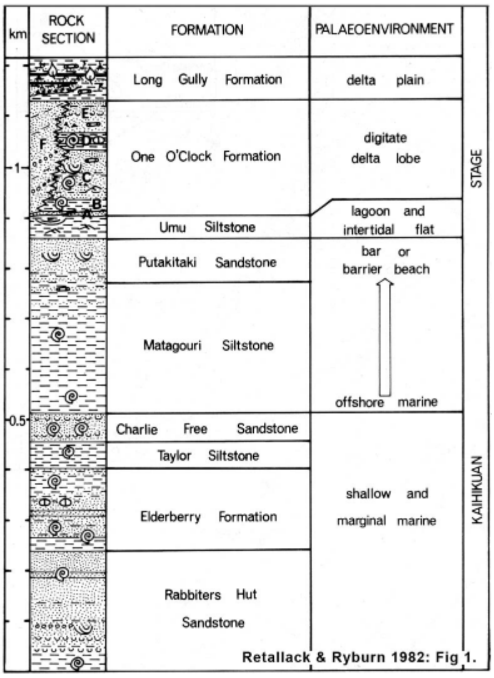
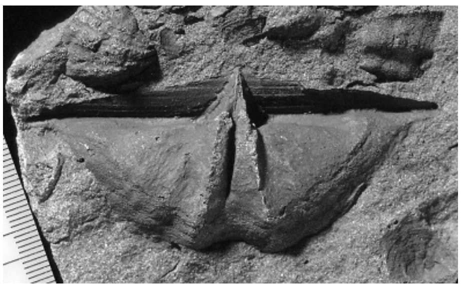


Fig. 17: Stratigraphy of the Kaihikuan sequence, Backyards Station, from Retallack & Ryburn (1982).

In the Backyards-Corbies Creek area, assemblages are diverse and, for Torlesse Triassic, well preserved. Key age indicators are the brachiopod *Alipunctifera kaihikuana* and the bivalve *Daonella* sp., but other brachiopods (lingulids, rhynchonellids, terebratulids), bivalves (including trigoniids, documented by Fleming 1987), gastropods, and crinoid remains occur. The fossils are generally decalcified, but otherwise may preserve fine details. Campbell & Warren (1965) noted that assemblages are comparable in diversity to those of Murihiku sequences.

Fig. 18: Right, Fossiliferous Kaihikuan strata, Backyards Station.

Fig. 19: Below, Age-diagnostic Kaihikuan brachiopod, *Alipunctifera kaihikuana*, from Backyards Station.

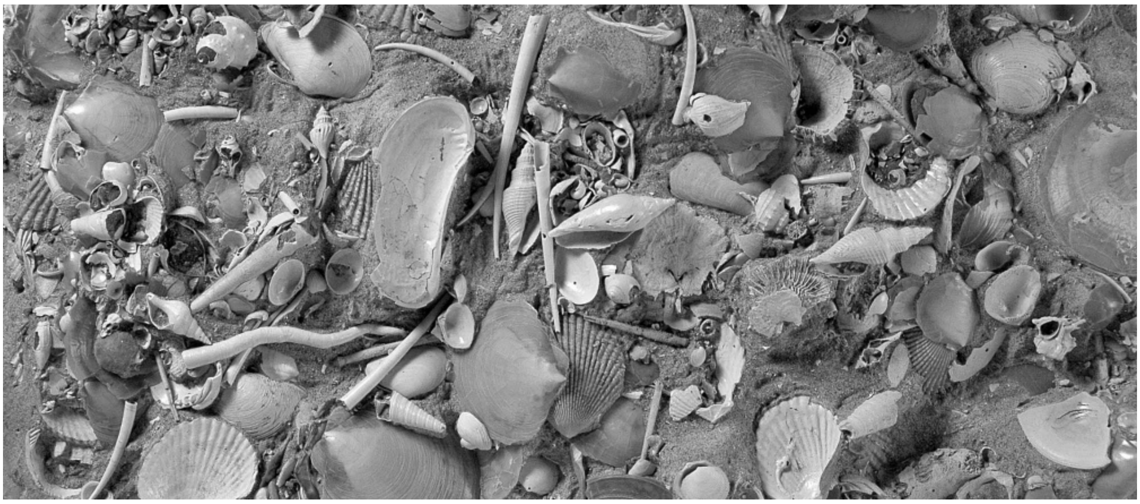


Route returns to **Kurow**, to cross the Waitaki River into South Canterbury, thence into **Hakataramea Valley**. Cross Hakataramea River, and take Meyers Pass Road.

HAKATARAMEA VALLEY

Kokoamu Greensand and **Otekaike Limestone** occur at the informally-named "Haughs' Quarry," also known as Hurstlea or Hakataramea Quarry, in Hakataramea Valley en route to Waimate. This quarry is one of New Zealand's single most prolific localities for fossil vertebrates (whales, dolphins, and penguins), under study here since 1987; group members are asked not to damage any bones found. The quarry is further significant for the exceptional macroinvertebrate assemblage at the top of the sequence.

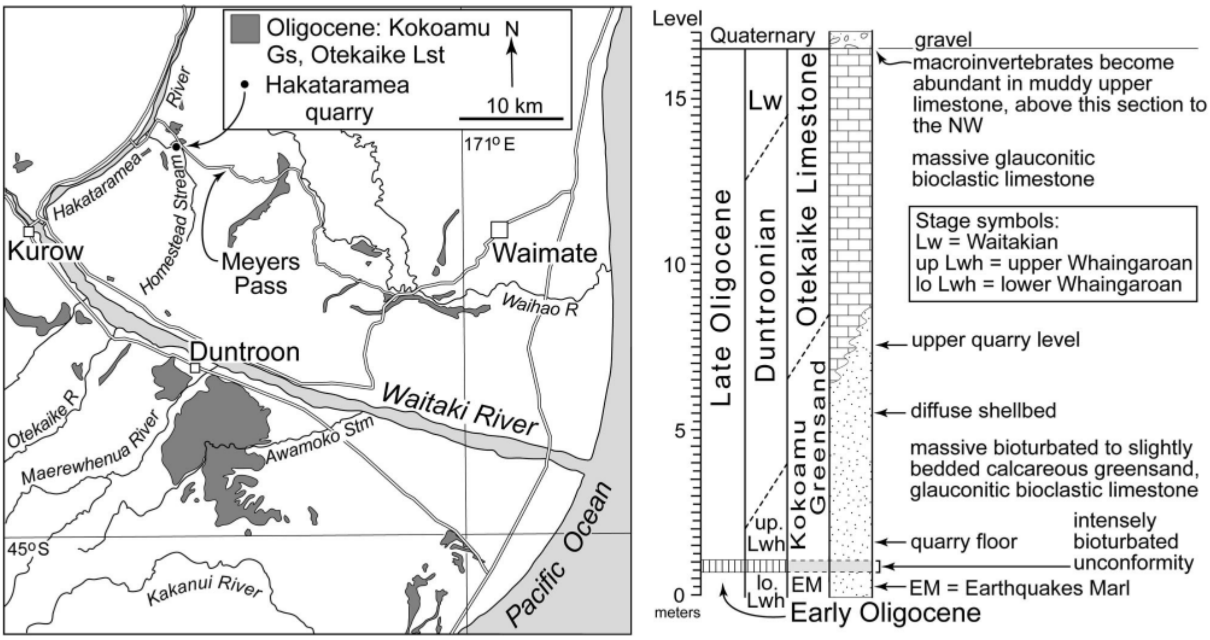
Fig. 20: Below, mollusc-dominated assemblage from muddy top of the Otekaike Limestone (Waitakian stage, latest Oligocene), Hakataramea Valley. Prepared blocks are displayed at the Vanished World Centre and at the Geology Museum, University of Otago.



The strata are part of a thin sequence which starts to the south in Homestead Stream with basal coal measures (**Taratu Formation**), and passes up through shallow marine sands of the **Kauru Formation** (early Eocene?), indifferently exposed **Waihao Greensand** (Bortonian), **Burnside Mudstone** (?Kaiatan), and **Earthquakes Marl** (early Whaingaroan).

The top of the sequence at Haughs' Quarry marks the gradational from Otekaike Limestone into mudstone of the **Mount Harris Formation**. Nearby (Brothers Stream), this contact is unconformable, with **Gee Greensand** present. **Southburn Sand** (Otaian or younger) forms a nonmarine top to the sequence. Mapping here as part of Otago's 200-level field class suggests that most units are locally quite variable in thickness, perhaps indicating local paleotopography.

Fig. 21: Below, locality map, guide to distribution of Otekaike Limestone and Kokoamu Greensand, and column for the Kokoamu Greensand and most of the Otekaike Limestone at Haughs' Quarry. From Gottfried, Fordyce and Rust, submitted.



To detail the quarry section, the basal Kokoamu Greensand is a massive bioturbated calcarenite, without macrofossils; the latter become apparent (*Lentipecten*, scattered bones) as bioturbation reduces; at the level of a diffuse brachipod-rich shellbed, the unit is indistinctly dm-bedded to massive. The underlying Earthquakes Marl can be seen only by trenching; it is a richly glauconitic calcareous mudstone. At the level of the working quarry, Kokoamu Greensand passes up into massive, bioturbated, slightly cemented, glauconitic, bioclastic very fine sand-calcarenite, the Maerewhenua Member of Gage (1957). Lower in the limestone there are sporadic para-autochthonous macroinvertebrates. A rich assemblage of macroinvertebrates (>200 species), as in Fig. 20, has been collected by University of Otago geology groups from the diffuse *Protula* shellbed in the muddy top of the limestone. Limestone was deposited remote from terrigenous inputs, in sheltered water below normal storm wave base – probably mid shelf, >75 m.

From **Hakataramea Valley**, take **Meyers Pass road** to cross into the Waihao Valley. Basement strata – **Torlesse** pelagic mudstone of phrenite-pumpellyite facies - at the top of Meyers Pass have yielded early Permian conodonts (Ford et al. 1999; Coombs et al. 1996). Views to the west show the eroded unconformable top on basement rocks dipping gently toward Hakataramea River; ridges beyond include the smooth crest of St Marys Range (see Fig. 3).

WAIHAO FORKS

Immediately south of **Waihao Forks** is a spectacular 500 m outcrop of cross-bedded **Otekaike Limestone** (Duntroonian-Waitakian, Late Oligocene).

Fig. 22: Scoured and cross-bedded Otekaike Limestone, Waihao Forks.

Fig. 23: Right, detail of scoured and cross-bedded Otekaike Limestone, from middle right of the panorama above.

Ward & Lewis (1975) gave a detailed account of the sedimentology and inferred environment for the limestone, which they termed **Arno Limestone** (following Riddolls 1968). Cross-bedded bioclastic and glauconitic sediments form beds 2-3 m thick, with sharp bases succeeded by internal crossbeds dipping eastwards. The sharp bases for the larger sediment packets are gently concave, plausibly formed by southerly currents related to storm events. The crossbeds mark a persistent westerly source for the bioclastic glauconitic sediments. The strata are in places heavily bioturbated, particularly by spatangoid heart echinoderms which produce a distinctive *Scolicia* trace. A few 100 m eastwards, the sequence is seen to overlie a few m of Kokoamu Greensand, which in turn unconformably succeeds Burnside Mudstone.

Reportedly, it was Alexander McKay who first suggested that the Waihao River originally ran from about the modern Waihao Forks towards Waimate, flowing through the **Waimate Gorge** (which we will follow by road). Stream capture diverted the flow to the east along the present route, south of the Waimate Hills.

Night in Waimate.

DAY 2

Depart Waimate, travelling north but inland via **Hunter** and Backline Road to pass historic **Bluecliffs Station**, stopping at Otaio Gorge.

OTAIO GORGE

This account is slightly changed from that of Fordyce et al. (2009). Canterbury Basin strata are well exposed at Otaio Gorge, where uplifted basement (Torlesse) strata upstream of the road are faulted against Cenozoic strata for about a km downstream of the bridge. (The fault, not seen here, can be localised elsewhere.) A basal unconformity is inferred, but not exposed. In summary, the basal strata comprise shallow east-dipping coal measures, above which is a marine sequence that is important for Eocene paleontology and stratigraphy. Basal shallow marine strata (shellbeds, Early Eocene?) are followed by a fining upwards sequence of greensand, mudstone, and muddy limestone that are presumed to represent an increasingly deep setting. Dips continue to steepen to and above the Marshall unconformity (Oligocene), but outcrops stop before thickest marine unit in the district (Bluecliffs Silt, or Tokama Siltstone of Field and Browne, = Mount Harris Formation; Miocene). Riverbed exposures vary considerably from month to year, depending on flood activity.

The coal-measures of the **Broken River Formation** include massive kaolinitic clay-siltstone, quartz sandstones, and lignite beds. The lowest units are indistinctly graded white-brown-gray siltstones to very fine sandstones, with vertical carbonaceous rootlets indicative of paleosols; preserved rootlets imply an anoxic setting, perhaps water-saturated. The first major coal seam encountered has an upper surface riddled with a complex meshwork of burrows, possibly indicating crustacean (crab) activity in a marginal marine setting. Further up section (Fig. below) are cross-bedded sandstones, some bi-directional, climbing ripples, possible synsedimentary slumped sandstone blocks, and alternating planar to lenticular thin seams of lignite-carbonaceous mudstone.

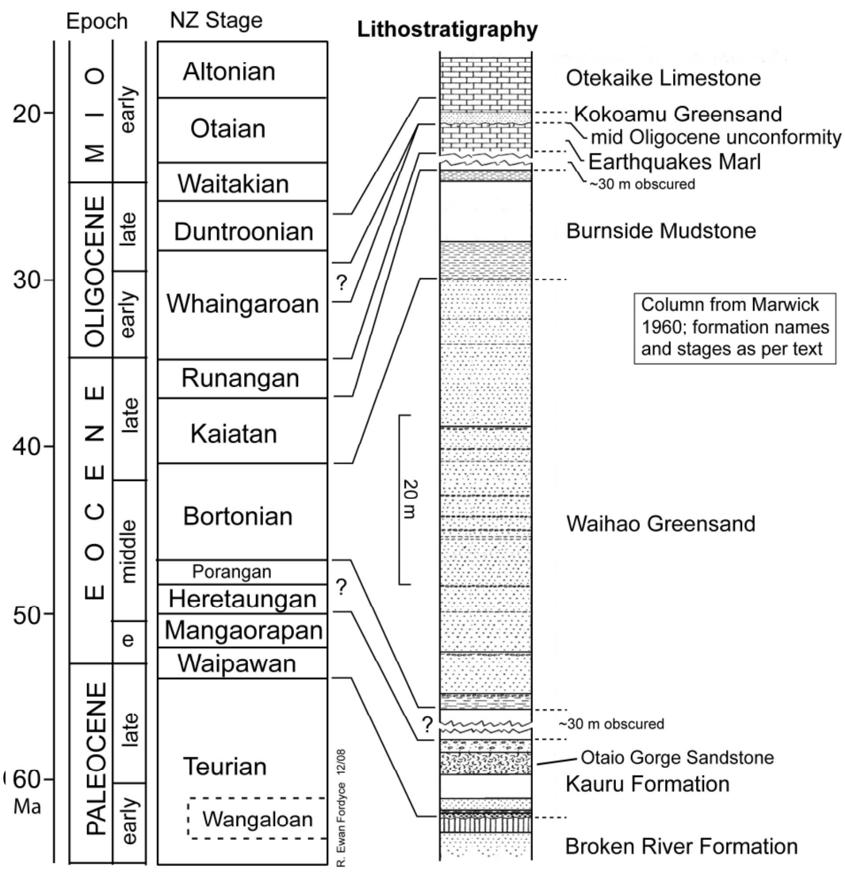
Fig. 24: Coal measures, Broken River Formation, Otaio Gorge. View faces north; river flows (and sequence youngs) left to right. Scale = 1 m.

The upper part of the Broken River Formation, exposed after a significant bend to the right as the valley opens further, comprises well-exposed alternating lignite and mudstone-quartz sandstone horizons, with sometimes-abundant roots in place. The top of the Broken River Formation is a burrowed unconformity; burrow diameters of >10 mm, depths of >100 mm, and varying orientations are consistent with a crustacean (probably crab) origin. Immediately overlying is brown siltstone and jarositic carbonaceous pebbly muddy sandstone/pebble conglomerate of the **Kauru Formation** (**Otaio Gorge Sandstone** of Gair 1959). After a short unexposed interval, the reknowned **Otaio Gorge shellbed** (of Marwick 1960 and others), within the Kauru Formation, is exposed in the river bed.

Fig. 25: Right, Otaio Gorge Shellbed section, formerly exposed in the 1980s, ~100 m to the northwest of the outcrop in the river; horizons of often-worn shells are associated with bi-directional cm-dm crossbedded sandstone.

The **Otaio Gorge shellbed** fauna is notable because, unusually, it contains well-preserved material that is older than local Bortonian Stage, later middle Eocene. Marwick (1960; source of column in Fig. 26) described the fauna, recording 33 species of bivalves and gastropods, of which 14 of were new. Of note are are species of *Cubitostrea, Eucrassatella, Glyptoactis, Hedecardium, Costacallista, Colposigma, "Colposigma", Perissodonta, Monalaria, Priscoficus, Pseudofax* and *Athleta* (list from Maxwell, in Fordyce et al. 1985). The late Phillip A. Maxwell, known for his deep insights into the Paleogene of the southern Canterbury Basin (Beu et al. 2007) considered the age relationships of the fauna (Maxwell 2003: 376), citing E. Crouch for a dinoflagellate age of Waipawan or Mangaorapan [early Eocene]. Thus, *Cubitostrea*, elsewhere regarded as reliably indicating an age no older than Lutetian, is clearly older here. The molluscan assemblage is thus temporally associated with the Paleocene/ Eocene Thermal Maximum, PETM. Maxwell was studying a diverse and roughly coeval molluscan fauna from nearby Pentland Hills at the time of his death.

Fig. 26: Litho- and chronostratigraphy, Otaio Gorge, interpreted on column from Marwick (1960). See Field & Brown (1989: J39, column 7) for a revised section.



For years, the relationship between the Kauru Formation and overlying units was not clear – as indicated in Marwick's column; Maxwell suspected an unconformity, but in early 2009 the well-exposed sequence showed the shellbed overlain by massive calcareous very fine sandstone-siltsone including *Atrina*, and consistent with a sheltered marine setting. (To the south, such lithology would be termed Kauru Formation.) The sequence becomes increasingly glauconitic, with some sharp-based beds, passing up into the Waihao Greensand. There is no clear evidence of an unconformable contact, in contrast to the Waihao Valley to the south, where Kauru is overlain unconformably by the Waihao Greensand. Maxwell (in Fordyce et al. 1985) noted substantial evidence from many localities on the east coast of the South Island for an important hiatus between Bortonian (or in some places, late Porangan) beds and underlying beds (typically Heretaungan), probably corresponding to a major sea-level fall (49.5 Ma). This part of the Otaio Gorge section warrants careful dating.

Waihao Greensand here comprises massive to indistinctly dm-bedded and, in places, concretionary, muddy calcareous greensand. Bortonian [later middle Eocene] molluscs occur about 50 m above the Kauru Formation; e.g. *Cubitostrea*, *Duplipecten*, the struthiolariid *Monalaria*, and turritellids. Other fossils of note include corals (*Balanophyllia*), a spiny lobster (*Linuparus*) and ray teeth (*Myliobatis*). The contact is not clear with the overlying **Burnside Formation** - grey, soft, massive, glauconitic, micaceous calcareous mudstone with occasional molluscs and a rich foraminiferal microfauna including Kaiatan stage (late Eocene). To the south, in Waihao Valley, the top of the Waihao Greensand is marked by an intensely bioturbated concretionary phosphatic greensand up to 1 m thick, which probably represents an unconformity – perhaps the Pr-1 sequence boundary at or near the top of the Bortonian. A distal marine setting for the Burnside, probably bathyal, is indicated by fossils. Contact details with the overlying **Earthquakes Marl** are uncertain; elsewhere in southern Canterbury Basin – for example in the Waihao Valley to the south – the contact is marked by an unconformity overlain by Nessing Greensand. The Earthquakes Marl is a muddy lateral equivalent of the Amuri Limestone. In the Otaio Gorge region, there is considerable facies change and only a few km to the north near Squires Farm the unit is a white moderately cemented limestone reminiscent of Amuri lithologies more-northern sites in the Canterbury Basin. Less-cemented facies yield rich foraminiferal faunas of the *Subbotina angiporoides* zone, lower Whaingaroan stage.

Kokoamu Greensand – a calcareous massive to dm-bedded greensand - is variably exposed, depending on the state of the river. The contact with the Earthquakes Marl is a deeply burrowed unconformity (see “Squires Farm,” below), overlain by intensively burrowed greensand. Kokoamu Greensand is overlain apparently conformably by cemented dm-bedded bioclastic **Otekaike Limestone**; note the increasingly steep dips of the upper part of the Otaio Gorge sequence. Contacts between the Kokoamu Greensand and Otekaike Limestone may be quite variable on a local scale: gradational over some m, or abrupt and unconformable.

From Otaio Gorge, travel <2 km northwest to **Silverstream**.

SQUIRES’ FARM

Silverstream Farm, long known as “Squires’ Farm”, is the type locality for the so-called Marshall Paraconformity of Carter and Landis (1972), namely the unconformity between the lower Earthquakes Marl/Amuri Limestone (lower ~1 m in the figure), and overlying Kokoamu Greensand (here thinner than at most other localities in southern Canterbury Basin).

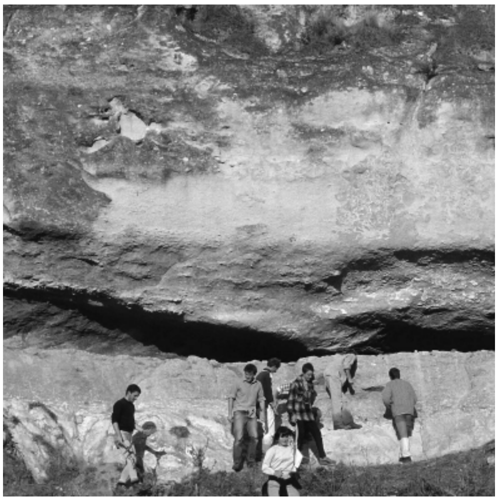


Fig. 27: “Squires’ Farm” outcrop, showing basal light-coloured Earthquakes Marl, unconformably overlain by Kokoamu Greesand and Otekaike Limestone.

The sequence is as follows (slightly modified from Hornibrook, in Fordyce et al. 1985):

30m Otekaike Limestone (Duntroonian-Waitakian, Late Oligocene-earliest Miocene). Hard nodular crystalline glauconitic limestone. The Waitakian index foraminiferan *Globoquadrina dehiscens* occurs in upper 12m. Grades down into:

4.5m Kokoamu Greensand (?Upper Whaingaroan-Duntroonian, Late Oligocene). Middle portion has about 0.7m uncemented pure crossbedded greensand; the mottled and muddy basal massive portion is extensely bioturbated, with chunks of the underlying marl in the basal 0.5 m. Fossils include the distinctive Duntroonian and younger benthic foraminiferan *Notorotalia spinosa*, occasional brachiopods (*Aetheia*), *Lentipecten*, and cetacean bones. Extensively burrowed Marshall Disconformity at base.

5m Earthquakes Marl (lower Whaingaroan, Early Oligocene). Bioturbated glauconitic white calcareous mudstone/ muddy limestone with rare macrofossils. Notable foraminifera are *Globigerina angiporoides* and *Notorotalia stachei*.

Carter and Landis (1972) suggested the name "Marshall Paraconformity" for this "extensive Oligocene unconformity...widespread in shallow marine sequences throughout southern Australia and New Zealand". They interpreted it as a submarine erosion feature caused by high velocity currents associated with Southern Ocean circulation. Carter and Landis (1982) later defined the Marshall Paraconformity formally as "the burrowed contact between the Squires Greensand and the Holme Station Limestone at the Squires Farm section..." At the type outcrop, we will see that the contact is not a paraconformity, but is a disconformity in the sense of Dunbar and Rogers (1957: Fig 57): an unconformity involving two parallel stratified rocks with a clear unconformable contact. Intriguingly, a few 100s of m to the north/northeast, the surface becomes an angular unconformity. Depositional complexity is further indicated by a planar top above the most basal 1.5 m of greensand, followed by ~ 1 m of prominently cross-bedded greensand. This “mid Oligocene” unconformity has been discussed widely (see e.g. Lewis and Bellis 1984, Maxwell in Beu and Maxwell 1990, Lever 2007) without clear consensus.
From Squires Farm-Otaio Gorge, return south on **Backline Road** towards Hunter, turning east towards **Makikihi**.

MAKIKIHI

Thick sands, gravels and sometimes muds in the Waihao to Makikihi districts, and inland toward the Hunters Hills, represent the Kowai Formation, a unit first recognised in North Canterbury. Strata are usually weathered, and may reach 180 m thick. Feldmann et al. (2008) reported on the sequence on the bank of Makikihi stream.

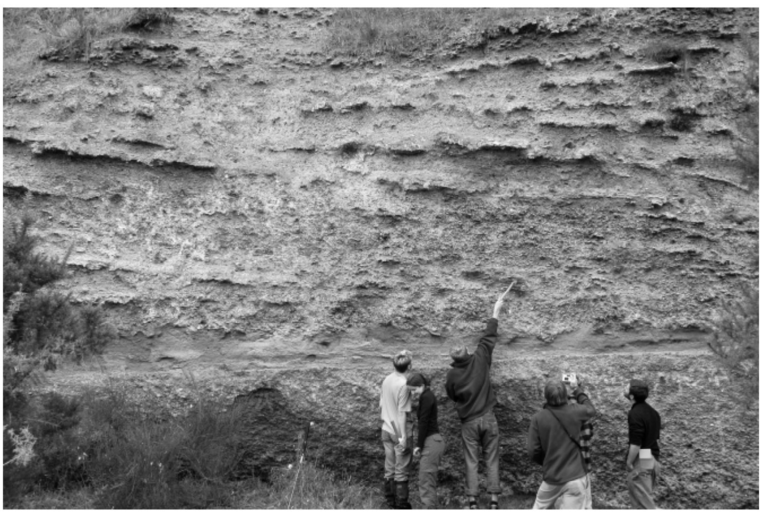


Fig. 28: Base of Kowai Formation at Makikihi Stream. People are at the level of a prominent fossil horizon discussed by Feldmann et al. 2008.

Here, the base of the sequence contains marine invertebrates including molluscs (*Ostrea, Crassostrea, Anomia, Stiracolpus, Trochus*) barnacles, an isopod, and crustaceans (Feldmann et al. 2008).

The molluscs indicate a Nukumaruan age, latest Pliocene. The arthropods occur in small nodules, whereas the molluscs also occur individually within the sediment. Some tens of m up section, cetacean bones were recovered from pebbly coarse sands. Feldmann et al. identified the paleoenvironment as a shallow water, active marine setting, supplied by Torlesse clasts probably originating from the uplifting Hunters Hills. Older literature referred to the strata as Elephant Hill and Cannington Gravels (e.g. Gair 1959).

Elsewhere, Kowai Formation crops out sporadically in the low hills west of SH1 near Morven, and in bluffs at Elephant Hill Stream and along the lower reaches of the Waihao River; strata are reported subsurface from boreholes near Waimate.

Travel south via Highway 1, thence to Waimate, Waimate Gorge, Waihao Forks, and Elephant Hill Stream.

ELEPHANT HILL STREAM

The aim here is to note the remarkable thickness, about 650 m, of the Mount Harris Formation, based on interpretation of Field and Browne (1989, column J40 c14). Field and Browne reported a succession from base to top comprising, in their terminology: Broken River Formation, Waihao Greensand, Tokama Siltstone, Southburn Sand, and Kowai Formation. Field mapping classes from University of Otago, and independent student project work by G. McMurtrie and Z. Boyd, have shown that the sequence beneath the Tokama Siltstone (the latter = Mount Harris Formation of this guide) includes other units disrupted by faults. For example, marine strata above the Broken River coals include lithologies more typical of Kauru Formation than of Waihao Greensand, while a calcareous mudstone facies identified as Burnside Mudstone overlies the Waihao Greensand. A thin horizon of relatively pure greensand with sparse foraminifera, presumed to be Kokoamu Greensand, unconformably overlies Burnside Mudstone.

Field and Browne (1989: column J40 c14) report microfossil dates for Mount Harris strata as Waitakian to Otaian, with the Otaian-Altonian boundary in the overlying Southburn Sand. Thus, 650 m of silts accumulated in perhaps 3 M years. This major increase in sedimentation presumably marks the development of new terrigenous sources related to plate boundary activity.

From Elephant Hill Stream, travel to **Glenavy**, thence on Highway 1 to **Oamaru**.

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