Geological Society of New Zealand Inc 2003 Annual Conference

1 - 4 December
University of Otago
Dunedin

Field Trip Guides

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Geological Society of New Zealand Miscellaneous Publication 116B
ISBN 0-908678-97-5

GEOLOGICAL SOCIETY OF NEW ZEALAND
ANNUAL CONFERENCE 2003
FIELD TRIP 8

CANTERBURY BASIN PALEONTOLOGY AND STRATIGRAPHY

Ewan Fordyce and Phillip Maxwell

INTRODUCTION

North Otago and South Canterbury preserve important marine and terrestrial fossiliferous sequences deposited in the southern part of the Canterbury basin in the Late Cretaceous and Cenozoic. On this field trip we will see some of these sequences as we travel north from Dunedin along the east Otago Coast and inland into the district around the Waitaki Valley. We will visit localities south of Oamaru, in the Waihao and Hakataramea Valleys, possibly upper Waitaki Valley, and near Duntroon.

The route and localities are shown in 2 maps (Figure 1), and there is a simplified summary of Cretaceous-Cenozoic stratigraphy (Figure 2). The trip will emphasise fossiliferous rocks. Several past field trip guides deal also deal with this theme (e.g. Hornibrook 1982, Fordyce et al. 1985) and there is extensive published literature cited below.

Localities include sites for Late Cretaceous-Early Miocene fossils including land plants, marine invertebrates and microfossils, and vertebrates. We will see significant unconformities and stage stratotypes. It should be possible to collect micropal samples, plants and invertebrates. The trip will visit the Vanished World Centre in Duntroon; registration includes centre entry and brochure (see also one-day field trips.) Emphasis is on Canterbury Basin fossils and strata, but we will look at Torlesse basement rocks if time permits.

ITINERARY

SATURDAY. Travel from Dunedin to Oamaru via coastal localities, to spend the night in Oamaru. Localities to be visited will depend on weather and group preferences, and will be chosen from amongst following:

Stop: **Shag Point** – Cretaceous sequence nonmarine to shallow marine with sparse macroinvertebrates and marine reptiles.
Stop: **Moeraki Boulders** – Paleocene concretions or **Waianakarua River** – Cretaceous greensand and concretionary siltstone.
Stop: **Kakanui Campbell's beach** –fossiliferous rocks include Eocene, Oligocene and Miocene limestones and greensands. **OR the next stop**
View/ stop: **Gees Bay view** – Ototara Limestone, Gee Greensand, unconformity Stop depends on state of tide and surf.
Stop: **Awamoa Beach** – Gee Greensand, Mount Harris Formation with rich invertebrate assemblages.
Stop: **Taylors Quarry** - Eo/Oligocene boundary sequence with Oamaru Diatomite and Ototara Limestone.
Stop: **Hutchinsons Quarry** – NZ's first geological reserve: Waiareka Volcanics, cobble bed (?lateral equivalent of Ototara Limestone), Gee Greensand.
Optional - evening: **Blue Penguin colony** – view penguins coming ashore at dusk.

SUNDAY. Travel from Oamaru north to Waihao, then northwest over Meyers Pass to Hakataramea Valley. Travel to Kurow, Duntroon and Awamoko Valley, then to Dunedin. Exact stops to be made will depend on weather and time available.

Stop: lower **Waihao Valley** – Don's Hole Eocene Waihao Greensand, Burnside Mudstone; Miocene Mt Harris formation.
Views/stop: mid **Waihao Valley** – Stony Creek Road - Quambys road shallow-water Eocene facies below Waihao Greensand.
Views/stop: **Meyers Pass** – Torlesse siltstones with sparse atomodesmids and conodonts - Permian.
Stop: **Hakataramea Valley limestone quarry** – Oligocene Kokoamu Greensand and Otekaike Limestone with rich invertebrates and vertebrates.
Stop: **Kurow** - toilets.
Stop: **Duntroon** - Vanished World Centre – part of a community initiative to foster understanding and conservation of fossils and other geological materials from the district.
Stop: **Earthquakes** – fossil site developed as part of the Vanished World Trail.
Stop: **Island Cliff** – extensive outcrops of Oligocene marine vertebrate locality.

A BRIEF SUMMARY OF GEOLOGY

Most of the strata seen on this field trip are part of the **Canterbury Basin sequence**, of Cretaceous and Cenozoic age. This sequence accumulated initially in fault-associated depressions which formed when New Zealand broke away from Gondwanaland (e.g. Sutherland 1999); middle parts reflect deposition in a passive margin, while upper parts preserve a signal of active plate boundary tectonics. Strata represent a **transgressive/regressive sequence**, deposited unconformably over basement rocks, and representing two distinct phases in the later Cretaceous-Cenozoic history of New Zealand:

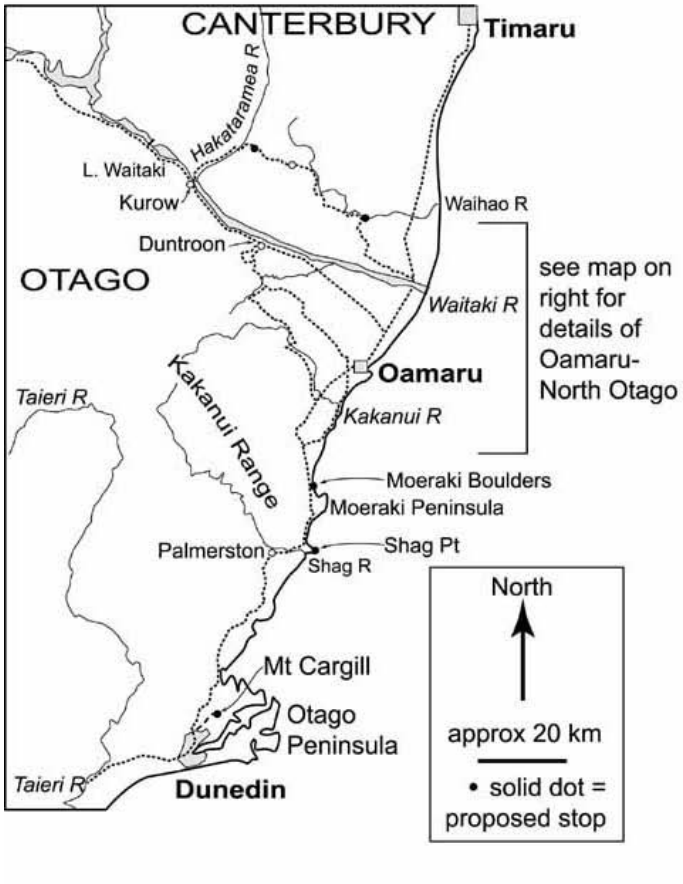
- **submergence** following breakup from Gondwanaland and erosion leading to subdued relief,
- **emergence** related to plate boundary activity from about the Early Miocene onwards, which accelerated about 5 Ma into the **Kaikoura Orogeny – the current uplift of New Zealand**.

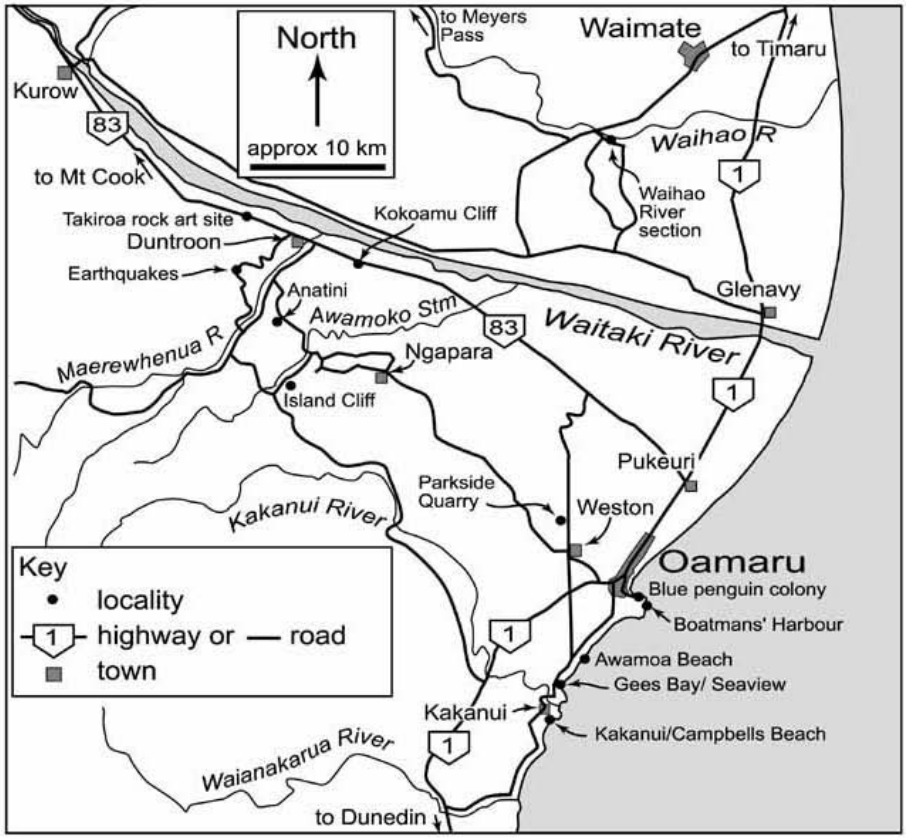
During the Oligocene, conditions were rather **quiescent**; widespread thin bioclastic limestones formed, associated with glauconitic and occasionally phosphatic terrigenous-starved sediments. These biogenic and authigenic sediments are an important source of marine invertebrates and vertebrates.

The figure of local stages and strata shows some of the more-broadly recognised formations/groups of the Cretaceous-Cenozoic sequence in the Waitaki Valley region – encompassing parts of North Otago and South Canterbury (Field and Browne 1989, Gage 1957).

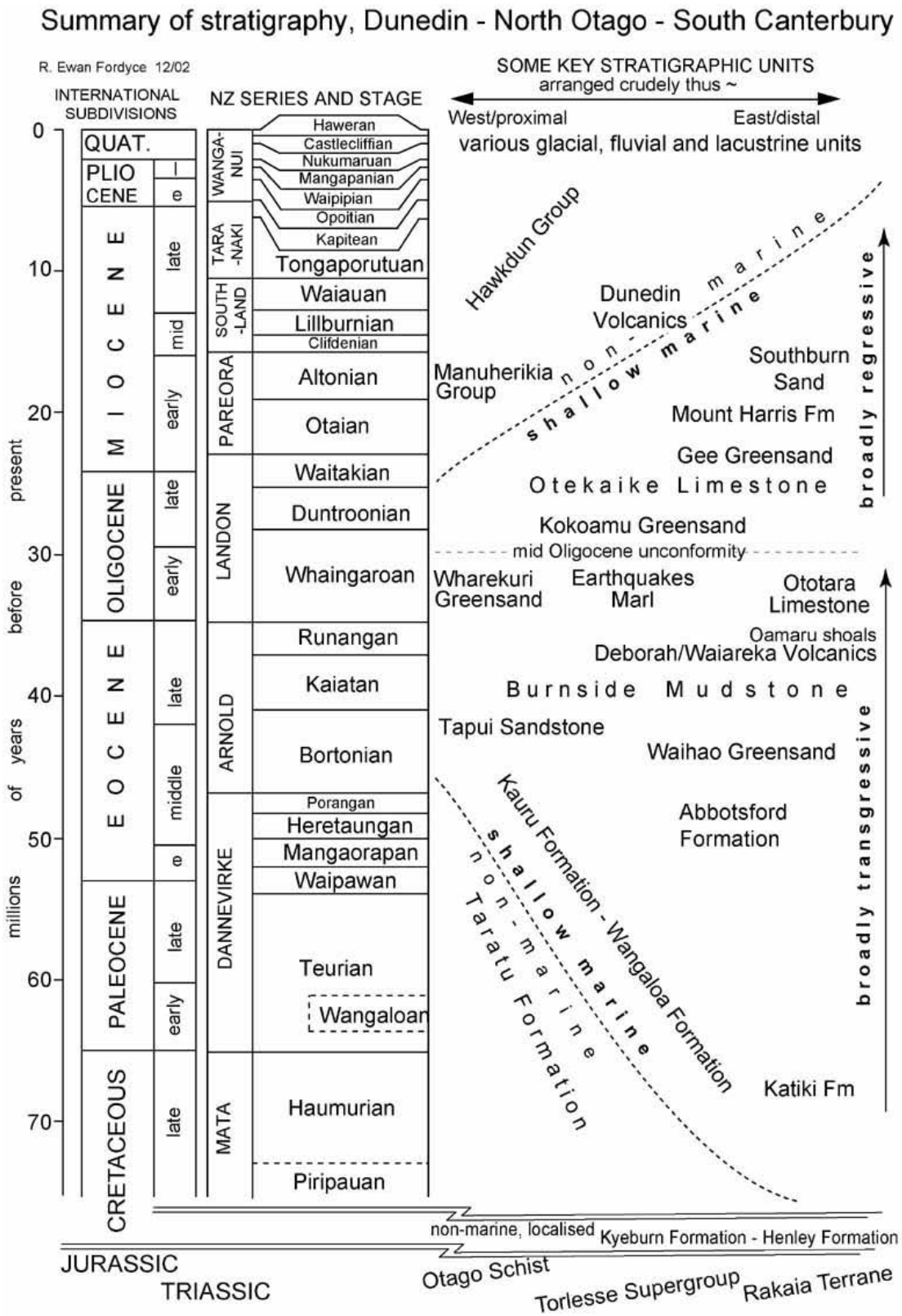
In the Canterbury Basin, marine strata are generally thicker to the east, representing a longer depositional history in the east. Compared to the eastern strata, thinner marine sequences to the west are also younger at the base and older at the top, indicating shorter time of marine submergence. Western strata also are of more-shallow water aspect. At the sequence at any one place, transgressive sediments crudely fine upwards, while the regressive strata coarsen upwards. Unsurprisingly, the transgressive/regressive strata preserve many unconformities beyond those at the base (immediately above basement) and top (below Late Neogene-Quaternary alluvium).

The local basement rocks comprise **Haast Schist** and meta-sedimentary rocks of the **Torlesse Supergroup** (in tectonostratigraphic terms, **Rakaia Terrane**). These units form parts of the Kakanui and St Mary's Ranges, where Torlesse strata yield Middle Triassic fossils.



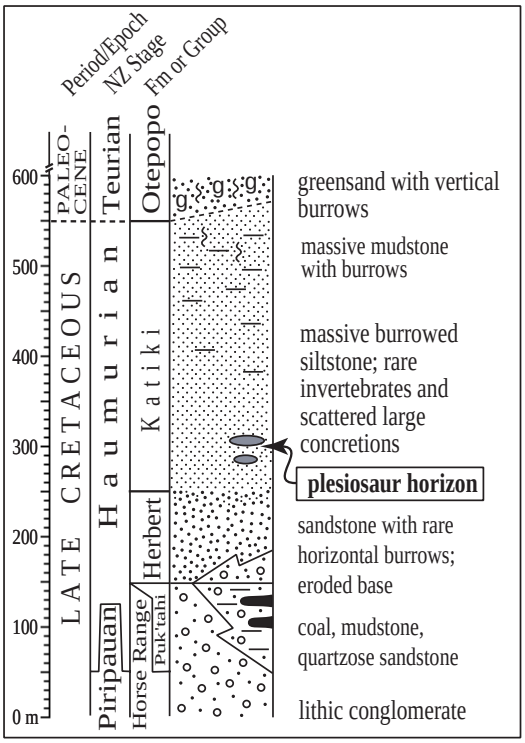


Waitaki region - North Otago and South Canterbury


Summary of stratigraphy, Dunedin - North Otago - South Canterbury
R. Ewan Fordyce 12/02
INTERNATIONAL SUBDIVISIONS
NZ SERIES AND STAGE
SOME KEY STRATIGRAPHIC UNITS
arranged crudely thus ~
West/proximal
East/distal
various glacial, fluvial and lacustrine units
millions of years before present
0
10
20
30
40
50
60
70
QUAT.
PLIO CENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
CRETACEOUS
late
early
mid
middle
Haweran
Castlecliffian
Nukumaruan
Mangapanian
Waipipian
Opoitian
Kapitean
Tongaporutuan
Waiauan
Lillburnian
Clifdenian
Altonian
Otaian
Waitakian
Duntroonian
Whaingaroan
Runangan
Kaiatan
Bortonian
Porangan
Heretaungan
Mangaorapan
Waipawan
Teurian
Wangaloan
Haumurian
Piripauan
WANGA-NUI
TARA-NAKI
SOUTH-LAND
PAREORA
LANDON
ARNOLD
DANNEVIRKE
MATA
Hawkdun Group
Dunedin Volcanics
marine
non-marine
shallow marine
Manuherikia Group
Southburn Sand
Mount Harris Fm
Gee Greensand
Otekaike Limestone
broadly regressive
Kokoamu Greensand
mid Oligocene unconformity
Wharekuri Greensand
Earthquakes Marl
Ototara Limestone
Oamaru shoals
Deborah/Waiareka Volcanics
Burnside Mudstone
Tapui Sandstone
Waihao Greensand
Kauru Formation - Wangaloa Formation
shallow marine
non-marine
Taratu Formation
Abbotsford Formation
broadly transgressive
Katiki Fm
non-marine, localised
Kyeburn Formation - Henley Formation
JURASSIC
TRIASSIC
Otago Schist
Torlesse Supergroup
Rakaia Terrane

SUMMARY OF LOCALITIES

SHAG POINT



The section at Shag Point, Coastal Otago, preserves rocks spanning Late Cretaceous to Paleocene (above); the sequence youngs to the north. Cretaceous rocks include marine strata which have produced sparse molluscs, plesiosaurs and mosasaurs. The marine reptiles – some of which are apparent in concretions on the shore platform - are from massive dark grey silty sandstone of the Katiki Formation. The lack of calcareous foraminifera and ammonites suggests a setting with restricted access to the open sea, perhaps a sheltered embayment or an estuary floored with a soft, soupy, oxygen-poor muds. Trace fossils, such as the branched *Thalassinoides* (shrimp burrow), and clusters of agglutinated foraminifera are abundant. Wood occurs frequently. Rare molluscs from sandier horizons include often-decalcified gastropods and bivalves and a few examples of the age-diagnostic belemnite *Dimitobelus*. These invertebrates indicate an age of Haumurian Stage, or latest Cretaceous. This is the type locality for the relatively complete unique specimen of the plesiosaur *Kaiwhekea katiki*, named and described by Cruickshank & Fordyce (2002); the specimen is on display in Otago Museum.

MOERAKI BOULDERS

Large (to 2 m) spherical concretions are part of the Paleocene Moeraki Formation, a massive marine mudstone which accumulated in a presumed outer shelf setting. The sequence is more or less continuous to the north as far as Oamaru, spanning the Paleocene, Eocene and Oligocene. Some concretions are known to form around a

central core – pebble or fossil; some have secondary carbonate septaria. According to Boles et al., the larger concretions formed over ~ 4 M years at relatively shallow depths (as indicated by vitrinite reflectance). Individual boulders are eroded by the sea and move ocean-ward by wave action undercutting the sand upon which the boulders sit. Eventually they reach a point where this action becomes ineffective and accumulate as groups of boulders. Maori legend tells the boulders history differently. They represent food baskets from a Maori canoe (waka) that ran aground on a reef off Shag Point further south and sank. The names of those aboard the canoe were given to local mountains.

KAKANUI - CAMPBELL'S BEACH

The sequence here, summarised below, is more complex than at first glance, and has attracted much debate from stratigraphers. There are 2 limestones in succession, each truncated by an unconformity marked by a karst surface. The lower limestone is the Ototara, characteristic of the Oamaru district, while the upper is the Otekaike, better developed inland and to the north. Most of the Tertiary sequences thicken to the east (basin-ward); the thin Otekaike indicates a nearby high late in the Oligocene (Field & Brown 1989).

The Ototara Limestone at Kakanui is reportedly the type horizon/ locality for the large fossil penguin *Palaeeudyptes antarcticus* Huxley; occasional cetacean bones are apparent. Macrofossils include brachiopods and echinoids. Of note, the limestone here is also the type locality for the important zonal planktic foraminiferan *Globigerina (Subbotina) angiporoides* Hornibrook. The basal Gee Greensand ("Isis bed")is a noted source of fossil sharks' teeth, plundered by rockhounds who have made it difficult to collect from this unit, but it also contains abundant alcyonarian corals and less common brachiopods, molluscs (including such supposedly deep-water taxa as *Acesta*, *Euciroa* and *Perotrochus*), barnacles and crabs. It is the type locality for the "giant" epitoniid gastropod *Epitonium* (?) *mackayi* (Marwick, 1943) which presumably fed on the prolific corals. From the Gee Greensand came the enigmatic toothed cetacean (Squalodontidae?), *Tangaroasaurus kakanuiensis* Benham 1935; the fossil was originally identified as a middle Tertiary ichthyosaur.

Beach sands and gravels	shoreface	late Quaternary "raised beach"
Mt Harris Fm – calcareous mst	Marine outer shelf	Otaian Stage, E Miocene
Gee Greensand – calcareous muddy gs	Shallow marine, deepening upwards	Waitakian-Otaian Stages, Late Oligocene - E Miocene
Otekaike Lst – cemented bioclastic lst with phosphate crust at karst surface	Marine shelf ?below storm wave base; karst = subaerial	Waitakian Stage, Late Oligocene
Ototara Lst – bryozoan bioclastic lst cemented in upper part, with karst surface developed into burrows	Marine shelf, shoal setting in active water associated with volcano; karst = subaerial.	Whaingaroan Stage, Early Oligocene.
Waiareka Volcanics – dm-bedded to massive crystalline basaltic tuff	Marine, reworked volcanics.	Whaingaroan Stage, Early Oligocene.

Molluscan assemblages from the Mount Harris Formation at All Day Bay include several species that are unknown or very rare at coeval (Altonian) sites near Oamaru, indicating this unit accumulated in a deeper water environment (bathyal zone) in the southern area. Foraminiferal assemblages also indicate a deep water setting.

GEES BAY VIEW

Revealing views are gained from the coast road north of Kakanui, at Gees Bay and especially near the Seaview café. The steeply-cliffed bay is Gees Bay; access is by scrambling down slope in a few places. Underneath loess and Quaternary beach sands and gravels is a sequence of Gee Greensand overlying a crust of Otekaike Limestone and thick Ototara Limestone. The shoreline reefs are formed by the Ototara. Near or at the vantage point, note blocks and/or outcrop of a brachiopod-coquina – the Everett Brachiopod Limestone of the Ototara Limestone. The rock is dominated by articulated valves, often with the loop preserved, of terebratulides; these have been studied by a succession of local paleontologists including, most recently, Daphne Lee (Department of Geology, University of Otago). Also present is abundant debris and whole specimens of bryozoans, echinoids, rare molluscs, and foraminifera. The Ototara Limestone rests in turn on the Waiareka Volcanics. To the north, note resistant volcanics at the far end of Gees Bay, and the sweep of Awamoa Beach leading to the distant Oamaru Cape (Cape Wanbrow).

AWAMOA BEACH

Fossiliferous siltstone of the Mount Harris Formation is intermittently exposed on the beach south-west of Awamoa Creek near Oamaru, at what is perhaps the most important new fossil locality to have been found in North Otago in the latter half of the 20th century. The site was discovered by Bill Lee of Oamaru in early 1999 and has been collected by Phillip Maxwell, Ewan Fordyce and others on several occasions since. The very rich molluscan fauna (>400 spp) includes most of the characteristic North Otago Altonian species, e.g. *Neilo awamoana*, *Lima colorata*, *Spissatella trailli, Tropicolpus cavershamensis*, *Galeodea apodemetes*, *Sassia maoria*, *Cirsotrema caelicola*, *Typhis hebetatus*, *Pterynotus laetificus*, *Coluzea dentata*, *Penion* spp, volutes (at least 10 spp), *Comitas fusiformis* and *Bathytoma haasti*, as well as many undescribed species. Other macrofossils include corals, brachiopods, barnacles, hermit crabs and echinoids. The locality has produced abundant fish otoliths and also significant cetacean material: two partial skeletons, an incomplete skull and isolated vertebrae in the siltstone, and four concretions with assorted bones including cranial material. This largely-unprepared material includes small dolphins and small to moderate-sized baleen whales (family not determined).

The site is important because of its geographic and stratigraphic proximity to Awamoa Creek, the type locality of one of the first Tertiary vertebrates to be described from New Zealand, the dolphin *Phocaenopsis mantelli* Huxley, 1859 (?Eurhinodelphinidae), which was based on a single humerus. It is not known if it came from the soft siltstone exposed in the stream itself, or from outcrops of richly fossiliferous, cemented beds formerly exposed on the beach near the mouth. No other specimens are known, but *P. mantelli* may be expected to turn up at Beach Road.

The lower part of the unit is highly glauconitic (Gee Greensand Member) with a basal decalcified shellbed, resting on Waiareka Volcanics. The only limestone (Ototara Limestone?) consists of thin, discontinuous lenses occupying hollows on top of the volcanics, in sharp contrast to the situation at Gees Bay about 1 km to the south-west. The middle part of the Mount Harris Formation probably accumulated at mid- to outer shelf depths (or even in the upper bathyal zone), but the upper part includes shellbeds (one with abundant brachiopods including *Notosaria nigricans*) and was deposited in substantially shallower waters (inner shelf).

TAYLORS AND PARKSIDE QUARRY

The Ototara Limestone at Taylors Quarry is a well sorted bioclastic limestone (bryozoan sand) with a small component of volcanic debris and occasional rounded quartz sand. The depositional setting was marine, probably in active shelf waters at shoals associated with small volcanic edifices elsewhere represented by the Waiareka Volcanics. The age is Runangan to Whaingaroan, late Eocene to early Oligocene. Edwards reviewed the stratigraphy in an extensive monograph (1991) which included important details of sequences including the columns for the Taylors Quarry.

Beyond the abundant bryozoa, fossils include rare molluscs (prismatic bivalves), occasional sharks' teeth, rare penguins, one cheloniid sea turtle, one archaic whale. Other localities, nearby produce better macroinvertebrate fossils. The Oamaru Diatomite is present locally below the limestone at the Taylors Quarry access road, and more extensively to the south.

BOATMANS HARBOUR

Here we see >200 m of excellent coastal exposures of the Eocene basaltic Waiareka Volcanics, including pillows, volcaniclastics (pyroclastic fall and surge, redeposited sediments), and clastic dykes. The pillows, first documented by James Park (1905), are particularly notable. R.A.F Cas, D.S. Coombs and others (Coombs et al. 1986) have documented the sequence summarised below. Cas considered such volcanics to have been deposited very rapidly, over a matter of weeks – as with the modern Icelandic volcano Surtsey. Wave action quickly eroded exposed and shallow marine parts of the volcano. Bioclastic and reworked horizons, in contrast, may have formed over thousands of years. Forsyth (1994) gave a useful short account for a broader audience.

loess	terrestrial	Quaternary
Beach sands and gravels	shoreface	Quaternary "raised beach"
Waiareka Volcanics: >50 m of basalt breccia; ~25 m massive to graded to hummocky facies, including bed of bioclastic Ototara Limestone; ~40 m pillows with interstitial fossiliferous carbonate; ~80 m bedded to surge cross-bedded lapilli tuffs, occasional breccia, bioclastics	Surtseyan volcano with pyroclastic fall and surge deposits, splatter deposits, aquatic slides and flows, turbidity current deposits, current reworked volcanics, bioclastics, occasional hardgrounds	Late Eocene in part, with Runangan stage fossils present in sequence below and above pillows.

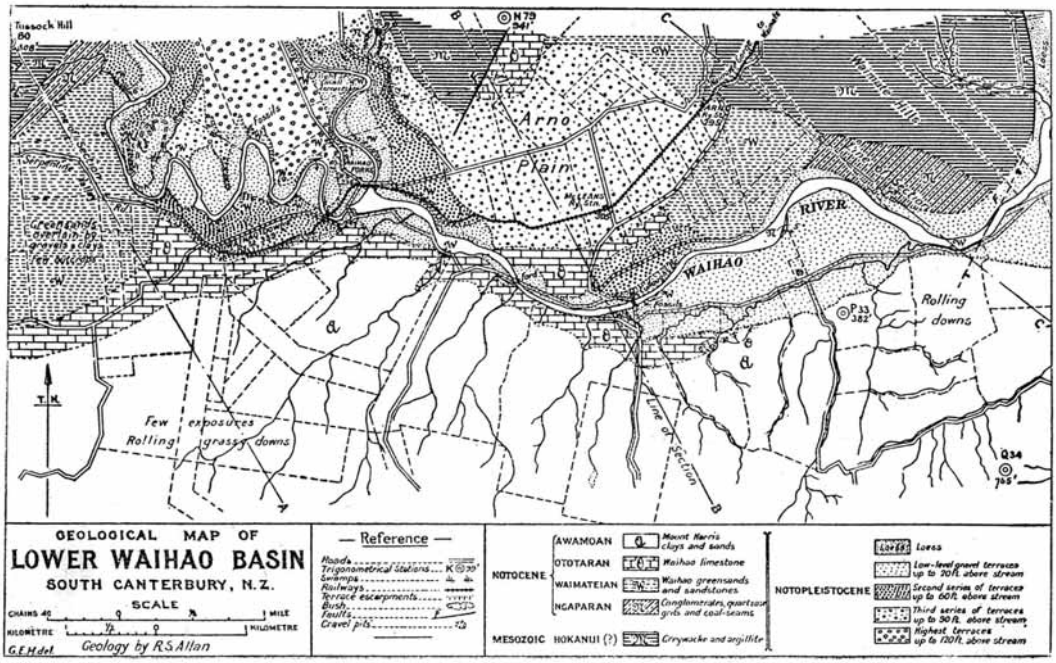
WAIHAO VALLEY: DONS HOLE TO MEYERS PASS

Sections along the banks of the Waihao River span roughly Early Paleocene to Early Miocene, and include some of the most important Eocene macrofossil localities in New Zealand (Pentland Hills, Waihao Downs, McCullochs Bridge, Kapua Tuff) (Beu & Maxwell 1990; Maxwell, 1992).

Some units here have produced important marine vertebrates. The Waihao Greensand (later Middle Eocene) is the source horizon for several specimens of dermochelyid or leatherback turtle, including the holotype of *Psephophorus terrypratchetti* Köhler 1995. Material was found by Sue and Phillip Maxwell and Ewan Fordyce in the 1990s. In 1879, Julius von Haast reported fossil teeth later identified as those of a *Zygorhiza*-like archaeocete (Fordyce 1985), and in the 1990s Phillip Maxwell discovered an incomplete skull of a dorudontine/dorudontid archaeocete nearby (Köhler & Fordyce 1997). These fossils, mostly curated in the Geology Museum at Otago, provide key Southern Hemisphere records of archaeocetes.

Dons Hole is the local name for a popular swimming hole on the Waihao River, about 7 km upstream from SH1, close to where the river is crossed by the Hunters Hill Fault (or Faults). Waihao Greensand (Bortonian) is overlain by Burnside Mudstone (mostly Kaiatan but possibly latest Bortonian at the base). Sandstone and conglomerate assigned to Kauru Formation (probably Waipawan or Mangaorapan) crops out about 200 m upstream. The lower part of the Burnside (Otaio Limonitic Member) is highly glauconitic, sandy and bioturbated and the contact with the Waihao is probably

disconformable. About 100m downstream from the swimming hole, Burnside Mudstone (dipping downstream) is faulted against Mount Harris Formation (Altonian), which dips steeply upstream. Otekaike Limestone, which is well-developed a few km upstream, is not known from Dons Hole or nearby, and although this may mean it has been faulted out, an alternative possibility – that it wedges out in this direction- cannot be discounted. The only macrofossils recorded from the Waihao Greensand here are a large but incomplete nut measuring 130 mm in maximum dimension and the partial skeleton of a bony fish (teleost). Burrows, wood and small, worn shark teeth occur at the base of the Burnside mudstone, and a badly crushed nautiloid (*Aturia* ? sp.) has been collected from the upper part of the unit. Well-preserved molluscs and fish otoliths are recorded from the Mount Harris Formation downstream from Dons Hole.



The famous **McCullochs Bridge** fossil locality (Maxwell 1992; see also Allan 1927 – map above) is on the right bank 100-200 m downstream from the bridge, but is now badly overgrown. Over 200 species of molluscs and less common brachiopods, corals and fish otoliths are recorded from a thin bed (Tahu Member, early Kaiatan) overlying the Otaio Limonitic Member in the lower part of the Burnside Mudstone. The molluscs indicate an outer shelf environment. Molluscs and other macrofossils are also present about 1 km upstream in the Kapua Tuff, a local unit within the Burnside Mudstone, possibly connected with the Waiareka Volcanics of North Otago.

The key Oligocene unit near McCullochs Bridge is a quartz-rich facies of the Kokoamu Greensand which reaches, uncharacteristically, more than 10 m thick. This formation has produced at least 5 species of mysticete and a fragmentary toothed cetacean (?archaeocete). Also significant are remains of two relatively complete large penguins, similar to others previously placed Huxley's genus *Palaeeudyptes*. The vertebrates were recovered by Fordyce and associates; the penguins were later studied by C.M. Jones, and mentioned in summary by Fordyce & Jones 1990. The Kokoamu Greensand is

overlain by the Otekaike Limestone which, surprisingly, has produced no significant marine vertebrates. Among the macrofossils recorded from the Kokoamu Greensand and Otekaike Limestone in this area are brachiopods, stemmed crinoids and echinoids (including the cidarid *Histocidaris mackayi*). The intimate association of cidarids and crinoids is particularly noteworthy, suggesting possible predator (cidarid) and prey (crinoid) interactions.

Mount Harris Formation (here Otaian to Altonian) is exposed at Dons Hole, near the summit of Mount Harris (a prominent hill south of the Waihao River) and Elephant Hill Stream, and in various hillside slips and road cuttings. Macrofossil assemblages from the unit are similar to those from Oamaru district but are less diverse. Southburn Sand (Altonian) is poorly exposed on hillsides north-west of Pikes Point (the source of spectacularly fossiliferous sandstone blocks that now grace a number of fireplaces in Waimate district.) There is also an isolated fossiliferous outcrop at Waihaorunga, faulted in between Torlesse rocks.

Weathered gravels underlying the low hills west of SH1 near Morven, and exposed in bluffs at Elephant Hill Stream and along the Waihao River east of Dons Hole are assigned to Kowai Formation (= Elephant Hill and Cannington Gravels). They have not been directly dated in this area, but are assumed to be of Wanganui Series age, although the lower part could be substantially older. Marine fossils including molluscs, barnacles, crabs and cetacean bones have been collected from the Makikihi River 18 km N of Dons Hole; the molluscs indicate a Nukumaruan age (Alan Beu, pers. comm.).

Kapua Swamp, a notable source of moa and other bird fossils occupies a low-lying area to the south of the upper end of Waimate Gorge. The gorge (in Permian Torlesse rocks) was cut by the former North Branch of the Waihao River before it was captured by the South Branch.

The spectacularly scoured and cross-bedded Otekaike Limestone exposed in bluffs at **Waihao Forks** is one of the most-photographed geological sites in New Zealand. A brief stop will be made to allow photography. Ward and Lewis (1975) interpreted the scours as generated by occasional storm events, with the crossbeds representing ongoing "background" sedimentation.

Excellent outcrops of Taratu Coal Measures and Waihao Greensand in the South Branch of the Waihao River are visible from **Stony Creek** and **Quambys Roads**. The age of the Taratu is poorly constrained in Waihao district, but the upper part of the unit has been dated as Waipawan. The *Asterocyclina speighti* bed (Kauru Formation) discovered by Bruce Riddolls crops out about 300 m upstream from Quambys Bridge – it is probably of similar age to other occurrences of *A. speighti*, i.e. Waipawan or Mangaorapan.

Pudding Hill, a block of Torlesse (or low-grade Haast Schist) is notable for the presence of sink-holes on its summit. No calcareous beds have been found on the hill itself.

The **Pentland Hills/Waihaorunga basin** is a partly fault-bounded outlier of Early Eocene to Late Oligocene (or earliest Miocene) rocks. The best exposures are in the

northern part of the basin near Pentland Hill – here at least, Taratu Coal Measures are absent and Kauru Formation rests directly on deeply leached Torlesse rocks. The Kauru and overlying Waihao Greensand/Opawa Sandstone are locally richly fossiliferous – besides molluscs the faunules include corals (e.g. *Balanophyllia hectori*, *Madracis dodecachora* and *Sphenotrochus* sp), shark and ray teeth, teleost otoliths and penguin and turtle remains. Burnside Mudstone also seems to be absent from the basin, although this unit is present to the northwest in Hakataramea Valley.

Soft Otekaike Limestone grading down to Kokoamu Greensand is exposed at **Ardlogie Quarry** near Meyers Pass – the associated diverse faunule (all calcitic species) comprises bryozoans, brachiopods, polychaetes, molluscs (including a single specimen of an undescribed species of the rock-dwelling limpet *Cellana*), barnacles, echinoids, crinoids, ophiuroids, shark teeth and penguin bones. Calcareous siltstone assigned to Mount Harris Formation is present at two localities – at one of these it includes well-preserved molluscs similar to those from better-known Waitakian sites in Hakataramea Valley.

HAKATARAMEA VALLEY – HAUGHS QUARRY AND ENVIRONS

Cenozoic strata in the Tabletop area of Hakataramea Valley represent a sequence toward the inner margin of the Canterbury basin and as a consequence there are some differences in lithofacies from the more distal sequences further to the east. At an active quarry, informally named **Haughs Quarry**, marine vertebrates have been recovered in ongoing work since 1987. The locality is perhaps the richest single locality in New Zealand for fossil Cetacea and penguins; it is notable also for teleost remains. Cetaceans include several species of archaic mysticetes (including stem-balaenopterids and problematica), one or more archaic Delphinida (stem Delphinidae?) and diverse Platanistoidea.

At Haughs Quarry is a well exposed sequence of Kokoamu Greensand which grades up into the Otekaike Limestone. These are the key fossiliferous Late Oligocene units of the Canterbury Basin, and can be seen at other localities nearby. A short summary of both follows:

The Kokoamu Greensand is generally a thin (<1-5+ m) calcareous glauconitic sandstone which formed at a time when land was distant and low-lying. The rock is massive, bioturbated and slightly muddy in the base, but more-obviously bedded towards the top. The base of the greensand has only sparse fossils, but assemblages may be rich higher in the unit. Brachiopods dominate thin shellbeds near the top of the greensand, and bones are found here often. A rich microfauna of foraminifera, ostracods and coccoliths supplemented by Sr dating indicates that the Kokoamu Greensand represents much of the Late Oligocene, >26-30 Ma. An unconformity at the base of the Kokoamu Greensand, not seen here, is a regionally to globally significant horizon which may represent a rapid sea level fall (glacioeustatic?) about 30 Ma.

The Otekaike Limestone is also a massive fossiliferous marine rock, more resistant than the Kokoamu. Typical outcrops show 10s of metres of moderately cemented, fossiliferous yellow-brown limestone, often with glauconitic or concretionary horizons.

Microscopic study shows that the limestone is composed of fossil fragments (particularly broken sea urchins, bryozoans, molluscs and brachiopods), microfossils, glauconite and occasional quartz grains. Macrofossils are common, particularly articulate brachiopods such as *Waiparia*, pectinid bivalves like the smooth-shelled *Lentipecten*, and heart urchins like *Pericosmus*. The very rich molluscan faunule has close similarities with those from other Waitakian localities in Hakataramea and Waitaki Valleys, and includes a few warm-water taxa such as *Spondylus* n.sp.(resented by a single, large articulated specimen) and *Guildfordia* n.sp. Many other groups can be found upon close inspection; corals, tube-worms, bryozoans, many other bivalves, gastropods, tusk shells, regular echinoids, barnacles, and decapod crustaceans (crabs). Microfossils are abundant and important in dating the rock; they show that it represents the later Oligocene to earliest Miocene, about 23-26 Ma. The microfossils also help to understand paleoenvironments. Foraminiferal faunas indicate quiet mid shelf depths in a sheltered setting; upper parts of the unit become more muddy and eventually grade into calcareous deep water mudstones of the Mount Harris Formation. The Otekaike is widespread, and can be traced northwards scores of km into Canterbury and beyond.

VANISHED WORLD CENTRE, DUNTROON

This Centre is discussed under Field Trip 4 in this guide.

THE EARTHQUAKES

The Earthquakes presents a fine Oligocene sequence, perhaps equalled only by those at Haugh's Quarry and a few other localities (Awahokomo and Trig Z). Here, the escarpment is formed by the massive Maerewhenua Member of the Otekaike Limestone which becomes more glauconitic in the base where it grades rapidly down into the Kokoamu Greensand. The limestone contains sparse but well preserved macrofossils including: *Lentipecten hochstetteri*, "*Chlamys"* sp., *Divalucina* sp., spatangoid echinoids, the brachiopod *Waiparia huttoni*, and barnacle plates.

The Kokoamu Greensand contains abundant macrofossils in its upper portion, which is more glauconitic, more distinctly bedded and less bioturbated than the macrofossil-poor lower portion. Macrofossils include a tiny dimorphic echinoid (*Fibularia* sp.), the brachiopods *Acrobrochus landonensis*, *Aetheia gualteri*, *Tegulorhynchia squamosa*, *Rhizothyris kokoamuensis* and *Waiparia elliptica* (brachiopods discussed most recently by Mackinnon et al 1993) and the calcitic molluscs *Mimachlamys chathamensis*, *Lentipecten subteres* and *Cirsotrema lyrata*. The lack of aragonitic molluscs probably reflects post-depositional solution. Many invertebrates, largely fragmented, are concentrated in narrow deep pockets in the greensand. Archaic baleen whales and penguins – rather indifferently preserved - also occur in the Kokoamu Greensand. One specimen, a baleen whale (broken skull, associated skeleton), is partly excavated and remains on display behind a protective cover for public viewing. This specimen was prepared as part of the Vanished World Trail.

The massive, silty, less glauconitic lower part of the Kokoamu Greensand largely lacks macrofossils, but is intensely bioturbated. Burrows are wide, subvertical, and meniscus-

infilled; they extend down to contact the poorly exposed Earthquakes Marl at the western end of the outcrop.

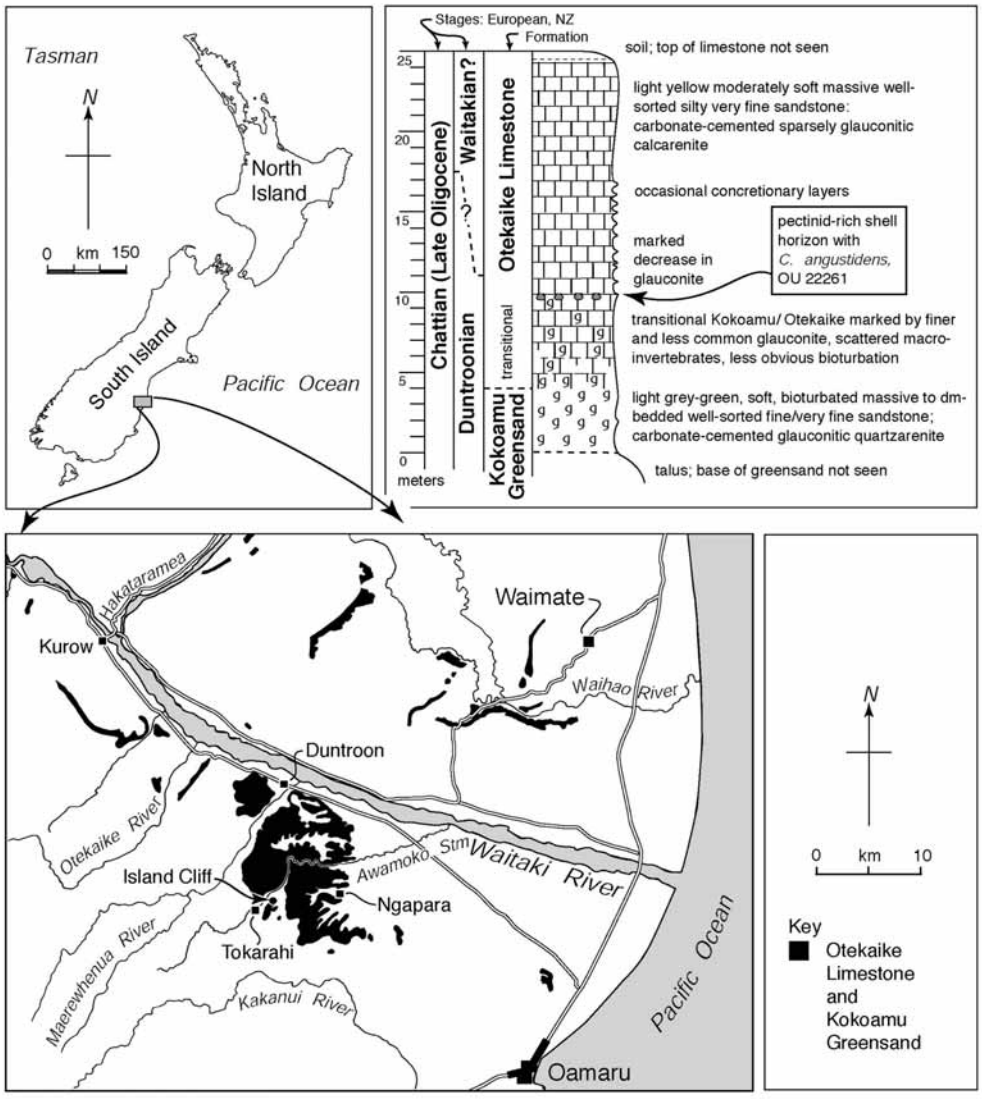
Fossil vertebrates from the Otekaike Limestone are noteworthy (Fordyce & Jones 1992, Fordyce &Jenkins 1993). These include elements of medium-sized penguins of the genus *Platydyptes*. Cetaceans include a superbly-preserved skull, jaws and other bones of a *Squalodon*-like shark-toothed dolphin (family Squalodontidae). The skull and jaws of a narrow-jawed baleen whale from the Earthquakes is one of several specimens which represent a new family-level clade of Mysticeti; the latter probably includes the enigmatic and widely figured *Mauicetus lophocephalus* of Marples 1956.

Otekaike Lst –bioclastic lst with nodular to concretionary and glauconitic horizons in places, grading down into	Marine shelf below storm wave base but shallower than Kokoamu Greensand	Duntroonian-Waitakian Stage, Late Oligocene
Kokoamu Greensand – bioturbated calcareous greensand with occasional phosphorite, richly fossiliferous in part	Marine shelf, below storm wave base	?upper Whaingaroan- lower Duntroonian Stage, Late Oligocene
Earthquakes Marl – massive calcareous mst truncated by burrowed disconformity	Marine distal, probably outer shelf	Lower Whaingaroan Stage, Early Oligocene (G. angiporoides zone, 32+ Ma)

See over for a representative section through KokoamuGreensand and Otekaike Limestone (figure modified from Gottfried & Fordyce 2001).

KOKOAMU CLIFF

A noted locality for Oligocene fossils, especially brachiopods and fossil vertebrates - whales, penguins collected by zoologist Brian Marples. It is the type locality for some vertebrates and, incidentally, the Kokoamu Greensand which represents much of the local Duntroonian Stage (roughly earlier Chattian, Late Oligocene). Several unconformities are present, notably the “mid” Oligocene feature likely to represent eustatic sea level fall about 29 Ma.



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