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FIELD TRIP 7

VANISHED WORLD

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INTRODUCTION

The trip has themes of: geological education/ geological sites; regional stratigraphy/ paleontology; and history of geology. It is based around localities from Papakaio to Duntroon-Maerewhenua, North Otago. We will visit a geological visitor centre - Vanished World Centre, Duntroon (www.vanishedworld.co.nz), and significant sites for the Paleogene of southern Canterbury Basin: Cameron's Pit (plant fossils, Cretaceous), Maerewhenua (shallow marine strata, sill, Eocene), and Awamoko-Duntroon (distal marine and unconformities, Oligocene). We will visit 1-2 of the sites specially developed for the public as part of the Vanished World Trail. Text, photos and graphics are by Ewan Fordyce.

VANISHED WORLD

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.

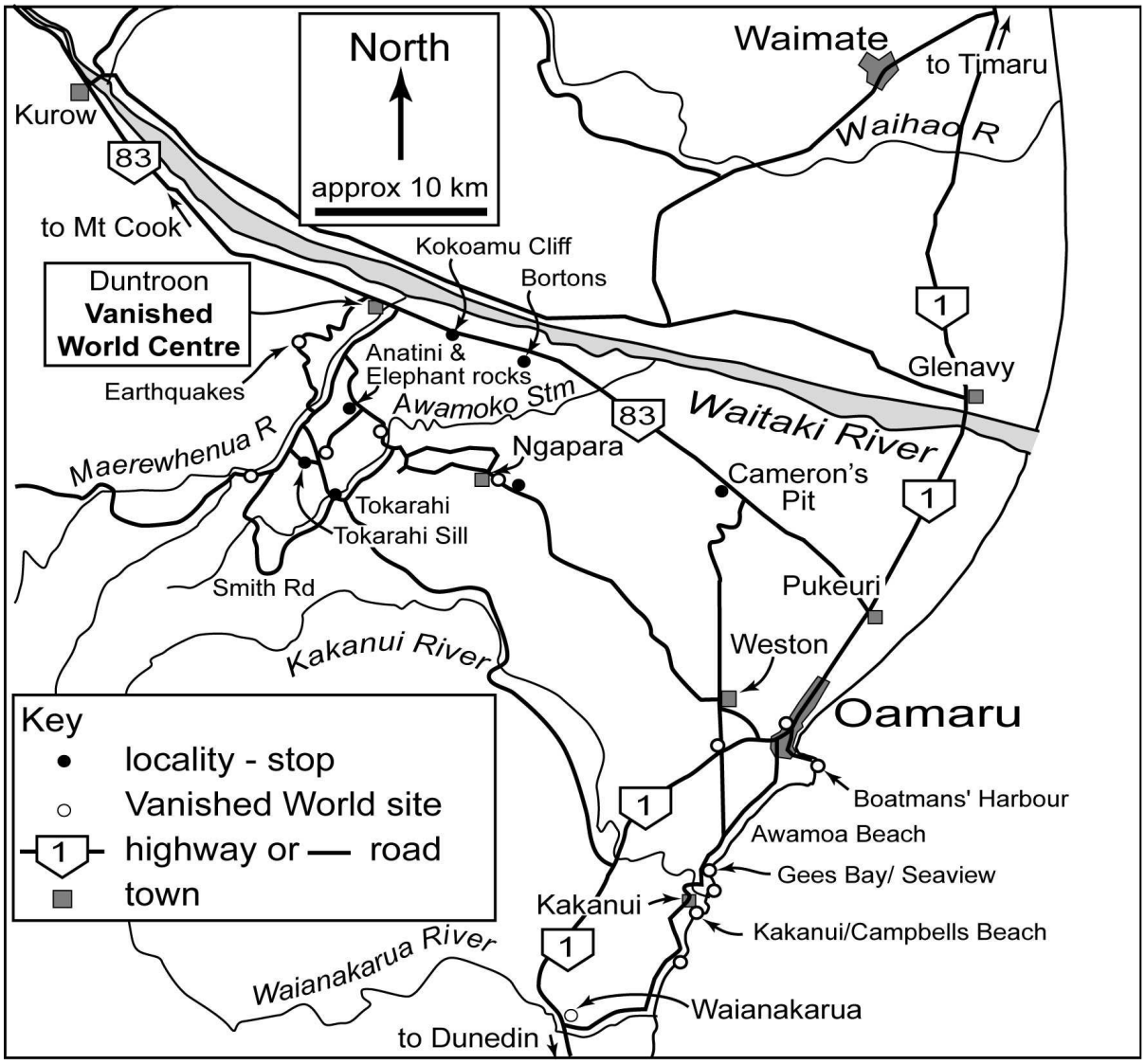
The **Vanished World Trail** sites - key outcrops, fossil localities, and landforms - are signposted, and most have explanatory plaques. A trail map, outcrop photographs and details of particular sites are given in the **Vanished World trail brochure** – an A3 folded colour document (Fordyce 2002) which 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 (shown above, with adjacent information board) 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 keen 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 (written and illustrated by Ewan Fordyce; assembled by Martin Fisher), for example, on geological time, geological maps, the Ototara Limestone, and the penguin *Platydyptes*.

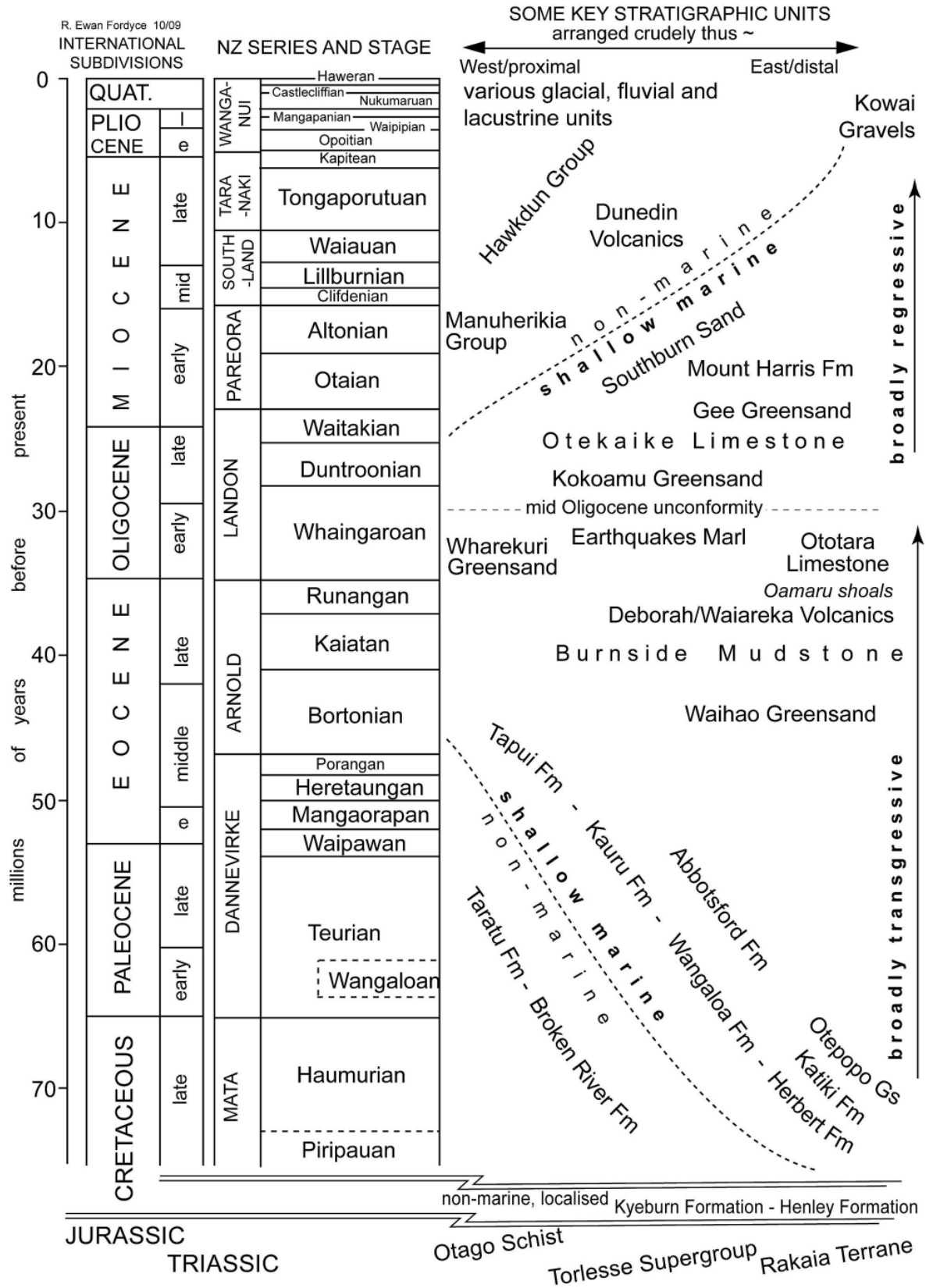
Display specimens, which are from the district, include original specimens and casts of fossil whales, dolphins, penguins, sharks. The replicas were produced by Andrew Grebneff and Rick Morcom in Fordyce's paleontology laboratory, using polyester resin and silicone moulds. There are diverse invertebrates, 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. Fossiliferous blocks outside the Centre include slabs of Tapui Formation with abundant molluscs (bivalves, gastropods, scaphopods) and occasional vertebrates including shark teeth and sea turtle bones. Some slabs of Mount Harris Formation from Awamoa Beach reveal a shallow water mollusc-dominated assemblage, with shells disarticulated, broken and abraded as a result of downslope movement into deep water depositional settings. 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. Information on the Trail and Centre is also on the web. An earlier Geological Society field guide, produced for geologists rather than lay visitors to the trail, 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 maintenance, such as at The Earthquakes – in the figure here). A complementary group, **Friends** of Vanished World, provides support through membership subscriptions.

MAP: KEY GEOLOGICAL LOCALITIES, STOPS, AND VANISHED WORLD LOCALITIES



GEOLOGY OF WAITAKI REGION



The Vanished World Trail is founded on the geology of the Waitaki region, particularly the sometimes-abundant and spectacular fossils of middle or late Eocene to early Miocene age. The fossils often occur in accessible, "layer-cake" sequences, and these attributes made North Otago and nearby regions important in early studies of New Zealand's Cretaceous-Cenozoic stratigraphy, biostratigraphy, and paleontology. The broader Waitaki region has received interest from many notable geologists, including McKay and Hector, a succession of locally based (Oamaru, Dunedin) geologists earlier in the 1900s - Park, Thomson, Uttley, Finlay, and Marwick, and, most significantly, Gage (1957) and Hornibrook (1961). In the early days, there was contentious debate about regional correlations of volcanics, limestones and greensands (e.g. Park 1918, cf Uttley 1920). Gage's mapping, backed up by Hornibrook's biostratigraphy, resulted in most of the stratigraphic names that are used today. Gage 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 (e.g. Papakaio = Taratu Formation, Rifle Butts = 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 North Otago rocks in a broader setting. Beyond the maps of Gage, see also Mutch (1964) and Forsyth (2002).

In the parts of North Otago spanned by Vanished World, the cover strata span mainly late Cretaceous to early Miocene, and Quaternary. Units are typically thin, and may be condensed. The Otago Schist basement is everywhere overlain unconformably by the cover strata, most of which were deposited in a passive-margin setting. The basal rocks may be nonmarine (particularly quartz-dominated conglomerates and sometimes coal measures of the Taratu Formation; late Cretaceous to ? middle Eocene – Haumurian- ?Bortonian), or shallow marine (Kauru Formation, Paleocene – Wangaloan and younger; Tapui Formation, middle Eocene - Bortonian). Nonmarine Taratu strata, if present, are overlain by shallow marine sandstones of the Kauru and Tapui Formations. Younger strata become terrigenous-poor, glauconitic, calcareous, and more massive, indicating a deeper marine origin. The patchily exposed Burnside Mudstone has been interpreted as marking outer shelf to upper bathyal settings.

Near the present coast, the basaltic Deborah-Waiareka volcanics and associated bryozoan-bioclastic Ototara Limestone are significant (Eo-Oligocene, Kaiatan-Runangan-Whaingaroan). Inland, the basaltic rocks occur as the Tokarahi Sill (middle Eocene – Bortonian), while the Earthquakes Marl (lower Whaingaroan) is laterally equivalent to the Ototara Limestone.

In the Duntroon area, the Earthquakes Marl is truncated by a “mid” Oligocene, or Marshall, unconformity which is followed by variably-developed Oligocene strata: Kokoamu Greensand (sometimes upper Whaingaroan in base, to Duntroonian), and resistant Otekaike Limestone (Duntroonian-Waitakian).

Whereas the massive, foraminiferal-rich Earthquakes Marl reflects 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. The sequence is well exposed and readily accessible at The Earthquakes – see the figure.

Otekaike Limestone produces prominent landforms in the Awamoko-Maerewhenua area, but both the Limestone and underlying Greensand thin eastwards, and may be absent from modern coastal localities. Commonly, inland outcrops of Otekaike Limestone are capped by loess and other Quaternary sediments, but in places the Limestone grades conformably up into basal Mount Harris Formation (= Waitoura Marl in part, and Rifle Butts Formation, of Gage) (Waitakian, Otaian and Altonian – mainly Early Miocene); the Mount Harris is significant north of the Waitaki. 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. Within the bounds of the Vanished World Trail, no younger marine rocks are seen over the Mount Harris Formation until the Quaternary.

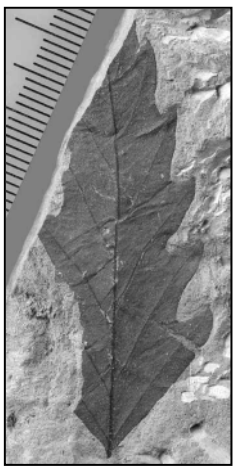
ITINERARY: OAMARU-DUNTROON RETURN

Drive north on Highway 1, turning west on Highway 83, bound for Waitaki Valley, at Pukeuri. Nondescript roadside outcrops show yellow mudstone of the Mount Harris Formation; this (hazardous) locality has produced important molluscs and foraminifera.

CAMERON'S PIT

Cameron's Pit shows a thick sequence of Taratu Formation [= Papakaio Formation of Gage 1957], with basal cm-dm bedded siltstone and sandstone overlain by thick poorly-cemented quartz pebble conglomerate (figure on right) which is quarried for roading material. The locality is regionally significant as a source of Cretaceous vascular plant fossils; the lower figure shows a leaf fossil horizon in the basal part of the Taratu Formation at Cameron's Pit.

To paraphrase Lee (in Fordyce et al. 2009): Cameron's Pit provides a diverse leaf assemblage of Late Cretaceous (Maastrichtian) age (PM2 palynological zone of Raine, 1984). The horizon is probably in the upper PM2 Zone, but its exact proximity to the K/T boundary is unknown (Kennedy 2003). Pole (1992) listed 10 leaf forms from Cameron's Pit, including *Nothofagus praequercifolia* (Ett.) Pole 1992 – see the bottom figure (specimen from Geology Museum, University of Otago), and *N. ulmifolia* (Ett.) Oliver 1950. About 40 leaf forms of dicotyledonous plants are now known, of which at least 8 have entire margins.



Pole interpreted the material from Cameron's Pit as representing a high-latitude, mixed deciduous angiosperm-conifer forest with Araucariaceae as the dominant gymnosperms (Kennedy 2003). Analysis of the leaf assemblage produced a mean annual temperature estimate of 7.7-9.3°C using leaf margin analysis, LMA. The CLAMP analysis of the same flora estimated a mean annual temperature of 8.9-11.3°C (Kennedy 2003). Mean growing season precipitation is estimated to be high (from 1704 to 2376 mm). Estimates of the paleolatitude of southern New Zealand during the Late Cretaceous vary from 50-60°S (Kennedy 2003) to about 70°S. The broad lamina and long petiole of some leaves is consistent with possible deciduous habit (Kennedy 2003).

BORTONS-KOKOAMU CLIFF

The highway follows a long outcrop of Otago schist to the northwest. Eventually, the planar upper (unconformable) surface on the schist dips below the ground near Doveys Road, Bortons. Across the fields to the south (to the left), poplar trees mark the site of the abandoned Bortons Lignite Mine, above which is a slope of brown Tapui Formation. This site, not visited, is the type locality for the Bortonian Stage of Park (1918). Higher exposures are indifferent for some km until Kokoamu Cliff, where Otekaike Limestone forms a resistant scarp, with Kokoamu Greensand and, in places, Earthquake Marl, exposed below. This is the type locality for the Kokoamu Greensand, widely cited in the context of the Marshall unconformity. Lewis and Bellis (1984) gave a useful account of the physical appearance of the unconformities at Kokoamu Cliffs, although without the benefit of detailed biostratigraphy.

DUNTROON – VANISHED WORLD CENTRE

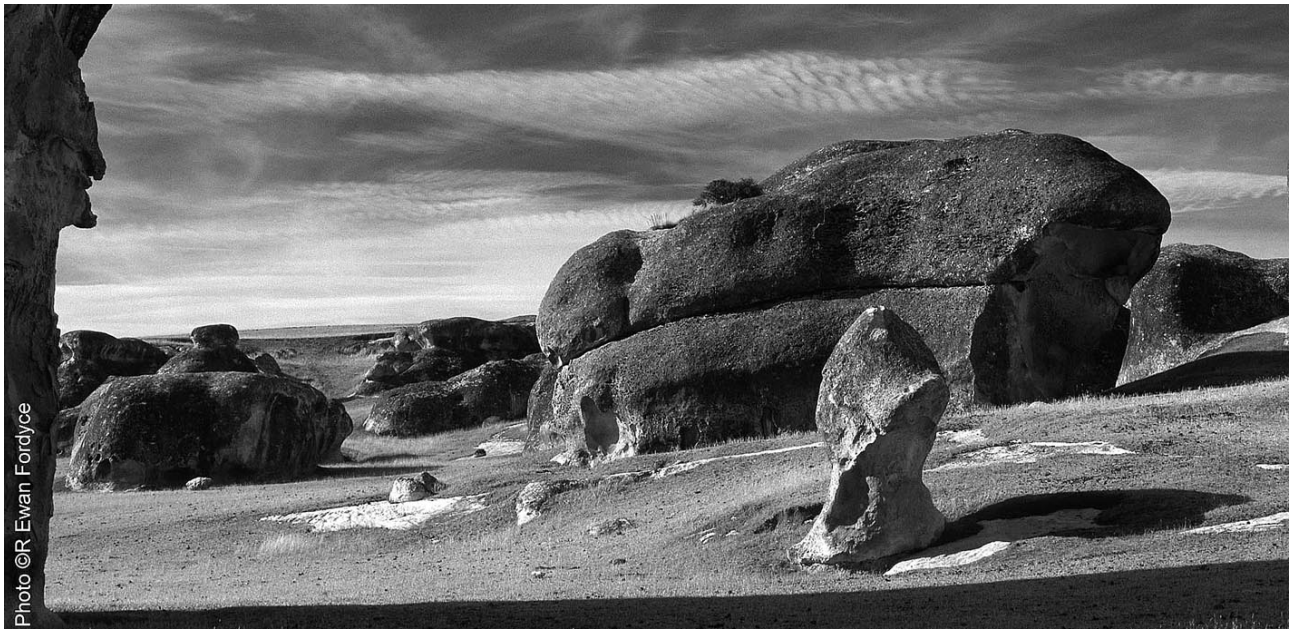
See details on the Vanished World above, in the introduction to the field trip.

Leave Duntroon and travel south-southwest up the Maerewhenua Valley, turning into the Duntroon-Awamoko-Ngapara Road.

ANATINI-ELEPHANT ROCKS

The Anatini fossil whale site is developed on private land, in a small valley cut into Otekaike Limestone. The dissected limestone includes spectacular honeycomb-weathered faces. The fossil is a baleen (toothless) whale represented by parts of the skull and associated skeleton, under an acrylic cover. It was recognised by bones projecting from outcrop, and was excavated to develop the spot as a visitor site. This was the first such site developed; there was initial enthusiasm for an acrylic cover, but acrylic is difficult to maintain, and a mesh cover has proven more effective at the nearby Earthquakes fossil whale site. A poster (1.8 m x 0.9 m) close to the Anatini whale offers these topics for the reader: - what is the fossil? – what bones are present? – is this a typical form of preservation? – how big was the whale? – how did the whale live? – when and where did the whale live? Interpretive graphics show the bones in situ, line art of a whale skeleton showing the position of the fossilised bones, a reconstruction of an ancient baleen whale, and a paleogeographic map of New Zealand during the Oligocene (based on a map by P.R. King).

Technically, the fossil whale is a species of Mysticeti (baleen whales), probably in the stem-Balaenopteridae. The material, which includes skull fragments, vertebrae, ribs and a scapula, is too incomplete to be sure of the identification. Elsewhere in the Waitaki Valley region, better-preserved stem-Balaenoperidae represent the widely-cited species *Mauicetus parki* – one of the oldest-reported baleen whales with a gulp-feeding lifestyle like that of the modern minke whale.



The Elephant Rocks locality (above), also on private land, is reknowned for spectacular Otekaike Limestone prominences emerging from flat ground. Overseas, such prominences are variously termed pepinos (pepino hills), hums (Serbo-Croat, = hill), or haystack hills, and they form as residual features typically in jointed flat-bedded limestone in regions of alternating wet and dry climates (see "pepino hill," Encyclopædia Britannica, 2009. Encyclopædia Britannica Online, accessed 12 Oct 2009). The locality is popular with rock climbers and photographers.

Travel via Grants Road south to Prydes Gully, passing the Vanished World site of Prydes Gully Quarry (Otekaike Limestone, source of hand-adzed blocks) at the Tokarahi Road. Travel to Dip Hill Road.

DIP HILL ROAD

Here is a spectacular section through about 7 m of the basaltic **Tokarahi Sill** which was emplaced into the Tapui Formation. As with other strata in the region, the sill dips gently to the north northeast; it is locally a significant landform. Some of the prominent columns have a subvertical darker mafic core a few cm diameter. The base of the sill is often glassy, and contains zeolite-infilled pipe vesicles perhaps generated by steam from contact with wet Tapui sediments. In places, the Tapui sediments are baked, although this surface is usually too altered by percolating groundwater and limonite to show details. At Dip Hill Road, the structure of the top of the sill is not clear, but eastwards, at Little Road toward Tokarahi, there are distinct pillows with feeders in a roadside outcrop (too hazardous for safe stopping). The pillows are consistent with emplacement onto the seafloor or within but near the surface of unconsolidated sediments of Tapui Formation. Thus, the sill is of Bortonian

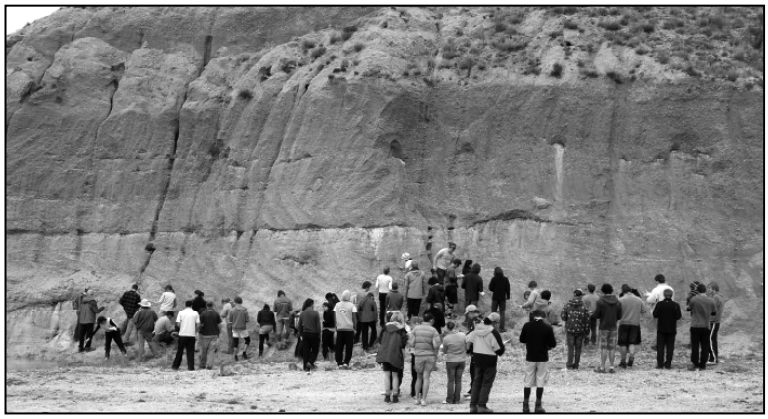
age, older than the basaltic volcanics to the east, for example, Kaiatan tuffs at Lorne, and Runangan-Whaingaroan basalt and tuffs at Weston, Kakanui, and beyond. Coombs et al. (1986) provided more comment on the sill.

SMITH ROAD

If time permits, we will travel southwards along the Danseys Pass Road, Maerewhenua Valley, before turning towards Livingstone to pick up **Smith Road**. This route provides roadside outcrops of quartz sandstones and conglomerates of Taratu Formation, variably massive, or cross-bedded, or channelled; in places, we will pass thick cobble conglomerate, sometimes with angular large clasts of kaolinite. The provenance is presumed to be Haast (Otago) Schist, although rare red chert pebbles suggest a minor Torlesse/semischist component.

Smith Road eventually rises onto the flat, north northeast-dipping, upper surface of the schist. The unconformable contact with the Taratu Formation is preserved in places, prompting thoughts of Hutton who, when seeing such contacts, felt giddy looking into the abyss of time.

Depending on time, again, we may stop at one of several local quarries in thick Taratu sandstones and conglomerates. These sequences fine upwards, and in places show bidirectional crossbeds suggesting alternating and possibly tidal settings. There is no clear contact with overlying Tapui Formation.



Smith Road affords excellent views of the Tokarahi Sill.

TOKARAHI

On the Tokarahi-Danseys Pass road, stop to see Tapui Formation near the Awamoko stream bridge (see photo): calcareous, glauconitic siltstone and sandstone of the Bortonian Stage (middle Eocene). Strata here are cm to dm-parallel-bedded to cross-bedded, with occasional calcareous concretions, and locally marked bioturbation including *Ophiomorpha*. Scattered macroinvertebrates include the age-diagnostic (Bortonian) scallop *Duplipecten ?waihaoensis* and, close by, *Monalaria concinna, Speightia spinosa*, and *Hedecardium* cf *brunneri*; all are consistent with a shallow (inner to mid shelf) marine setting. The upper Tapui Formation at Tokarahi is indifferently exposed, but scattered concretions of Tapui high up slopes near outcrops of Otekaike Limestone indicate a thickness of 40+ m. There are no certain occurrences of Burnside Mudstone which, to

the east and on the Otago Coast, is known to overlie Tapui Formation and/or represent the Bortonian-Kaiatan.

Travel from Tokarahi via Awamoko Valley, to Ngapara, and the Waiareka Valley.

NGAPARA

In **Ngapara**, note the historic flour mill, which was sited here because of the proximity of coal. In 2009, earthworks at an abandoned rubbish pit about 1 km east of Ngapara exposed a clean face of Taratu Formation with a conspicuous coal seam; see the figure.

Return to Oamaru via Waiareka Valley, Enfield, and Weston.

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