FOSSIL TREASURES OF THE GEOLOGY MUSEUM

Daniel B Thomas, Jeffrey H Robinson, and Daphne E Lee
University of Otago

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Fossil Treasures of the Geology Museum (Thomas, Robinson, and Lee)

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This text was compiled on 08/02/2025

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Introduction

The Geology Museum is one of the most inspirational spaces to be found at Ōtākou Whakaihu Waka – University of Otago. Located in the south end of the Department of Geology Building, the Geology Museum holds a wealth of fossils from ancient ecosystems preserved across deep time. These include the forerunners of species living today, including relatives of taoka species with deep local significance (see: World's oldest whitebait swam in volcanic lake). Geology, Zoology, Botany and Marine Science students can learn about the wealth of species that give form to the tree of life (see: Small boulders of fossil bacteria). Research students, visiting scholars, and resident academics can delve into particular fossils, ultimately helping us to enrich our understanding of the ancient and interconnected world in which we live (see: Transitional fossil at the dawn of baleen whales). The Geology Museum is a hub of learning and discovery as are all museums, but is particularly important for the richness of fossil taoka from Te Waipounamu, the South Island of Aotearoa New Zealand.

The Geology Museum is a globally important part of the research infrastructure of the University of Otago. Like the *RV Polaris II*, the Mellor Laboratories Clean Lab facility, or the micro-computed tomography scanner within the Department of Anatomy, the Geology Museum is an asset that produces internationally-significant research outputs. These include discovering many species that are new to science, revealing the history of our biological heritage, providing deep insights into environmental change, and making major contributions to the formation of the first United Nations Educational, Scientific and Cultural Organisation (UNESCO) Global Geopark for Aotearoa.

The discoveries and other insights from the Geology Museum represent a tradition of high quality teaching and research that stretches back 150 years. Students and scholars from around the world have travelled to Ōtepoti Dunedin for the fossil taoka housed within, and to work with the staff who have helped to build the Geology Museum into the valuable collection it is today.

In this volume we invite you to explore fossils from the Geology Museum collections, whether you are able to visit in person or read and explore these fossils using modern technology. Here you can learn about selected fossils, discover when those fossils were found and by whom, and gain insight into why they are important.

We hope you enjoy.

Acknowledgements

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Many people have contributed to *Fossil Treasures of the Geology Museum*. We owe special thanks to Richard White (Manager, Copyright & Open Access) and Kate Thompson (Library Liaison Service & Subject Librarians: Law) from Ōtākou Whakaihu Waka – University of Otago who first gave us the idea of presenting *Fossil Treasures* as an eBook, and who have been generous guides throughout its production. We also thank Richard White for writing the first version of the Acknowledgement of mana whenua section of this eBook, and Frank Edwards (Associate University Librarian: Māori and Strategic Development) for providing guidance on that same section.

We are indebted to the many generations of academic and professional staff, postgraduate and undergraduate students, and visiting researchers and members of the public who have collected, identified, catalogued and described fossils housed in the University of Otago Geology Museum collections since the earliest days of the University. Growing and maintaining the collections is a community achievement that reflects the dedication of many students and other volunteers.

We wish to specifically acknowledge the contributions to the Geology Museum collections made by the late Emeritus Professor Ewan Fordyce FRSNZ, to whom this eBook is dedicated. Ewan's paleontological field and laboratory investigations led to more than 200 publications, most of which addressed the morphology, taxonomy, systematics, and phylogeny of Cetacea (whales, dolphins and porpoises) that are now part of our collections. In addition, Ewan worked on a wide range of other fossil vertebrates such as penguins, fish, turtles as well as a variety of invertebrates over his 40-year career at Otago.

Many of these fossils, especially the large vertebrates, were extracted from the rocks in which they were preserved with assistance from many people whom we have aimed to acknowledge directly in each of the relevant chapters. In addition, one fossil preparator, the late Andrew Grebneff (1959–2010) deserves special mention, as he worked with meticulous care on many of the specimens figured here from 1985 until 2010. More recently, we wish to acknowledge Sophie White, Dianne Nyhof, Marcus Richards and Shane Meekin who worked as preparators of some of the fossils.

We have greatly benefitted from the knowledge and support of our colleagues. Especially Dr Donald MacFarlan for advice on brachiopods and Dr Uwe Kaulfuss for co-writing the chapters on fossil insects. We thank readers and reviewers including Tatsuro Ando, Kane Fleury, Craig Jones, Dan Ksepka, Bill Lee, Donald MacFarlan, Cody Phillips, Sophie White and Yutong (Mike) Wu.

We thank Cody Phillips, Shannah Rhynard-Geil and Kane Fleury for bringing the *Kaiwhekea katiki* skull to the Department of Geology so that it could be 3D scanned.

Professor Andrew Gorman (Head of the Department of Geology) has been supportive of this project since its inception, along with all of our initiatives surrounding paleontology at Otago.

Lastly, we wish to thank Cushla, Catherine and Bill for their unfailing support and encouragement.

Acknowledgement of mana whenua

Ōtākou Whakaihu Waka – the University of Otago – stands on the whenua of Kāi Tahu, the principal iwi of Te Waipounamu, the South Island of Aotearoa New Zealand.

We acknowledge the mana whenua of this region, in particular the three rūnaka whose rohe include this area: Te Rūnanga o Moeraki, Kāti Huirapa Rūnaka ki Puketeraki, and Te Rūnaka o Ōtākou.

We honour their enduring relationship with the land, waters, and all that lies within and upon them — including the fossil taoka held in our museum collections. We recognise the rūnaka as kaitiaki, whose mātauraka (knowledge) and stewardship continues to guide our understanding of this place and its geological treasures.

Dedication



R. Ewan Fordyce examines a composite skeleton of bones assembled from two species of *Kairuku* fossil penguin. Image credit: RE Fordyce. See: When penguins were giants with spear-like bills.

We dedicate this eBook to Dr R. Ewan Fordyce (1953-2023), an inspirational figure who joined the Department of Geology at the University of Otago in 1983. Over time Dr Fordyce became Associate Professor, Professor, FRSNZ, Emeritus Professor. But this eBook is dedicated to that young Dr Fordyce of the 1980s. He had little idea of just how impactful and inspirational his passion for nature would be, and how his path would transform the Geology Museum within the Department of Geology into a globally-recognised centre for fossil vertebrate research.

That early Dr Fordyce didn't have a clue about the great legacy he would leave. But he knew that his position in the Department of Geology and the connection with the Geology Museum it provided brought wonderful opportunities to build meaningful relationships with hundreds of people across Otago and around the world. And by nurturing these relationships Dr Fordyce would build a rich network of friends and colleagues, with whom he would discover and describe fossils that would radiate scientific impact around the world. That early Dr Fordyce reminds us that by staying true to our curiosity and holding people at the centre of what we do, we can achieve great things.

A huge proportion of this eBook are descriptions of those 'great things'. And so we owe a lot to the curiosity and hard work of Ewan. Emeritus Professor R. Ewan Fordyce FRSNZ. Colleague and dearly missed friend.

—Daniel, Jeffrey and Daphne

About the Authors

All three authors of *Fossil Treasures of the Geology Museum* followed their undergraduate studies in geology with PhD research in paleontology at the internationally-acclaimed Department of Geology at Ōtākou Whakaihu Waka – University of Otago. They are excited to share with readers the remarkable and highly diverse collections of fossils housed in the Geology Museum within the Department of Geology, collected by staff, students and members of the public over the past 150 years.



Daniel Thomas is a vertebrate paleontologist with a particular interest in the functional morphology of living and fossil penguins and other birds. He has been Convenor of the Geoscience Society of New Zealand Paleontology Special Interest Group, and, with Jeffrey Robinson and Carolina Loch, co-authored a Special Issue of the *Journal of the Royal Society of New Zealand* in 2024 which celebrates the fossil record of Aotearoa New Zealand and the continuing contributions of Zealandia to global knowledge of vertebrate diversity and evolution.



Jeffrey Robinson has focused his research on invertebrates including living and fossil brachiopods from New Zealand. He is currently working on a database which will eventually include all 60,000 identified fossil specimens housed in the Geology Department collections. This includes photography, reorganisation of the collections and coordinating volunteers.



Daphne Lee has been co-ordinator of research at Foulden Maar since 2003 and has a particular interest in lagerstatten deposits. Her research interests are many and varied, ranging from fossil plants to freshwater diatoms and fish to living and fossil marine invertebrates. In 2017, she received the McKay Hammer from the Geoscience Society of New Zealand, the premier award for geological research in New Zealand, based in part on publications on aspects of Foulden Maar.

CHAPTER OVERVIEW

1: Vertebrates- Fish

While, according to Stephen Jay Gould (1941–2002), there is “no such thing as a fish”, the term ‘fish’ can still be usefully and accurately applied when describing particular groups of aquatic animals. For example, cartilaginous fish (Chondrichthyes) include sharks, rays, sawsharks and chimaeras, which are animals that have inherited a skeleton constructed mostly of cartilage from the ancestor they shared most recently. Ray-finned fish (Actinopterygii) are aquatic animals with mineralised skeletons, with most species in the group having pectoral fins that fan open with the support of thin bones. There are far more species of ray-finned fish living today than there are of cartilaginous fish or any other major group of animals with vertebrae, and we are fortunate to have discovered spectacular examples of both Actinopterygii and Chondrichthyes fossils in Aotearoa New Zealand.

This section introduces some of the cartilaginous and ray-finned fish that are part of the Geology Museum collections. These specimens have been collected from both freshwater and marine depositional environments, and have been recognised from isolated teeth, earbones, or recovered as nearly complete skeletons. Fossil fish are a very important area of vertebrate paleontology which is still relatively understudied in New Zealand. Thus, there are many great opportunities for future researchers to contribute to the fossil record of New Zealand by studying something which famously doesn’t exist.

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1.10: Game fish have ancient history in the South Pacific

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1.1: Exceptional mega shark- distant ancestor of Jaws

Chondrichthyes, Elasmobranchii: *Otodus angustidens*

A set of more than 150 teeth from the extinct mackerel shark, *Otodus* (formerly *Carcharodon) angustidens*, is one of the most complete and best-preserved of its kind in the world.



Teeth and vertebrae from the mega shark *Otodus* (*Carcharodon*) *angustidens* (specimen OU 22261). More than 150 teeth were found as part of this fossil. Image credit: RE Fordyce.

It is unusual to find a complete set of fossil teeth from one shark; rather, most fossil shark teeth are found one at a time. In living sharks, teeth are replaced continuously. Each tooth moves into position in the jaw where it works for a short time – perhaps a few weeks – before it drops out and is replaced. The shed teeth fall to the sea floor to become fossilised single teeth. A natural set of fossil teeth like this specimen marks the final resting place of a single animal. Here, the body of the shark decomposed, to leave only teeth, and a few vertebrae from the spine.

Print Ready

Did you know there is a 3D printable model of this fossil for you to view online and download? Follow this link to learn more: 3D model—Exceptional mega shark: distant ancestor of Jaws.

Otodus angustidens would have resembled the living great white shark, *Carcharodon carcharias*, but was larger than any living shark species. Proportions of teeth and vertebrae suggest that the extinct shark was more than 9 metres long and perhaps weighed around 8 tonnes. Living great white sharks reach about 6 metres long and weigh about 1.2 tonnes.

The specimen is from the upper Kokoamu Greensand or possibly the lower Otekaike Limestone and was discovered near Tokarahi, west of Oamaru. Of late Oligocene age, it was an apex predator in the shallow seas of North Otago, preying on penguins, fish, dolphins and baleen whales. The specimens are on display in the foyer showcase outside the Geology Museum. More teeth and vertebrae from this specimen can be viewed in the *Southern Land, Southern People* gallery in Tūhura Otago Museum in Ōtepoti Dunedin and a replica is displayed at the Vanished World Centre in Duntroon.

—Written by R Ewan Fordyce, with modifications by Daphne E Lee

***Specimen number*:** OU 22261	***Age*:** Approximately 26 million years old (late Oligocene, Duntroonian stage)
***Locality*:** Tokarahi, North Otago	***Rock Formation*:** Transitional zone between Kokoamu Greensand and Otekaike Limestone
***Collected by*:** RE Fordyce, A Grebneff, B Black, H Ichishima, J Daniels, C Jenkins, G McMurtrie, G Curline, S Rust	
***Citation*:** Gottfried MD, Fordyce RE. 2001. An associated specimen of *Carcharodon angustidens* (Chondrichthyes, Lamnidae) from the Late Oligocene of New Zealand, with comments on *Carcharodon* interrelationships. Journal of Vertebrate Paleontology 21:730–739. doi.org/10.1671/0272-4634(2001)021[0730:AASOCA]2.0.CO;2	

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1.2: Small-and-tall shark teeth from deep waters

Chondrichthyes, Elasmobranchii: **Odontaspis sp.**

The living smalltooth sand tiger shark *Odontaspis ferox* mostly occurs along the outer continental shelf and upper continental slope where it hunts along the sea floor. Also known as deepwater nurse sharks, these sharks can also be encountered in shallower waters and at the sea surface but in New Zealand this protected species is more typically found in waters several hundred meters deep around Rangitāhua (Kermadec Islands), and in North Island offshore waters south to New Plymouth and Hawkes Bay. This preference for deeper and temperate to tropical waters has likely been maintained across much of the evolutionary history of sand tiger sharks. Hence, being able to recognise *Odontaspis* fossils collected from a sedimentary horizon can provide geoscientists with useful insights about the ancient environment in which the animals lived.



Fossil teeth from the ancient sand tiger shark *Odontaspis* sp. collected from two different locations (left: OU 9045; right: OU 9046). Differences in the chemistry of the groundwater at each fossil location have resulted in each tooth gaining a different colour while it was buried. Image credit: JH Robinson.

Odontaspis sharks have distinctive teeth that have been found in many locations across Aotearoa New Zealand and around the world. The teeth of *Odontaspis* are often relatively small at 1 or 2 cm long. Each tooth has a primary cusp with one or more lateral cusplets. The root of the tooth curves upwards towards the central point of the tooth. The root is also broad, where it can be as wide as the central point of the tooth is tall. The teeth assist in biting and holding prey, usually smaller fish and crustaceans, caught as the sharks glide along close to the sea floor.

The outer layer of the teeth of *Odontaspis* are formed from enameloid, a tough calcium phosphate material. This material can preserve a sharp cutting edge even millions of years after burial. Enameloid can experience chemical alteration during burial and incorporate a range of elements that alter the colouration. Fossil teeth from sharks including those from *Odontaspis* often appear white, cream, brown, or blue because of these additional elements.

The collections of the University of Otago Geology Museum include *Odontaspis* from several locations including Island Cliff and Kokoamu Bluff in North Otago and Hakataramea Valley in South Canterbury. Other localities further south where *Odontaspis* has been collected include the Pomahaka River and Wangaloa. The discovery of small-but-tall *Odontaspis* shark teeth in these marine sediments contributes to our knowledge of environmental change and helps us realise that inland South Canterbury and South Otago were once occupied by seas considerably warmer than those surrounding the South Island today.

The distinctive teeth of *Odontaspis* sharks are a great toolkit fossil for everyone to keep in mind when they are out looking for fossil remains in New Zealand.

—Written by Daniel B Thomas

***Specimen numbers*:** OU 9045 & OU 9046	***Age range*:** OU 9045, approximately 40 million years old (late Eocene, Bortonian); OU 9046, approximately 25 million years old (late Oligocene, Waitakian)
***Locality*:** OU 9045 Pentland Hills, South Canterbury; OU 9046 Clarendon Hill, South Otago	***Rock Formation*:** OU 9045, Pentland Hills Shellbed; OU 9046, Milburn Limestone
***Collected by*:** RM Carter	
***Citation*:** Chapman F. 1918. Descriptions and revisions of the Cretaceous and Tertiary fish remains of New Zealand. New Zealand Geological Survey Paleontological Bulletin 7:1–45.	

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1.3: Stingrays- opportunities for discovery

Chondrichthyes, Myliobatiformes

Despite being an ecologically-important group of vertebrates in Aotearoa New Zealand and around the world, and being found relatively commonly as fossils, New Zealand fossil stingrays have received very little attention. Indeed, while there are examples of fossil sharks, fossil sawsharks, and fossil bony fish from New Zealand that have been identified as distinct species (see Giant moonfish buried three layers deep), the same level of description has never been reported for a fossil stingray from New Zealand. Which means that at the time of writing, there are many opportunities to contribute to the New Zealand fossil record by studying and describing stingrays.



Two views of a tooth plate from an unidentified species of stingray (specimen OU 22788). The upper view shows the side of the tooth plate with the occlusal surface (i.e. food-grinding surface) towards the top. The lower view shows the ridges on the ventral side (underneath side) that anchor the tooth plate into the jaw. Image credit: JH Robinson.

One of the challenges faced with describing ancient stingrays is that their skeletons are almost entirely constructed from cartilage which tends to break down before it can be preserved in the fossil record. Fortunately, stingrays have tooth plates that are constructed from mineralised tissues and which preserve very well as fossils. These tooth plates have a distinctive shape as they are narrow bars with a smooth occlusal surface on one side (surface for processing food), while on the opposite side there is a surface with ridges where the tooth is embedded into the jaw. Stingrays use their tooth plates to crush the carapaces of crabs and the shells of bivalves, their most common types of prey. Hence, the parts of the stingray skeleton that is most likely to preserve as a fossil is also likely to be informative about ancient diet.

There are many locations across New Zealand where fossil tooth plates have been found. For example, the University of Otago Geology Museum collections include stingray tooth plates from Cosy Dell and Brydone in Southland. This material is a great starting point for any paleontologist who aspires to fill in the major gap in the New Zealand fossil record by studying ancient stingrays.

—Written by Daniel B Thomas

***Specimen number*:** OU 22788	***Age*:** Approximately 26 million years old (Oligocene, Duntroonian stage)
***Locality*:** Waimumu, Southland	***Rock Formation*:** Chatton Formation
***Collected by*:** GSNZ fieldtrip attendee	
***Citation*:** Lee D, Lindqvist J, Beu A, Robinson J, Ayress M, Morgans H, Stein J. 2014. Geological setting and diverse fauna of a Late Oligocene rocky shore ecosystem, Cosy Dell, Southland. New Zealand Journal of Geology and Geophysics 57:195–208. doi.org/10.1080/00288306.2014.898666	

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1.4: Ghostly trace of an egg capsule

Chondrichthyes, Chimaeriformes: *Chimaerotheca reperepe*

Most of the fossils we are familiar with are the sturdier parts of ancient organisms such as shells, bones, teeth and wood. These mineralised or lignified parts are more likely to resist decomposition, and also stand a better chance of remaining intact during burial, uplift and the subsequent exposure to weathering. Fossils that form from the soft, unmineralised parts of animals are very rare by comparison. However, when traces of soft tissues are discovered they can provide insights into the biology and ecology of ancient life beyond what it is possible to learn from bones and teeth alone.



The left image shows a fossilised impression of an egg case, *Chimaerotheca reperepe* (specimen OU 22689). This trace fossil shows where an egg case from a chimeroid once lay against the sediment of an ancient sea floor. The right image shows an egg case from a living species of chimeroid. Image credit: JH Robinson.

In 2014 an impression of an egg capsule from a close relative of a shark was reported from Late Triassic rocks in Southland. The Triassic was the earliest period in the Mesozoic era, which is more commonly known as the age of the dinosaurs, and relatively few fossils from vertebrates have ever been reported from rocks as old as these in New Zealand. Moreover, at the time of discovery this fossil represented the earliest evidence of cartilaginous fish (chimaeras, sharks and rays) in the fossil record of New Zealand.

Did you know there is a 3D printable model of this fossil for you to view online and download? Follow this link to learn more: 3D model—Ghostly trace of an egg capsule.

The egg capsule fossil is from a chimeroid chondrichthyan. Chimeroids are animals within the group Chimaeroidei which includes the reperepe or elephant fish/ Australian ghostshark (*Callorhinchus milii*). Reperepe live in the waters around southern Australia, Tasmania and northern Aotearoa today. Chondrichthyans are fish which have skeletons mostly made from unmineralised cartilage. Like many of their shark relatives, chimeroids reproduce by laying eggs that are protected by a toughened egg capsule constructed from collagen. Chimeroid egg capsules have distinctive shapes, and the Triassic fossil from Southland has a similar shape and size to the egg capsule produced by living reperepe. The similarity in shape tells us that the basic mode of reproduction for chimeroid chondricthyans has remained essentially the same for the last 200 million years.

The fossil is the result of the egg capsule becoming buried in silt and very fine sandstone. The sediment was pressed in close against the outer surface of the egg capsule and became cemented. Over time the collagen and other biological material in the egg capsule decomposed, leaving behind a trace fossil impression. This trace fossil of the chimeroid egg capsule was named *Chimaerotheca reperepe*.

During the time that the animal which made the egg capsule was alive Zealandia was still part of the giant southern landmass Gondwana. The discovery of *Chimaerotheca reperepe* extended the fossil for chimeroids living in the ancient southern ocean alongside Gondwana by more than 100 million years. The discovery also revealed that chimeroid chondricthyans were living at high southern latitudes during the Late Triassic given that Zealandia has drifted northwards in the time since the egg capsule was made.

—Written by Daniel B Thomas

***Specimen number*:** OU 22689	***Age*:** Approximately 208 million years old (late Triassic, Warepan or Otapirian stage)
***Locality*:** Taringatura Hills, Southland	***Rock Formation*:** Murihiku Terrane (formation not identified in publication)
***Collected by*:** G Asher	
***Citation*:** Gottfried MD, Fordyce RE. 2015. A Late Triassic chimaeroid egg capsule from New Zealand: early evidence of chimaeroid reproductive mode from the eastern margin of Gondwana. Journal of Systematic Paleontology 13:371–375. doi.org/10.1080/14772019.2014.880752	

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1.5: Robinson's pilchard- the importance of earbones

Osteichthyes, Clupeiformes: *Sardinops robinsoni*

Some species have parts to their skeletons that look almost identical to that same part from a different species. For example, it can be difficult to identify which species of dolphin a rib might belong to or which species of bird a toe bone might be from: many species of fish have similar looking fin rays. Often the shapes of these bones are the same between species and only the sizes of their bones varies. This means that if we find a fossil rib separated from the rest of the skeleton then we might be able to say that rib is from an ancient dolphin, but we would probably never know which species of dolphin it came from.

In contrast, sometimes a small body part is so distinctive that it identifies a species all by itself. This is the case with otoliths in fish.

Otoliths (ear stones) are mineral structures in the inner ear that have an important role in helping an animal to sense movement and maintain balance. When a fish moves its head the otoliths within also move, applying a gentle force to the surrounding tissue and giving the fish its sense of motion. Otoliths aren't technically part of the skeleton however. Instead, otoliths are accumulations of calcium carbonate, the same material that molluscs use to construct their shells, and not calcium phosphate, the material that bones and teeth are built from. Regardless, otoliths are important to the sensory systems of all vertebrate species including humans and have particularly distinctive shapes in ray-finned fish (Actinopterygii).

In 2017 Werner Schwarzhans and his coauthors recognised 32 species of fossil fish by studying otoliths from New Zealand, with 14 of these species being new to science. These species were from six locations of late Oligocene age across the southern South Island of New Zealand. The number of otoliths collected from each location varied with one site producing several hundred specimens. It was at this location that Robinson's pilchard was discovered (*Sardinops robinsoni*).

An otolith from *Sardinops robinsoni* is approximately 2 mm long and without a microscope might be mistaken for a coarse grain of sand. On closer inspection an otolith from this species "…is easily recognised by the characteristic shape of the rostrum and the deep excisura and moderately large antirostrum…" In simpler terms, this otolith has a smaller upper curve that is separated by a deep groove from a larger and pointed lower curve. Which is nearly exactly what the otolith in a living sardine looks like.

Sardines today (*Sardinops sagax*) have a global distribution which includes New Zealand where they are known locally as mōhimōhi, mōhi, and pilchards. Sardines are most commonly found in warmer coastal waters and along the continental margin in large embayments like Tīkapa Moana (the Hauraki Gulf). Slightly unusually, Robinson's pilchard was collected from sediments deposited in a rocky shore to shallow subtidal environment, which might indicate that sardine ecology has changed over time. However, as the evolutionary relationship between living sardines and Robinson's pilchard is not yet clear we don't know how New Zealand connects with the global sardine story. Given how important pilchards are to local marine food webs though, the discovery of Robinson's pilchard provides important insight into the marine food webs of Zealandia during the late Oligocene.

—Written by Daniel B Thomas

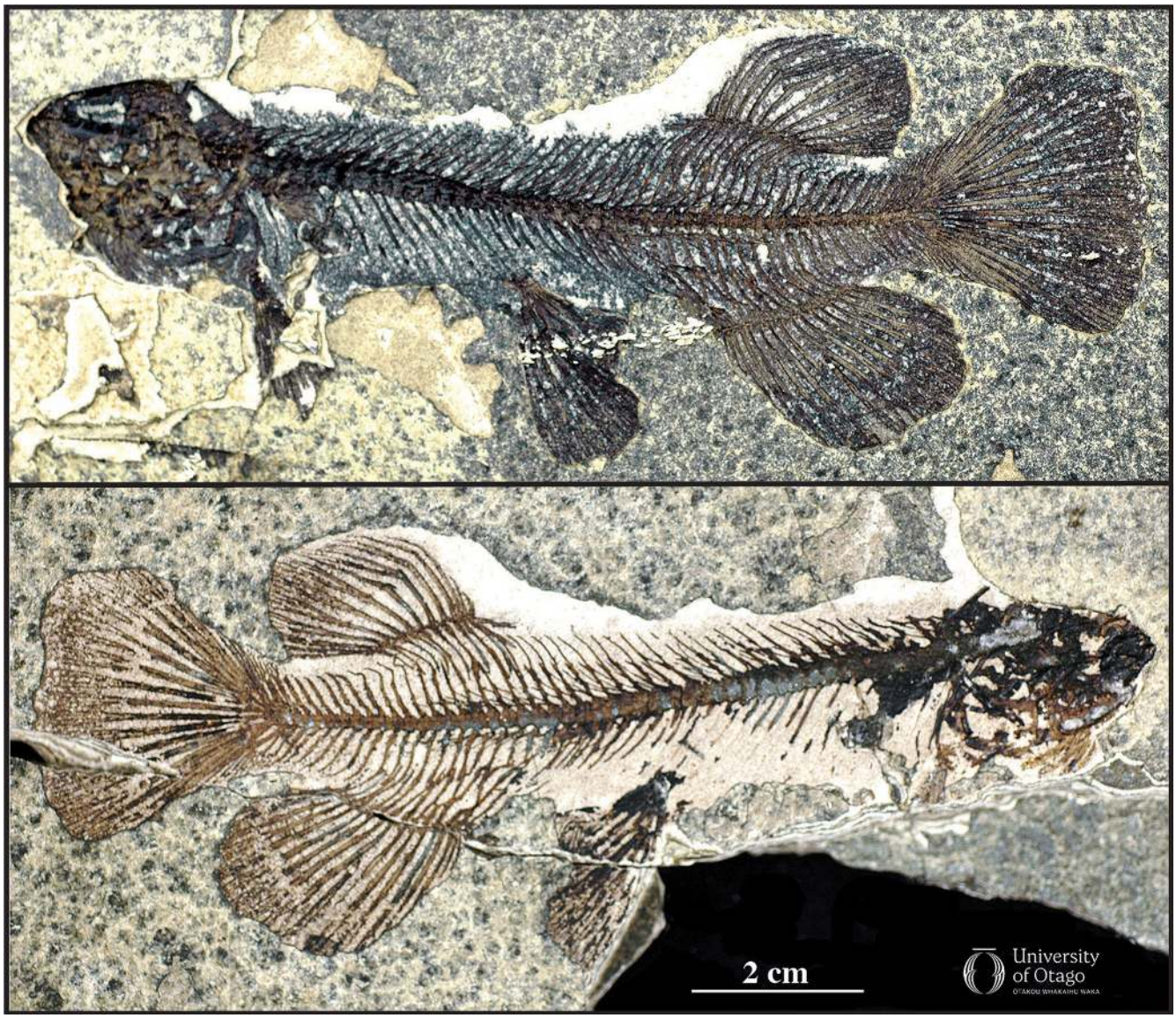
***Specimen number*:** OU 22806	***Age*:** 25.4 to 24.4 million years ago (late Oligocene, boundary between the Duntroonian and Waitakian stages)
***Locality*:** Waimumu, Southland	***Rock Formation*:** Chatton Formation
***Collected by*:** HJ Gard	
***Citation*:** Schwarzhans W, Lee DE, Gard HJ. 2017. Otoliths reveal diverse fish communities in Late Oligocene estuarine to deep-water paleoenvironments in southern Zealandia. New Zealand Journal of Geology and Geophysics 60:433–464. doi.org/10.1080/00288306.2017.1365734	

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1.6: World's oldest whitebait swam in volcanic lake

Osteichthyes, Galaxiiformes: *Galaxias effusus*

'Galaxiid' is the name often given to a distinctive Southern Hemisphere group of small to medium-sized freshwater fish (100 mm to 580 mm long as adults) that have no scales and lack an adipose fin. More than 20 species are currently recognised in the modern New Zealand fauna, but the exact number of species is a little unclear. The juveniles of five species that make up 'whitebait' were once abundant in many New Zealand streams, rivers, lakes and swamps, but are now under threat from habitat modification and overfishing. Local names for galaxiids include galaxias, mudfish, inanga or inaka (for Kāi Tahu) and kōkopu, amongst many other te reo Māori names used variously by iwi for adult and juvenile fish. The family name Galaxiidae refers to the small, silvery-gold star-like patterning seen on many galaxiid fish.



The part and counterpart of the holotype of *Galaxias effusus* (OU 22650). The 14 cm long fish was given the species name *effusus* because of the 'lavish or extravagant' fins compared to living species in the same genus. The original delicate fish bone material has been mostly dissolved (decalcified) and partly replaced by pyrite and brownish black residual material. Image re-use permission kindly provided by Journal of the Royal Society of New Zealand and originally published in: Lee DE, McDowall RM, Lindqvist JK. 2007. *Galaxias* fossils from Miocene lake deposits, Otago, New Zealand: The earliest records of the Southern Hemisphere family Galaxiidae (Teleostei). Journal of the Royal Society of New Zealand 37:109–130. doi.org/10.1080/03014220709510540.

Long considered to be of Gondwanan origin, galaxiids are found today in Tasmania, Australia, New Caledonia, South America, including the Falkland Islands, as well as New Zealand. In Aotearoa today, species occur from Northland to Stewart Island and as far afield as the Chatham Islands, Auckland and Campbell Islands. Most species are diadromous, spending the early part of their life cycle at sea before returning to freshwater environments to reproduce. A few species are land-locked and non-diadromous (from choice or chance) and their entire life cycle takes place in lakes.

Globally, the only known galaxiid fossils occur in lake deposits in Otago. The species *Galaxias effusus* found at Foulden Maar, at 23 million years old, is the oldest found so far. The best-preserved and most complete fish to be found at Foulden was effectively 'filleted' by a field knife splitting the laminated diatomite in which it occurred, with one side preserved on one layer and the counterpart on the other. The fish is more stout-bodied than most living *Galaxias* and differs from all modern species in its relatively low vertebral count, and expansive dorsal, anal and caudal fins.

More than 100 galaxiid fossils have now been collected from the two small Foulden mining pits; most are articulated, laterally compressed skeletons. They range from 40 mm larvae (whitebait) to 140mm long adults. Randomly dispersed throughout the exposed diatomite sequence, the little fish show no preferred orientation and no mass mortality layers have been observed. The exceptional preservation of soft tissue with eyes, skin and skin patterning is one of the reasons why the term *Konservat-Lagerstätte* is applied to Foulden Maar.

The stratified nature of the maar lake meant that only the upper few metres had sufficient oxygen for fish to thrive. The deeper bottom waters were anoxic so the fish may have succumbed to low oxygen levels if they swam down too far (many specimens died with gaping mouths). The lack of current activity and absence of bioturbation or scavenging at the bottom of the deep lake meant that the little fish remains lay undisturbed until covered by each successive seasonal rain of diatoms.

At Foulden Maar, the remarkable level of preservation allows us to identify the food of these 23 million year old fish. Living galaxiids in New Zealand are generalised invertebrate predators, eating beetles, moths and caterpillars, as well as aquatic insects including caddisflies, mayflies, midges and their larvae. Some of the Foulden fish have gut contents that preserve their final meal and indirect evidence for their food is abundant in the form of coprolites.

—Written by Daphne E Lee

***Specimen number*:** OU 22650	***Age*:** 23 million years old (early Miocene, Waitakian stage)
***Locality*:** Middlemarch, Otago	***Rock Formation*:** Foulden Hills Diatomite
***Collected by*:** DE Lee	
***Citation*:** Lee DE, McDowall RM, Lindqvist JK. 2007. *Galaxias* fossils from Miocene lake deposits, Otago, New Zealand: the earliest records of the Southern Hemisphere family Galaxiidae (Teleostei). Journal of the Royal Society of New Zealand 37:109–130. doi.org/10.1080/03014220709510540	

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1.7: Giant moonfish buried three layers deep

Osteichthyes, Lampriformes: *Megalampris keyesi*

The Waitaki Whitestone Global Geopark is celebrated for being the first United Nations Educational, Scientific and Cultural Organization (UNESCO) Global Geopark in New Zealand. The journey towards recognising this international landmark has its origins in the early partnerships formed between Ewan Fordyce, the Department of Geology, University of Otago, and local land owners and custodians. These partnerships began in the 1980s and 1990s when Ewan was developing his paleontology field programme across North Otago and South Canterbury. In the mid-1990s he visited the limestone bluffs of Island Cliff in the heart of the future UNESCO Global Geopark to search for ancient whales.



Bones from the giant moonfish *Megalampris keyesi* (specimen OU 22268). This fossil is currently on display at Tūhura Otago Museum in the Southern Land, Southern People gallery. Image credit: K Fleury.

At this site, Ewan and his team discovered the best preserved example of a large fossil shark that had ever been found in Aotearoa New Zealand (read about this discovery here: Exceptional mega shark: distant ancestor of Jaws). Several blocks of limestone containing the fossil teeth and vertebrae were cut from the bluffs by a small team during the summer of 1995, and the blocks were encased in plaster jackets for transport back to the Geology Department. Upon peering into the pit resulting from the fossil excavation, the team discovered another fossil lying beneath the burial site of the fossil shark. This second specimen, the skull of an archaic dolphin, would later be studied by one of Ewan's students. Peering back into the pit again after the dolphin skull had been removed, the team discovered yet another fossil. This third fossil would become the type specimen of *Megalampris keyesi*, the largest bony fish fossil ever discovered in Aotearoa New Zealand.

Megalampris keyesi is an extinct member of the Lampriformes order of bony fish. Living species within Lampriformes are characterised by an extremely elongate body: species like scalloped dealfish *Zu elongatus*, unicornfish *Lophotus capellei* and especially the oarfish *Regalecus glesne* are rarely seen around New Zealand. In contrast, the more oval-shaped moonfish, *Lampris guttatus* and opah *Lampris immaculatus*, are encountered more commonly in New Zealand waters. Moonfish prefer tropical to temperate waters and around New Zealand they have been found in surface waters down to 500 metres, reaching a full length of 200 centimetres.

Megalampris keyesi was twice as large as living moonfish at approximately four metres long. The fossil fish was collected in three limestone blocks that revealed bones from the skull all the way through to the tail. Large bones associated with the pectoral fins suggest that *Megalampris keyesi* moved by paddling through the water just like living moonfish. The giant fossil specimen was

collected from sediments deposited in quiet waters along the middle to outer continental shelf, a similar environment to that inhabited by moonfish today. At the time of discovery *Megalampris keyesi* was the first fossil species within Lampriformes ever reported from the Southern Hemisphere. A possible second discovery may have been made in Raglan in the North Island of New Zealand, and has been investigated by Michael Gottfried, lead author on the study that described *Megalampris keyesi.*

The Island Cliff fossil locality within the UNESCO Waitaki Whitestone Global Geopark is now famous for producing both the best preserved large fossil shark and the largest fossil fish, both from the same spot.

—Written by Daniel B Thomas

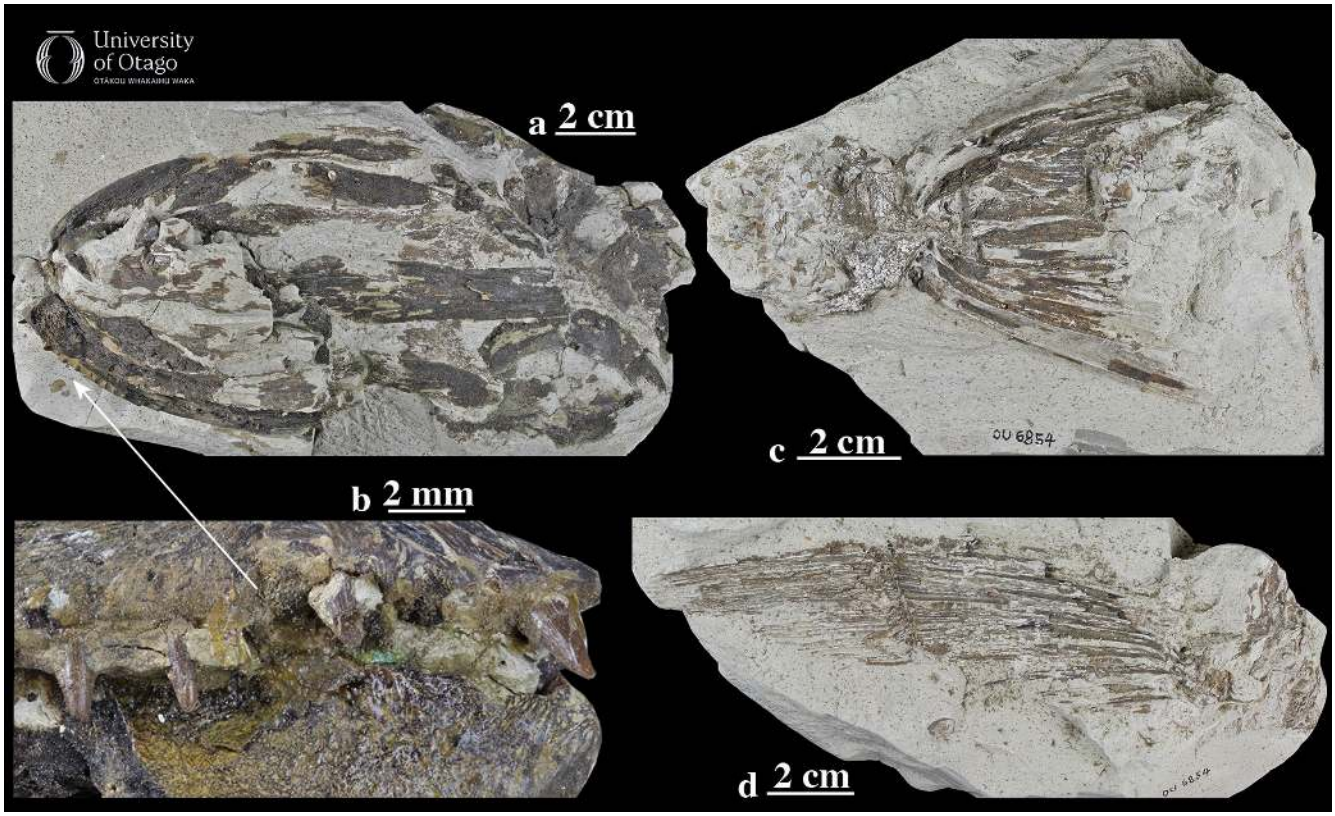
***Specimen number*:** OU 22268	***Age*:** Approximately 26 million years old (late Oligocene, Duntroonian stage)
***Locality*:** Tokarahi, North Otago	***Rock Formation*:** Otekaike Limestone
***Collected by*:** RE Fordyce, A Grebneff, B Black and associates	
***Citation*:** Gottfried MD, Fordyce RE, Rust S. 2006. *Megalampris keyesi*, a giant moonfish (Teleostei, Lampridiformes) from the Late Oligocene of New Zealand. Journal of Vertebrate Paleontology 26:544–551. doi:10.1671/0272-4634(2006)26[544:MKAGM	

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1.8: Dawn barracouta from Dunedin studied across time

Osteichthyes, Scombriformes: *Eothyrsites holosquamatus*

The University of Otago Geology Museum holds within its collections many fossils with long and storied histories. Advances in knowledge and new discoveries can mean that a fossil might be studied and restudied by many students and other researchers often decades apart. This is one of the key reasons it is important to protect natural history collections for future generations – with fresh ideas from new researchers using emerging technologies we know there can be more to learn! And such has been the case with an ancient fish unearthed in a quarry near Ōtepoti Dunedin, less than ten kilometres from the University of Otago Geology Museum.



Fragments of the Dawn barracouta *Eothyrsites holosquamatus* (specimen OU6854). Images labelled a) and b) show the skull of the ancient fish, including a close up of the teeth. Image c) shows the tail of the fish and image d) shows one of the fins. Image source: Figure 3 in S Rust, and JH Robinson (2024) Revisiting *Eothyrsites holosquamatus* Chapman (Trichiuroidea: Gempylidae), an Eocene gemfish from the Burnside Mudstone, Dunedin, New Zealand, which is licensed under CC BY-NC-ND 4.0. Image credit: JH Robinson.

Between 1929 and 1933 fragments of a fossil fish were found in a quarry in Burnside, a western suburb of Dunedin. The fossil was brought to the Chair of Geology and Mineralogy at the University of Otago, Professor WN (Noel) Benson. Professor Benson recognised that the fossil remains were from a fish and were important, and looked for help with identifying the fossil. But because geoscience expertise was still developing in Aotearoa New Zealand there was no one locally to provide the help that Professor Benson was seeking. Fortunately though, help was waiting on the other side of the Tasman Sea.

Frederick Chapman was the inaugural Australian Commonwealth Palaeontologist and was based in the National Museum in Melbourne, Australia. He had described fish fossils from Aotearoa in 1918, many years before Professor Benson received the Burnside fossil fish material. In 1933 Professor Benson visited Melbourne with two fossil fish from the University of Otago Geology Museum collections. One of these fossils was the Burnside fish, which was preserved in several fragments all from the same animal. The preserved parts included vertebrae, scales, a pectoral fin, and a fragment containing the lower jaw. Mr Chapman studied the material and recognised that the fish was a relative of predatory species found in the Australian and New Zealand region today. Mr Chapman named the fossil *Eothyrsites holosquamatus*, or ‘dawn barracouta entirely covered in scales’.

Eothyrsites holosquamatus was a long and slender fish that would have hunted other fish in the upper layer of open ocean waters that were 200 meters or more deep, an environment occupied by the living manga/maka New Zealand barracouta *Thyrsites atun* today. *Eothyrsites holosquamatus* would have been around 700 mm long and had a skull that was about 190 mm long. This ancient predatory fish lived in the middle to late Eocene between about 39 and 36 million years ago.

In the mid-1950s, more fossil fish fragments were discovered in the same location within the quarry in Burnside and were added to the Geology Museum collections. With Chapman's death more than a decade earlier, Professor Benson looked elsewhere for help with studying these newly discovered fragments. However, this project would remain incomplete in Benson's lifetime, and the new material drifted into obscurity in the Geology Museum collections. Decades later in the 1990s, University of Otago student Seabourne Rust rediscovered these fragments and re-examined them as part of his Master of Science thesis research. And several decades beyond that in the early 2020s, Seabourne Rust and Jeffrey Robinson would describe how the fragments discovered in the 1930s and in the 1950s were from the same individual fish, solving a 90 year old puzzle.

So is it barracouta or barracuda? Some readers might be more familiar with the latter spelling, especially if they know the famous song by Heart. Barracouta and barracuda are both correct but they are names for distantly-related fish. Species that are distant relatives can look very similar when they are the descendants of lineages that have faced similar challenges. The barracouta in this story refers to a type of snake mackerel in the family Gempylidae. Barracuda are instead species within the family Sphyraenidae. Both barracouta and barracuda are large, slender and swift predators, and have gained similar names owing to their similar appearance.

—Written by Daniel B Thomas

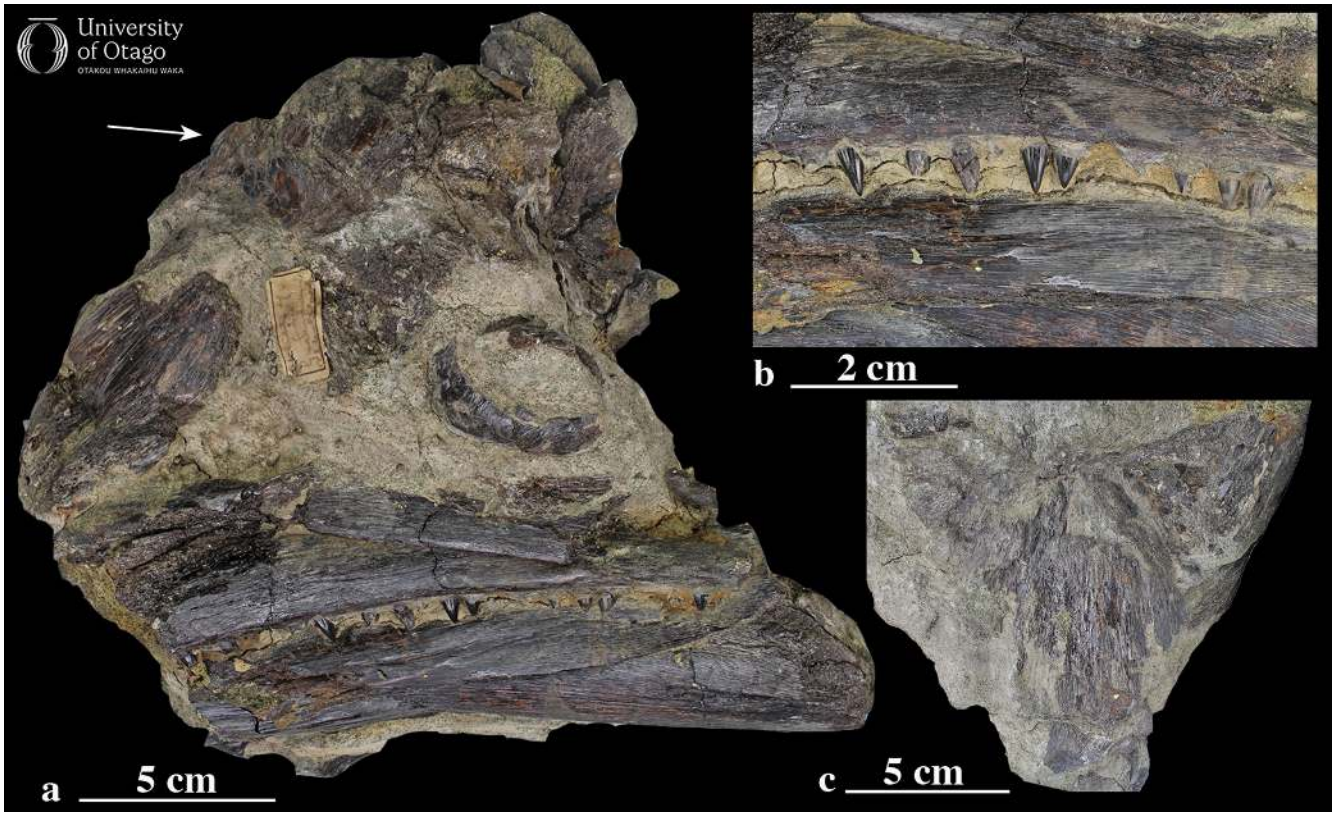
***Specimen numbers*:** OU 6329, OU 6332, OU 6854	***Age*:** Approximately 36 million years old (late Eocene, Kaiatan stage)
***Locality*:** Ōtepoti Dunedin, Otago	***Rock Formation*:** Burnside Marl
***Collected by*:** Information not recorded	
***Citations*:** Chapman F. 1935. Descriptions of fossil fish from New Zealand. Transactions and Proceedings of the Royal Society of New Zealand. 64:117–121; Rust S, Robinson JH. 2024. Revisiting *Eothyrsites holosquamatus* Chapman (Trichiuroidea: Gempylidae), an Eocene Gemfish from the Burnside Mudstone, Dunedin, New Zealand. Journal of the Royal Society of New Zealand 54:584–601. doi.org/10.1080/03036758.2023.2228211	

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1.9: A fast-swimming ancient mackerel-like fish from Abbotsford

Osteichthyes, Scombriformes: *Scombrinus dunedinensis*

In the early 1930s Professor William Noel Benson took a small collection of fossil material to a fossil fish expert Frederick Chapman in Australia (read more about this here: Dawn barracouta from Dunedin studied across time). One of the specimens that Professor Benson had with him was a crushed but still impressive partial skull with a row of ferocious teeth. The skull measures about 18 cm tall, 17 cm long and around 12 cm wide. The fossil preserves 16 teeth but a full set would have comprised 36 teeth. The fossil is embedded in a marly greensand matrix. Chapman would eventually describe this skull as a new species of ancient mackerel-type fish.



Three views of the skull of the ancient mackerel-like fish *Scombrinus dunedinensis* (specimen OU 6855). View (a) shows the partially-preserved skull, view (b) shows a close-up of the well-preserved teeth, and view (c) a view of the other side of the fossil block. Image credit: JH Robinson.

Professor Benson had borrowed the skull from the ‘Marshall collection’, a subset of fossils within the University of Otago Geology Museum that had been curated by Professor Patrick Marshall. From 1901 to 1906 Marshall was a lecturer, and then professor, in the Otago School of Mines, the predecessor to the Department of Geology.

When Chapman described the fossil skull he used the name “Portheus”, which is no longer used. Instead the specimen is now named *Scombrinus dunedinensis* while it awaits new and more detailed study. *Scombrinus* is an extinct genus of mackerel-like bony fish that lived during the Eocene. The specimen is unlike any other fossil or living fish known from Aotearoa New Zealand and most closely resembles mackerel-like fish collected from the Eocene London Clay, on the other side of the world from Ōtepoti Dunedin.

—Written by Daphne E Lee and Jeffrey H Robinson

***Specimen number*:** OU 6855	***Age*:** Approximately 47 million years old (middle Eocene, Heretaungan stage)

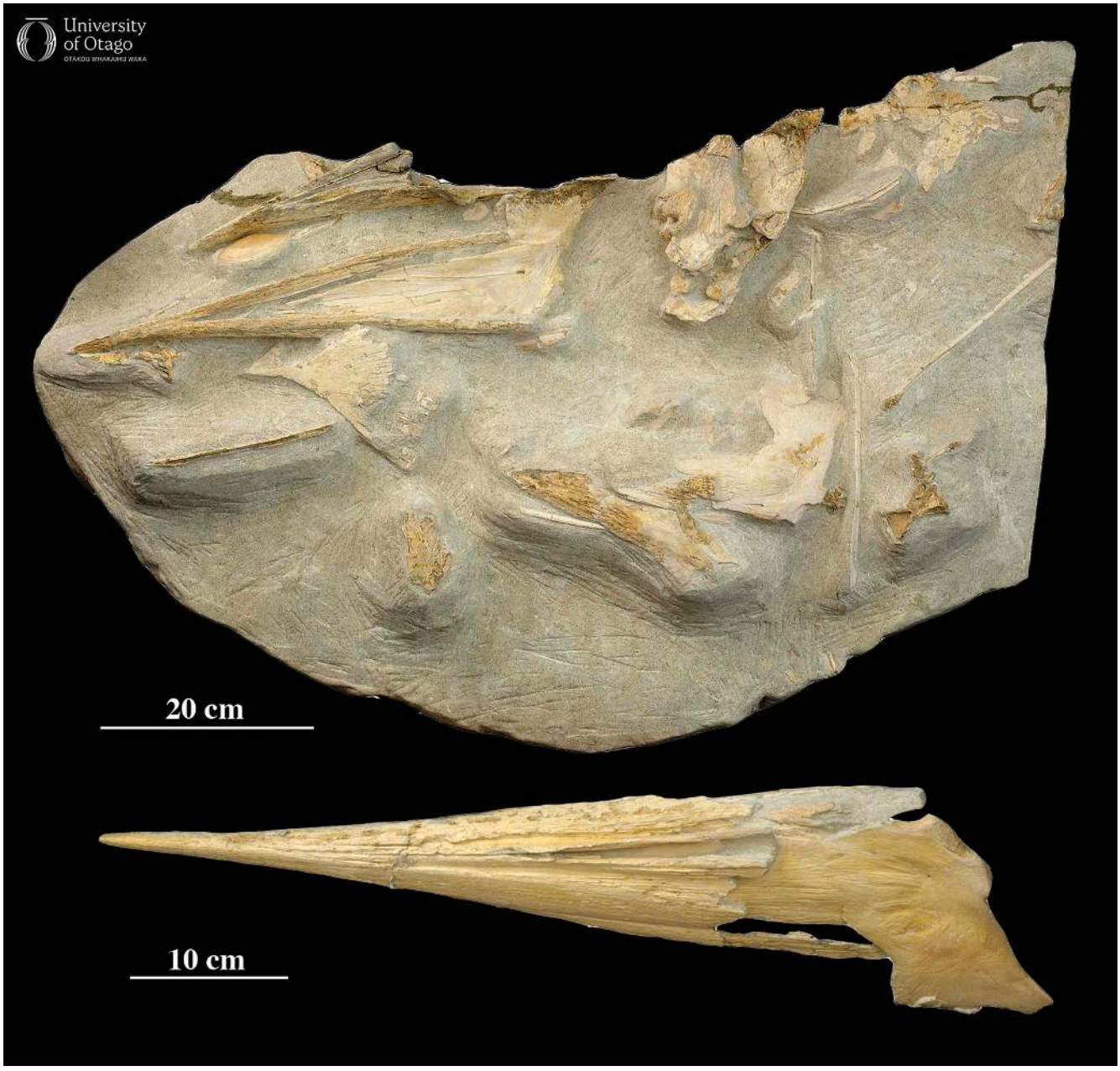
***Locality*:** Ōtepoti Dunedin, Otago	***Rock Formation*:** Abbotsford Formation
***Collected by*:** Information not available	
***Citation*:** Robinson JH, Lee ED, Richards MD, White SEM, Fordyce RE. 2024. The fossil vertebrate primary type specimens in the collection of the University of Otago Department of Geology, Journal of the Royal Society of New Zealand 54:566–583. doi: 10.1080/03036758.2024.2363436	

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1.10: Game fish have ancient history in the South Pacific

Osteichthyes, Scombriformes: *Aglyptorhynchus hakataramea*

Billfish are large marine bony fish that today include marlin (e.g. *Makaira nigricans*), sailfish (e.g. *Istiophorus platypterus*) and swordfish (*Xiphias gladius*). In addition to their iconic pointed bills, billfish are known for being top predators that feed on other fish as well as squid and crustaceans. Today billfish are found in temperate and tropical waters worldwide but have a fossil record that is mostly restricted to the Northern Hemisphere. Only fragments of skeletons had been reported from Chile, Peru, southern Africa, and Antarctica. This all changed with an incredible discovery made by Brett Black in 1998 in South Canterbury, New Zealand.



Bones from the billfish *Aglyptorhynchus hakataramea* (specimen OU 22396). The upper image shows fragments from the skull and the lower image shows the pointed upper jaw or 'bill' for which this group of fish are named. Image credit: RE Fordyce.

Bones from a fossil fish were found in a limestone quarry in the Hakataramea Valley. The limestone in this quarry dates back to the late Oligocene giving the fossil an estimated age of around 25 or 26 million years old. The bones from the fossil were spread out in a broad line across more than three metres, and the limestone containing these fossils was collected as four large blocks for transport back to the Department of Geology. There the fossil was revealed to be a partial skeleton that included the iconic pointed bill of a billfish along with the lower jaw, sections of the back of the skull, 12 vertebrae, bones from the fins, and several ribs. The fossil was described in 2012 by Michael Gottfried, Ewan Fordyce and Seabourne Rust as *Aglyptorhynchus hakataramea*. Species of *Aglyptorhynchus* billfish had previously been found in Europe and the USA, and so the discovery of *Aglyptorhynchus hakataramea* revealed a much broader geographic distribution for this group of fish than had previously been known. Indeed, the latitudinal range of the ancient *Aglyptorhynchus* billfish now more closely matched the range of living billfish such as swordfish, providing support for the idea that these top predatory fish have ranged across the world's oceans for tens of millions of years.



Did you know there is a 3D printable model of this fossil for you to view online and download? Follow this link to learn more: 3D model—Game fish have ancient history in South Pacific.

When the researchers described *Aglyptorhynchus hakataramea* they reflected on an unusual feature of billfish that might have explained this broad geographic range. Billfish and all other ray-finned fish (actinopterygians) are ectothermic which means they mostly rely on external sources of energy for heat (are 'cold-blooded'). However, living species of billfish have the rare ability to generate their own warmth using a modified eye muscle, so are 'warm-blooded' to a limited extent. This allows billfish to hunt and swim in a wide range of sea temperatures. If *Aglyptorhynchus* billfish also had the ability to generate their own heat then this feature might have allowed them to live in seas with a broader range of temperatures, potentially explaining the wide geographic distribution of these fish in the fossil record.

The discovery of *Aglyptorhynchus hakataramea* added another large bony fish to the fossil record for New Zealand alongside the previously described giant moonfish *Megalampris keyesi* which is on display at Tūhura Otago Museum in Ōtepoti Dunedin. Based on the length of the rostrum of *Aglyptorhynchus hakataramea* (i.e. rostrum is the technical term for the bill), and the position of the eye, the researchers estimated that *Aglyptorhynchus hakataramea* had a body length of between three and four metres, similar in size to billfish living today. *Aglyptorhynchus hakataramea* shows a jaw shape that the researchers suspected meant that it primarily hunted squid in the open ocean surrounding Zealandia.

—Written by Daniel B Thomas

***Specimen number*:** OU 22396	***Age*:** Approximately 26 million years old (late Oligocene, Duntroonian stage)
***Locality*:** Hakataramea Valley, South Canterbury	***Rock Formation*:** Otekaike Limestone
***Collected by*:** RE Fordyce, S Rust, A Grebneff, S Wilson	
***Citation*:** Gottfried MD, Fordyce RE, Rust S. 2012. A new billfish (Perciformes, Xiphioidei) from the late Oligocene of New Zealand. Journal of Vertebrate Paleontology 32:27–34. doi:10.1080/02724634.2012.634471	

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CHAPTER OVERVIEW

2: Vertebrates- Reptiles

The term ‘reptile’, like ‘fish’, can be usefully applied to groups of animals today even if the way these words have been used has changed over time (see Vertebrates: Fish).

Living reptiles encompass a huge range of biodiversity which includes turtles, tuatara, lizards, snakes and crocodiles. These are all ectothermic animals (‘cold-blooded’) with skin covered in scales. Reptile biodiversity becomes even broader when we include extinct marine reptiles such as mosasaurs, plesiosaurs and ichthyosaurs. Living and extinct, these reptile groups are each the descendant of an ancestor with skin containing scales made from keratin (the material our hair and nails is constructed from), having hatched from an egg with a protective outer shell, and possessing a skull with two open spaces on both the left and right sides used for muscle attachment. The challenge here is that dinosaurs are descendants of that same ancestor, and birds are descendants of dinosaurs. The term ‘reptile’ becomes less useful for describing a scaly ectotherm when we need to also include birds in that same definition. This section features the diapsid and anapsid amniotes that are not dinosaurs: here we refer to those animals as ‘reptiles’, and save birds for their own section.

2.1: Marine reptile from oceans ancient before Zealandia formed

2.2: Predator lizard discovered in the Waipara Valley

2.3: Fossil from the Discworld? Giant turtle named for famed author

2.4: Most complete dinosaur-aged reptile from Aotearoa

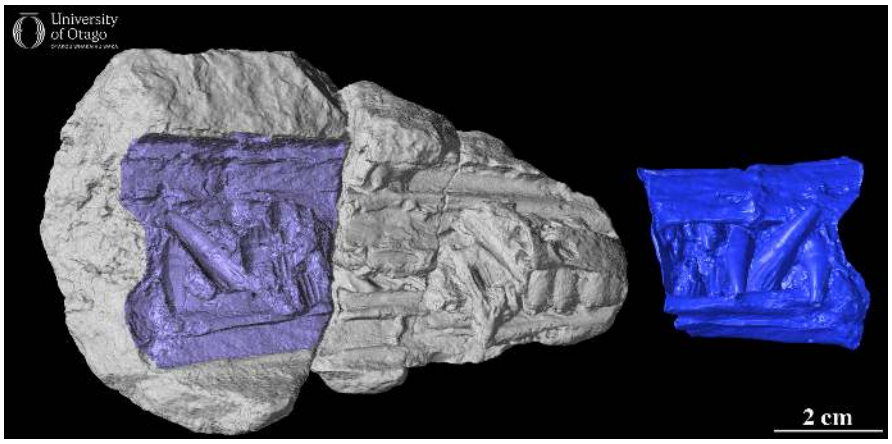
2.5: Crikey! Lake crocodilian from Central Otago

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2.1: Marine reptile from oceans ancient before Zealandia formed

Sauropsida, Ichthyosauria

Ichthyosaurs, plesiosaurs and mosasaurs are among the most recognisable groups of reptiles that patrolled the oceans during the age of the land-dwelling dinosaurs. Ichthyosaurs were approximately dolphin-shaped animals with the key distinction of having a vertical tail fin.



The left image shows a 3D scan of the natural mould of the snout from an unidentified species of ichthyosaur (specimen OU 3859). A natural mould, or trace fossil, shows where the jaws of the marine reptile pressed into the sediment of an ancient sea floor. The light blue region on the left image shows the section of the fossil where a cast was made. The right image shows a 3D scan of the cast made from the natural mould. The shapes of the teeth are clearly visible in the cast. Image credit: DB Thomas.

A deeply-ancient group, ichthyosaurs first appeared at the beginning of the Triassic about 250 million years ago and survived until the beginning of the Late Cretaceous around 90 million years ago. This means that ichthyosaurs died out before Zealandia had completely separated from the larger southern landmass Gondwana. Ichthyosaurs instead lived in oceans so old that marine rocks containing their fossil remains have been incorporated into the weathered and eroded basement rocks of Zealandia. Ichthyosaurs are thus among the least known marine reptile groups from Aotearoa New Zealand but one remarkable discovery was made by University of Otago paleontologist John Douglas (Doug) Campbell during the summer of 1964 while he was undertaking field work in the Hokonui Hills, Southland.

Print Ready

Did you know there is a 3D printable model of this fossil for you to view online and download? Follow this link to learn more: 3D model—Marine reptile from oceans ancient before Zealandia formed.

The Hokonui Hills ichthyosaur is a natural fossil mould that formed when the decaying body including jaws and teeth of an ichthyosaur sank onto ancient sea floor sediment more than 217 million years ago during the Triassic. The bones later dissolved, leaving behind a mould of the fossil rather than the remains of the animal itself. The natural mould records a fragment of the skull from close to the tip of the snout. The preservation detail is so fine that delicate impressions of ridges on the teeth are clearly visible.

Doug Campbell sent a cast of the fossil to Dr Alan Jack Charig, Curator of Fossil Amphibians, Reptiles and Birds at the Natural History Museum in London, with a request for help with an identification. The fossil was then described in an article published in the New Zealand Journal of Geology and Geophysics along with Dr Charig's statement that "…[*t*]*he specimen consists of parts of the jaws and teeth of a medium-sized ichthyosaur, apparently indistinguishable from the corresponding fragment of various forms in the Lower Lias of Dorset…*[*t*]*he specimen, like all post-Triassic ichthyosaurs, has teeth of the usual ichthyosaur type set in an open groove and not in separate alveoli…*".

Very little else about the Hokonui Hills ichthyosaur is currently known. Ichthyosaurs are thus another fossil group where a future researcher could make important contributions to the New Zealand fossil record.

—Written by Daniel B Thomas

***Specimen number*:** OU 3859	***Age*:** 219 to 217 million years ago (late Triassic, upper Otamitan stage)
***Locality*:** Otamita Stream, Southland	***Rock Formation*:** Mandeville Sandstone
***Collected by*:** JD Campbell, RM Carter	
***Citation*:** Campbell JD. 1965. New Zealand Triassic saurians. New Zealand Journal of Geology and Geophysics 8:505–509. doi:10.1080/00288306.1965.10426420	

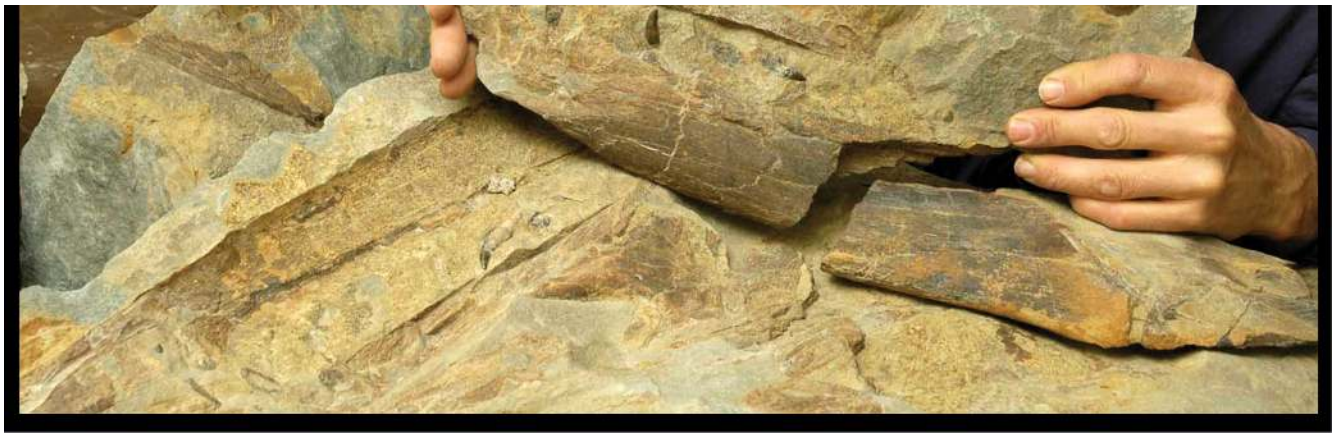
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2.2: Predator lizard discovered in the Waipara Valley

Sauropsida, Mosasauria

Mosasaurs are extinct marine lizards that are more closely related to geckos and skinks (te reo Māori: mokomoko) than they are to birds (te reo Māori: manu) and other dinosaurs. Unlike geckos and skinks though, mosasaurs grew to be several metres long and looked a little like large crocodiles with paddle-like flippers. Mosasaurs patrolled the world's oceans for millions of years until around 66 million years ago when they became extinct along with non-avian dinosaurs, plesiosaurs and other animals during the great catastrophic extinction event at the end of Cretaceous times. Mosasaur fossils are not common discoveries in Aotearoa New Zealand but have been reported from a few regions around the country since the mid-1800s.





Collection and preparation of the mosasaur fossil from the Waipara Valley. Image credit: RE Fordyce.

In April 2004 one of the most complete mosasaur skulls ever discovered in Aotearoa was found in the Waipara region of North Canterbury. The skull was from an animal that was perhaps 5 m long and shared similarities with another mosasaur found in the same region, *Prognathodon waiparaensis*. Before this discovery, fossil reptiles were last described from the Waipara region in 1971 by Samuel Welles (University of California, Berkeley) and Don Gregg (then Curator of Geology at Canterbury Museum). Welles and Gregg named *Prognathodon waiparaensis* based on a partial skull from the Waipara region.

The University of Otago Geology Museum mosasaur fossil was spotted in a deep fissure in a large concretion of cemented siltstone. One end of the concretion had split away to reveal a cross section of the skull, a jaw, and some teeth. It was clear that the fossil would be scientifically rewarding so, with permission of the landowner and the farm manager, a recovery operation was planned. It took two trips of three and four days involving at least three people each time to extract the fossil. To remove the fossil from the concretion the team used a petrol-driven rock drill to make holes around the fossil. Wedges were driven into the holes to split slabs of rock away from the fossil without damaging the specimen. The team also used a petrol-driven masonry saw to trim the blocks in the field. These methods reduced the largest block to about 120 kg. Several teams of people moved the blocks on a stretcher to a vehicle so that it could be brought back to the Geology Museum for study.

The skull and jaws are nearly in life position so it seems that the mosasaur was buried in quiet conditions after death. The sea was sheltered and perhaps was quite deep. Fossils from nearby sediments, both older and younger than sediments in which the mosasaur was buried, indicate a Late Cretaceous age.

The fossil potentially represents a new species of mosasaur and richly deserves to be prepared and studied. Once out of the rock it will help us to understand the nature of predators in the Late Cretaceous seas of Zealandia. Indeed, the fossil may reveal the way in which ecological niches, or lifestyles, have evolved amongst large marine predators from ancient past to modern days.

—Written by R Ewan Fordyce and Daniel B Thomas

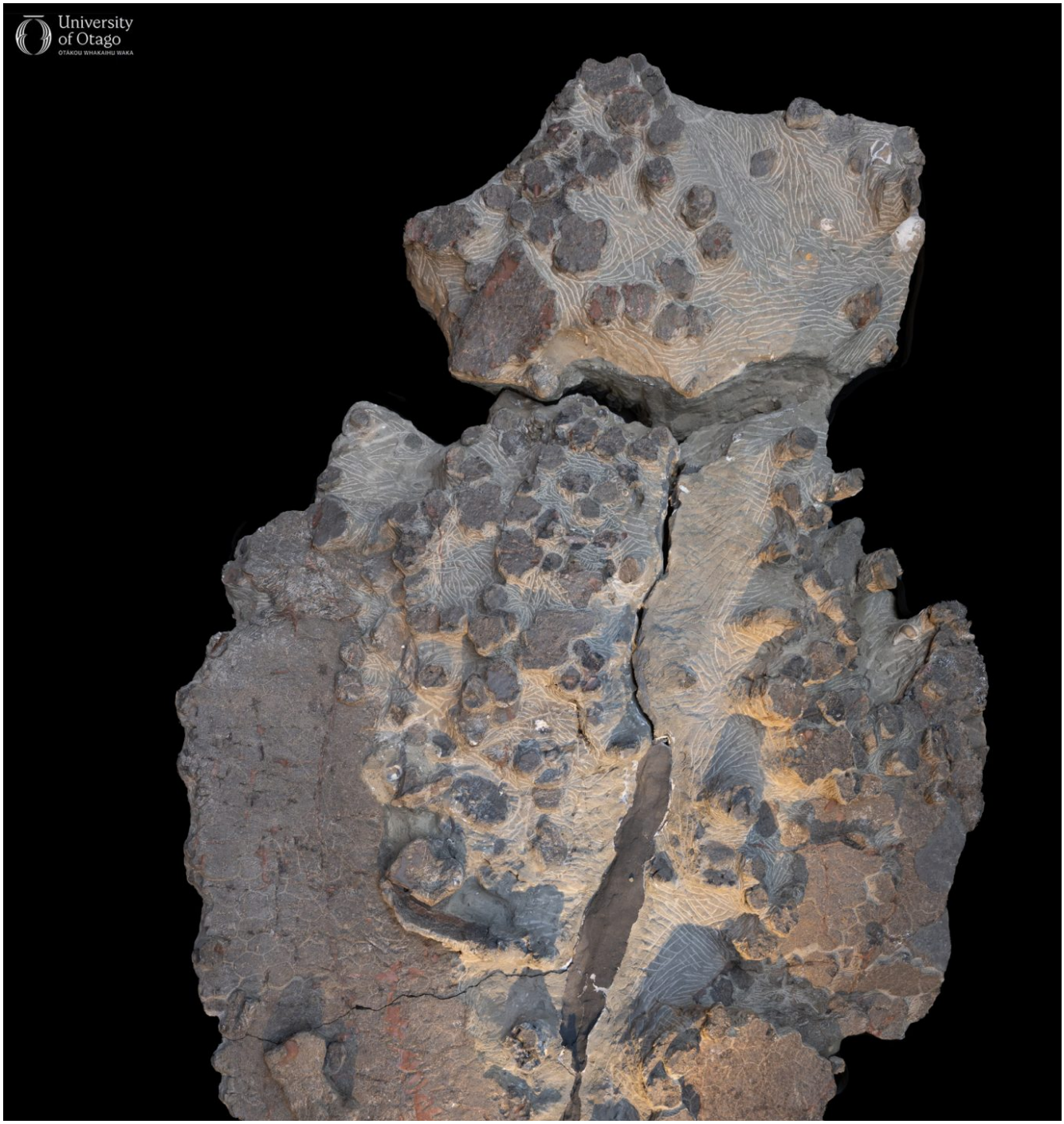
***Specimen number*:** OU 22600	***Age*:** Approximately 70 million years old (late Cretaceous, upper Haumurian stage)
***Locality*:** Waipara Valley, North Canterbury	***Rock Formation*:** Conway Formation
***Collected by*:** RE Fordyce, D Fordyce, T Cross, CM McGoverin, DB Thomas	
***Citation*:** Not yet described	

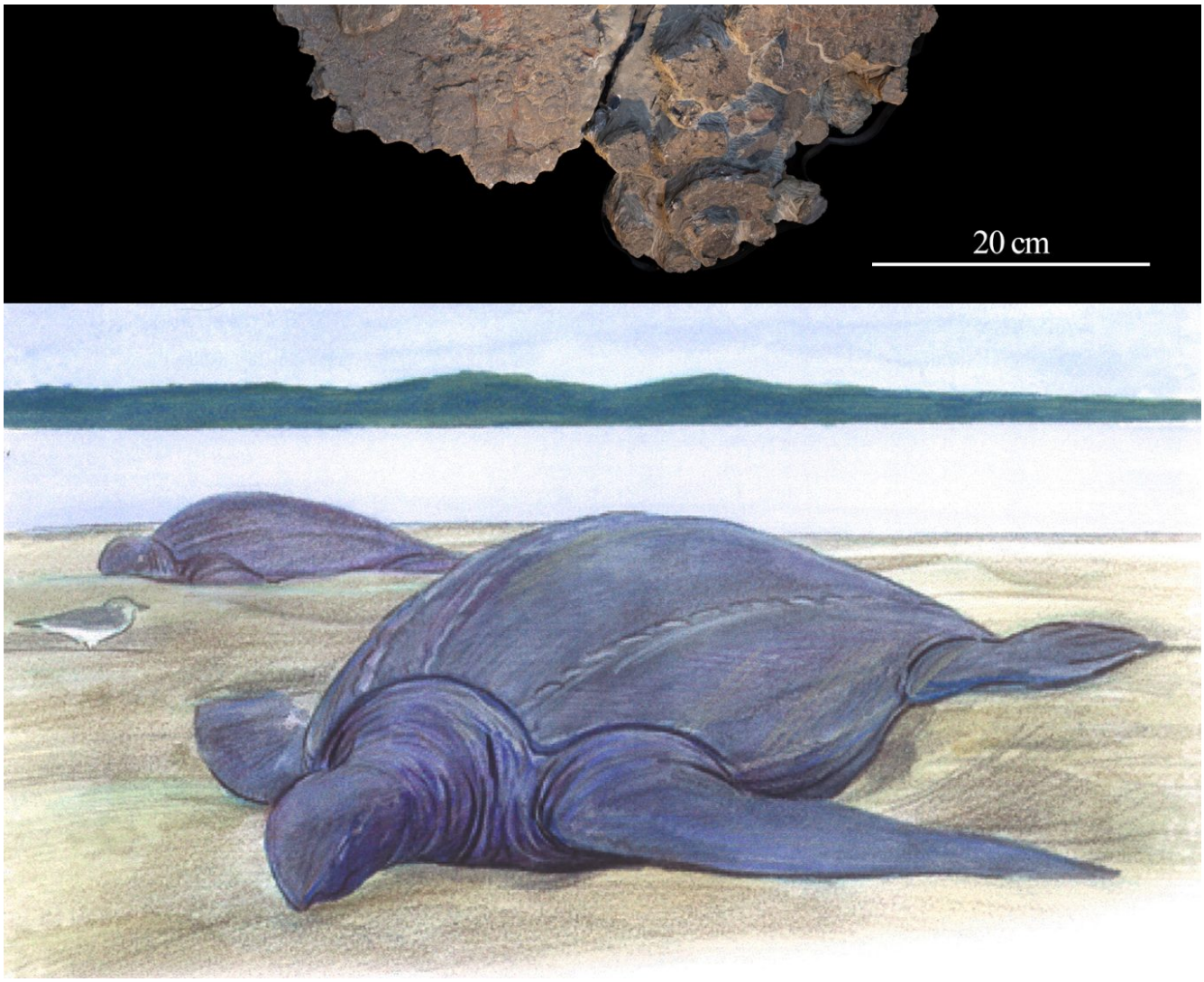
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2.3: Fossil from the Discworld? Giant turtle named for famed author

Sauropsida, Testudines: *Psephophorus terrypratchetti*

Turtles have lived in the seas surrounding Zealandia since at least the Late Cretaceous when the continent was beginning to drift away from the larger southern landmass Gondwana. Although not common in the fossil record, a string of discoveries from each epoch up until the Pliocene show that turtles have been part of the marine fauna of Zealandia for almost the entire history of the now mostly-submerged continent. Cooling global temperatures began to restrict sea turtle distributions towards the tropics following the Pliocene. Today sea turtles are only rare visitors to the northern-most parts of Aotearoa New Zealand although their fossil remains can be found all across the country. A terrestrial freshwater turtle, a possible meiolaniid, is recorded from fragments of a pelvis and a vertebrae in the St Bathans fauna.





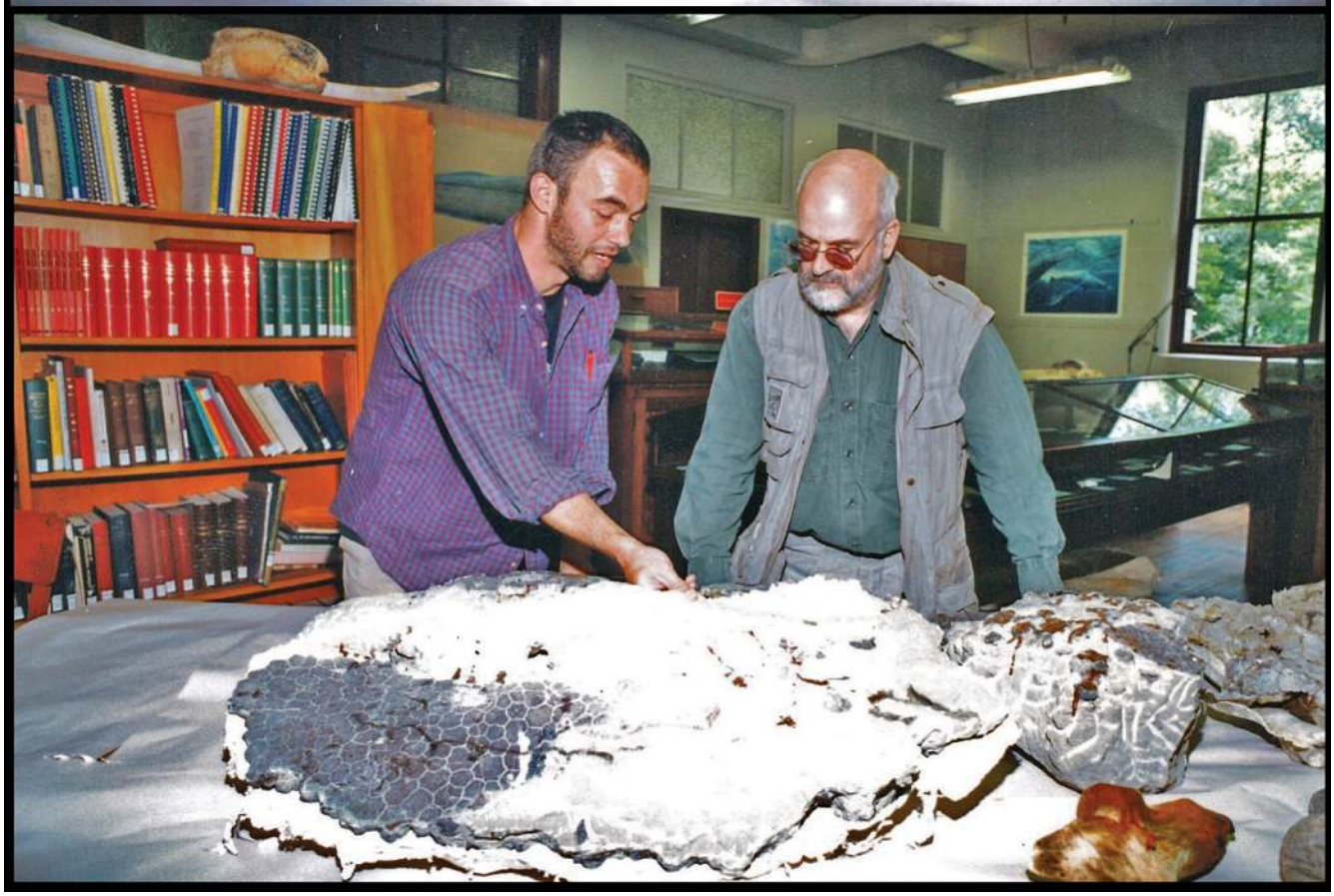
Bones from the giant marine turtle *Psephophorus terrypratchetti* (specimen OU 22177). This fossil is currently on display at Tūhura Otago Museum in the Southern Land, Southern People gallery. Image credit: K Fleury (photograph), C Gaskin (reconstruction).

New Zealand marine turtle fossils have mostly been found as isolated ossicles, or fragments thereof. Ossicles are bones that make up the carapace and plastron of turtles. These ossicles can be 1 cm or more thick, have a spongy structure in cross section, and can feature an ornamented surface. Fossil turtle bones other than platelets are relatively rare discoveries in Aotearoa, and the discovery of hundreds of bones resting alongside one another as they would have been in life has only been reported once.

Did you know there is a 3D printable model of this fossil for you to view online and download? Follow this link to learn more: 3D model—Fossil from the Discworld? Giant turtle named for famed author.

In the 1990s a near-complete specimen of the ancient sea turtle *Psephophorus terrypratchetti* was discovered near Waimate in South Canterbury. This fossil was found in a loose block of Waihao Greensand, a grey to dark-green silty fine sandstone that indicates a quiet marine environment far offshore. This fossil preserves ribs, vertebrae and several hundred ossicles making up the turtle shell. This ancient sea turtle lived during the Eocene, around 40 million years ago, and would have been several metres long in life, slightly smaller than the largest known leatherback turtles.





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Author Sir Terry Pratchett was thrilled to have a fossil turtle named after him and visited the Otago University Geology Museum to see the specimen. Two images show Richard Köhler describing the turtle to Terry Pratchett. Image copyright: Max and Antonia Köhler. Permission to use this copyrighted work must be obtained from the owner or someone they have authorised.

In the *Discworld* Series of novels and associated media for which Sir Terence (Terry) Pratchett was famous, the eponymous world is a disc that is supported on the backs of four elephants who stand astride a giant turtle. The concept of a World Turtle appears in the mythologies of several indigenous peoples and was adopted by the novelist for the *Discworld* setting where the World Turtle is named Great A'Tuin. In 1995, Otago PhD student Richard Köhler described and named the Waihao Greensand fossil turtle *Psephophorus terrypratchetti* "…[*i*]*n honour of the British novelist Terry Pratchett, whose wonderful style and great sense of humour, combined with his deep affection for turtles, merits the naming of this new species after him...*" Terry Pratchett who saw the fossil on a visit to Dunedin on 23 June 1994 (he gave a talk at the University Bookshop on this visit) is reported to have been proud of the name, writing "Of course I'm proud of it. It tickles my imagination. Forty million years ago this thing was paddling around the globe, eating jellyfish, and now there's this link to this short bald guy whose own species, at that time, was still saying 'ook'"

Psephophorus terrypratchetti is described as having "a body armour made up by numerous smooth ossicles which did not show any sculpturing." This University of Otago fossil is currently on loan to Tūhura Otago Museum in Ōtepoti Dunedin where it can be viewed in the *Southern Land, Southern People* Gallery.

—Written by Daniel B Thomas

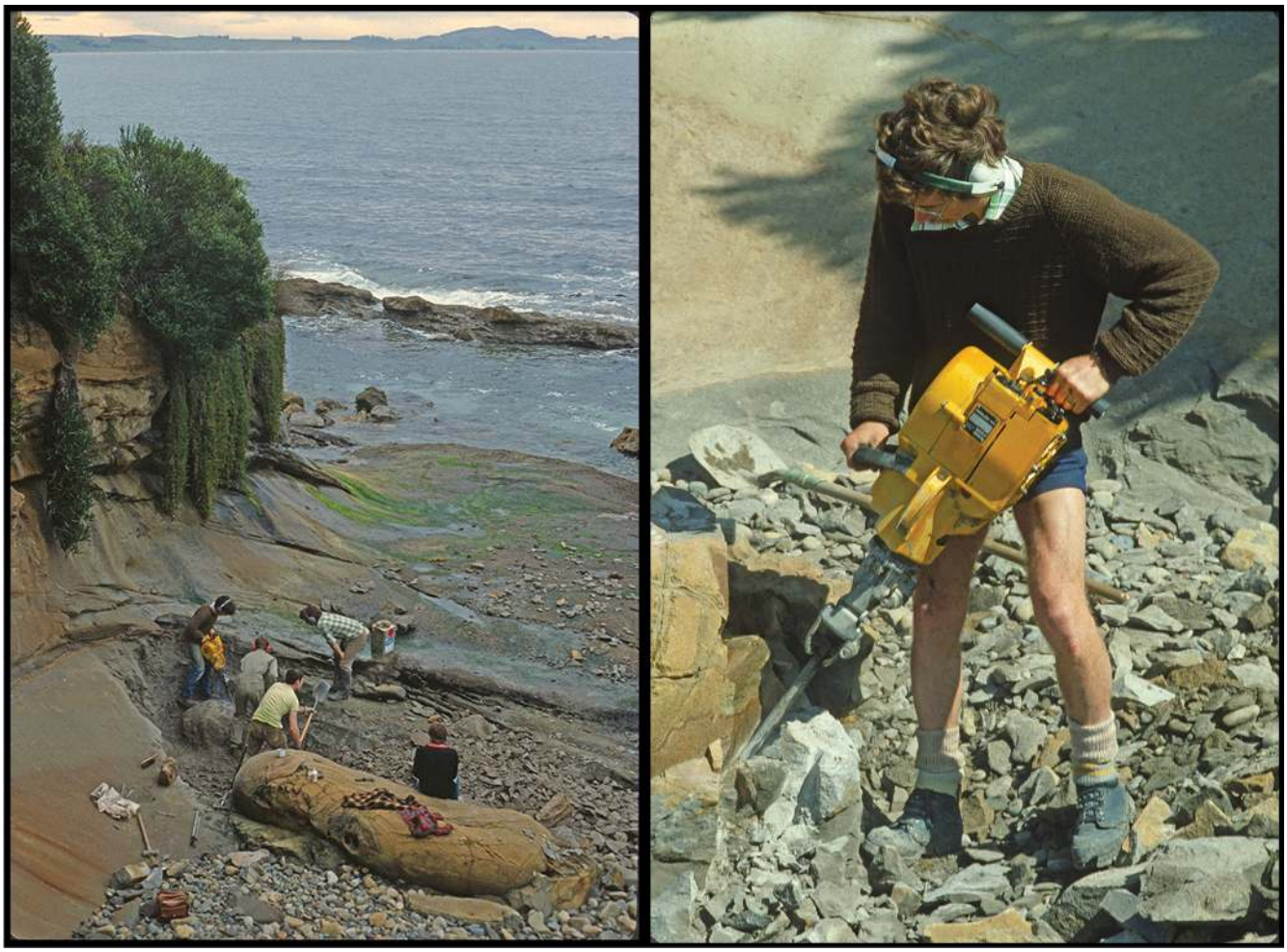
***Specimen number*:** OU 22177	***Age*:** Approximately 40 million years old (middle Eocene, Bortonian stage)
***Locality*:** Waihao Downs, Canterbury	***Rock Formation*:** Waihao Greensand
***Collected by*:** RE Fordyce, A Grebneff, CM Jones	
***Citation*:** Köhler R. 1995. A new species of the fossil turtle *Psephophorus* (Order Testudines) from the Eocene of the South Island, New Zealand. Journal of the Royal Society of New Zealand 25:371–384. doi:10.1080/03014223.1995.9517495	

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2.4: Most complete dinosaur-aged reptile from Aotearoa

Sauropsida, Plesiosauria: *Kaiwhekea katiki*

The plesiosaur *Kaiwhekea katiki*, named by Arthur Cruickshank and Ewan Fordyce in 2002, is one of the most complete fossil reptiles described from New Zealand. The seven metre long fossil includes the skull, jaws, vertebrae and ribs articulated almost in life position.



Staff from the Department of Geology and other volunteers extracting the plesiosaur fossil from the discovery location near Matakaea (Shag Point). Image credit: Unknown.

Plesiosaurs and other marine reptiles, such as mosasaurs, have been known from New Zealand since the 1860s when British anatomist and paleontologist Richard Owen identified the first specimens. Much field work was carried out in the late 1800s, leading to recognition of many new species. However, all of the named specimens are fragmentary, without clearly associated skull and skeleton. *Kaiwhekea* is the first plesiosaur described from New Zealand to have skull, limbs and other elements clearly associated.

Did you know there is a 3D printable model of this fossil for you to view online and download? Follow this link to learn more: 3D model—Most complete dinosaur-aged reptile from Aotearoa.

Kaiwhekea was recovered from the Katiki Formation near Matakaea (Shag Point), Otago where some blocks with vertebrae showing on the surface were discovered by amateur fossil collectors Gary Raper and his son in early 1983. The plesiosaur was

preserved inside a large concretion which was riddled with cracks, allowing it to be broken apart into manageable blocks. Over about 30 days of field work, the numbered blocks were hauled up the steep cliff behind the beach and taken to the Department of Geology for preparation. As excavation proceeded, it was discovered that percolating water had decayed much of the bone leaving natural moulds in the rock. Most of the bones, however, are articulated and were barely disturbed from life position when the animal's carcase fell onto the muddy sea floor in a sheltered embayment where it was preserved from would-be predators and scavengers in a soft, oxygen-poor sediment. Belemnite fossils and fragmentary mosasaurs from nearby indicate an age of Haumurian Stage, or Late Cretaceous – around 70 million years old.



Researcher studying *Kaiwhekea katiki* (specimen OU 12649) in the *Southern Land, Southern People* gallery at Tūhura Otago Museum in Ōtepoti, Dunedin. Image credit: RE Fordyce.

The particular combination of skull features is unlike any previously-described plesiosaur, which is why a new generic name *Kaiwhekea* was proposed. On the skull of *Kaiwhekea*, the large forward-looking orbit hints at binocular vision. A large temporal fenestra indicates large fast-acting and/or powerful jaw muscles. Teeth are slim, small and roughly uniform in shape and size, consistent with a diet of medium-sized soft-bodied prey such as fish. The neck is long, but in life was probably not particularly flexible. Proportions of the hind-flipper are consistent with fast swimming capabilities. Perhaps the plesiosaur fed at depth, where the large eyes might have been an advantage.

Reconstructions of the ancient geography of Zealandia suggest that, when *Kaiwhekea* lived, the Otago region was much closer to the polar circle. This region of ancient Zealandia probably had quite a seasonal climate, with long summer days and long winter nights. At the time, New Zealand was already isolated from Gondwana, but Australia, Antarctica and South America were still connected.



The skull of *Kaiwhekea katiki* (specimen OU 12649). Image credit: RE Fordyce.

This is the only known specimen of *Kaiwhekea*, so little can be said about the time range for the species. As for elsewhere in the world, no plesiosaur remains younger than Cretaceous have been found in New Zealand. It is widely thought that plesiosaurs went extinct during the same event at the end of the Cretaceous that accounted for the demise of non-avian dinosaurs. The unique specimen of *Kaiwhekea katiki* is on loan to Tūhura Otago Museum in Ōtepoti Dunedin in the *Southern Land, Southern People* gallery.

—Written by R. Ewan Fordyce, with additional contributions by Daniel B Thomas

***Specimen number*:** OU 12649	***Age*:** Approximately 70 million years old (late Cretaceous, upper Haumurian stage)
***Locality*:** Matakaea (Shag Point), Otago	***Rock Formation*:** Katiki Formation
***Collected by*:** RE Fordyce, J Williams, and team	
***Citation*:** Cruickshank AR, Fordyce RE. 2002. A new marine reptile (Sauropterygia) from New Zealand: further evidence for a Late Cretaceous austral radiation of cryptoclidid plesiosaurs. Palaeontology 45:557–575. doi.org/10.1111/1475-4983.00249	

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2.5: Crikey! Lake crocodilian from Central Otago

Sauropsida, Crocodilia

The first fossil crocodilian to be described from Aotearoa New Zealand is a small dark fragment of jaw from Early Miocene lake sediments in Central Otago. The specimen was found by Mike Pole near St Bathans during a study of fossil plants from Central Otago, and was described by Ralph Molnar and Mike Pole in 1997. While the fossil has been described, the genus and species to which it is belongs have not yet been formally identified.



Bone from the lower jaw of an unidentified species of crocodilian (specimen OU 22228). Image credit: RE Fordyce.

The St Bathans fossil fragment is a little less than 7 cm long and is from the right lower jaw of a small crocodile. Given the proportions of the jaw in modern crocodiles, the original lower jaw was perhaps 20 cm long and the animal probably had a skull of a similar length. A Pleistocene fossil crocodilian from Fiji *Volia athollandersoni* was around two to three metres long and may have been a similar size to the specimen from St Bathans.

The crocodilian lower jaw came from the Bannockburn Formation. Fossils from Bannockburn Formation include freshwater mussels (*Hyridella*), abundant fish remains including isolated bones and otoliths (See: Robinson's pilchard: the importance of earbones), bones of many species of ducks, shelducks and geese, and broken eggshell. Plant fossils are abundant in places and algal stromatolites or oncolites are known (See: Small boulders of fossil bacteria). The strata were deposited in an extensive shallow "Lake Manuherikia" which occupied much of what is now Central Otago.

The animal to which the jaw fragment belonged was possibly a member of the Mekosuchinae group of crocodilians. Mekosuchines are a distinct and extinct group of crocodiles first recognised in Australia and now known from other localities including Fiji (e.g. *Volia athollandersoni*), New Caledonia and Vanuatu. Mekosuchines originated at least 53 million years ago during the early Eocene and lived through to the Holocene. At least one mekosuchine crocodile from Vanuatu apparently co-existed with humans only a few thousand years ago.

Mekosuchines dispersed across oceans through the southwest Pacific. Judging from the known distribution of other mekosuchines in space and time, these animals could have lived in New Zealand either intermittently or continuously; an open question in New Zealand paleontology.

The St Bathans crocodilian jaw is currently on loan to Tūhura Otago Museum in Ōtepoti Dunedin where it can be seen in the *Southern Land, Southern People* gallery, along with many other specimens from the University of Otago Geology Museum.

—Written by R. Ewan Fordyce, with additional contributions by Daniel B Thomas

***Specimen number*:** OU 22228	***Age*:** 19 to 16 million years old (early Miocene, Altonian Stage)
***Locality*:** St Bathans, Central Otago	***Rock Formation*:** Bannockburn Formation
***Collected by*:** M Pole	
***Citation*:** Molnar RE, Pole M. 1997. A Miocene crocodilian from New Zealand. Alcheringa 21:65–70. doi.org/10.1080/03115519708619185	

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CHAPTER OVERVIEW

3: Vertebrates- Seabirds

Aotearoa New Zealand is a global biodiversity hotspot for seabirds where approximately one quarter of the world's seabird species breed today. Seabirds are species in five taxonomic orders and include albatrosses, shearwaters and relatives (order Procellariiformes), gannets, cormorants and relatives (order Suliformes), penguins (order Sphenisciformes), skuas and terns (order Charadriiformes), and tropicbirds (order Phaethontiformes).

The fossil record of Aotearoa reveals that a rich diversity of seabirds have been living around Zealandia for a long time. Some of these discoveries represent ecological niches that are long extinct for seabirds, as is the case with the giant fossil penguins. These are species that were taller and heavier than living emperor penguins and potentially foraged in deep environments that penguins don't access today. Several other fossil seabirds have been discovered that would have looked and behaved in similar ways to seabirds living today.

The University of Otago Geology Museum collections are globally important for seabird fossils. In particular, fossils from the Geology Museum have helped us to understand when and how Zealandia first became the Seabird Capital of the World. In this section we introduce ancient seabirds that have featured in a decades-long programme of evolutionary, faunal and biogeographic research.

3.1: First penguins from 'just after' the big extinction

3.2: Without this one bone we wouldn't know Maxwell's penguin ever existed

3.3: When penguins were giants with spear-like bills

3.4: Small penguin was forerunner of today's tiny divers

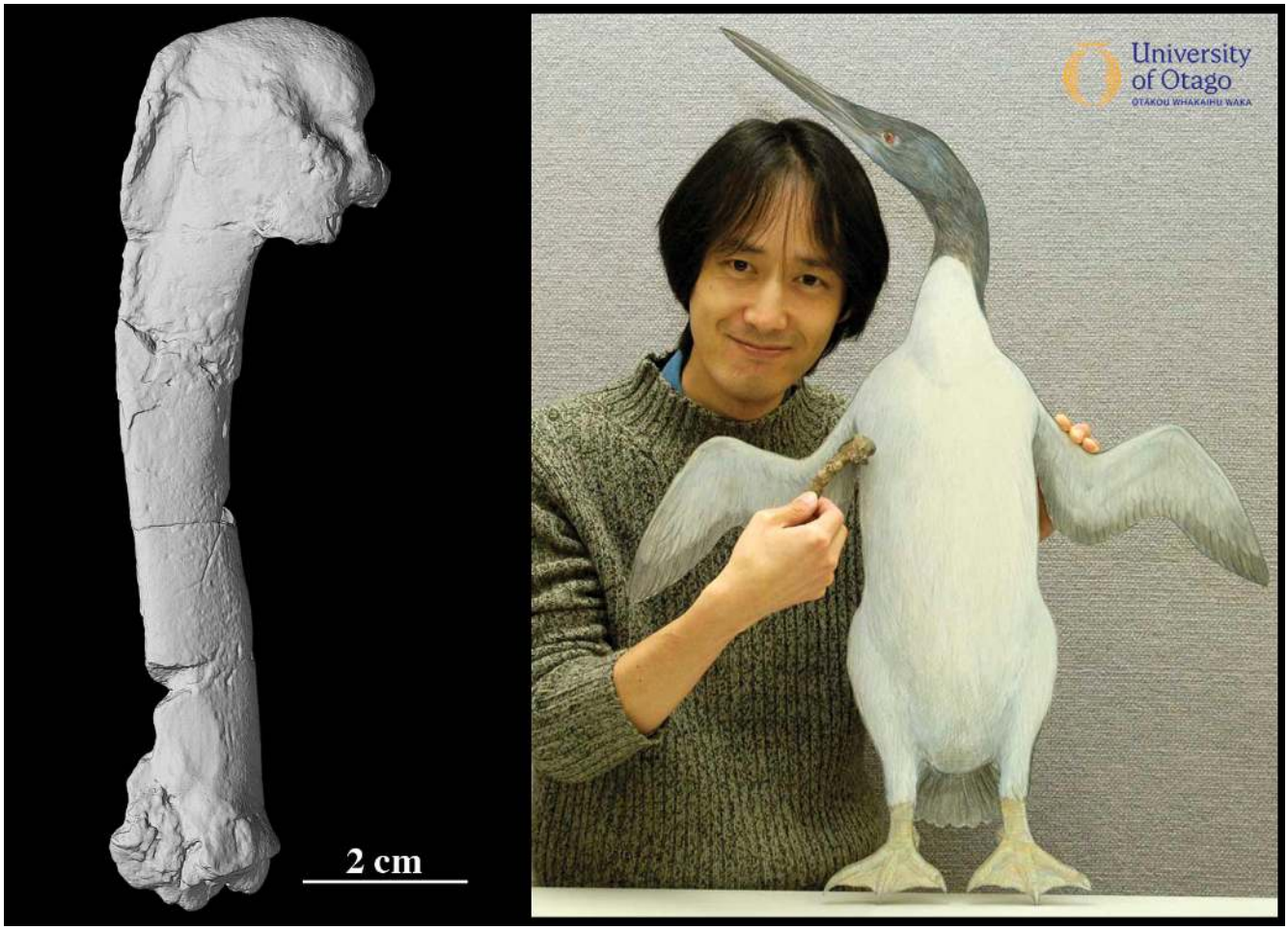
3.5: Ancient mariner albatross soared over Zealandian oceans

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3.1: First penguins from 'just after' the big extinction

Aves, Sphenisciformes: *Muriwaimanu tuatahi*

Penguins are an ancient and charismatic group of birds that are important to marine food webs in many regions across the Southern Hemisphere today. Much has been learned about the origins of penguins by studying fossils from Aotearoa New Zealand. One of the most important milestones in penguin evolutionary research occurred in 2006 when researchers revealed penguin fossils that were around 60–62 million years old. Almost as far back in time as the age of the non-avian dinosaurs.



The left image is a 3D scan of the uppermost wing bone (humerus) from the early penguin *Muriwaimanu tuatahi* (specimen OU 12651). The right image shows Dr Tatsuro Ando holding the fossil humerus against a reconstruction of Muriwaimanu tuatahi produced by Chris Gaskin. Image credit: RE Fordyce.

These ancient *Muriwaimanu* and *Waimanu* penguins (collectively known as 'Waipara penguins') lived in shallow seas off eastern Zealandia during the Paleocene and were about the size of living hoiho (yellow-eyed penguins; around 60 cm tall). Waipara penguins had a more flexible elbow than living penguins, a long spear-like bill, and probably looked a little like a shag (cormorant). Importantly, Waipara penguins had compressed and dense wing bones like living penguins which means that they could use their wings to swim underwater but probably could not fly in air.

Because the Waipara penguins are well dated in terms of geological age it is possible to use that known age to better understand the evolutionary relationships of living birds. If early penguins lived in southern seas not long after the extinction of dinosaurs, then other bird groups more distantly related to penguins must have been established even earlier. Many groups of living birds potentially originated well back in Cretaceous times when dinosaurs were thriving. Thus, *Muriwaimanu* and *Waimanu* helped to reveal that many modern lineages of living birds, not just penguins, had ancient origins.

—Written by Daniel B Thomas

***Specimen number*:** OU 12651	***Age*:** 62 to 60 million years old (Paleocene, Teurian stage)
***Locality*:** Waipara Valley, North Canterbury	***Rock Formation*:** Waipara Greensand
***Collected by*:** B Field	
***Citation*:** Slack KE, Jones CM, Ando T, Harrison GL, Fordyce RE, Arnason U, Penny D. 2006. Early penguin fossils, plus mitochondrial genomes, calibrate avian evolution. Molecular Biology and Evolution 23:1144–1155. doi:10.1093/molbev/msj124	

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3.2: Without this one bone we wouldn't know Maxwell's penguin ever existed

Aves, Sphenisciformes: *Kaiika maxwelli*

For birds and many other groups it is unusual for researchers to propose a new scientific name for a species when only a single specimen from one individual animal is known (e.g. one bone). This is because a scientific name is an hypothesis, and must therefore be able to be proven wrong. For an example of why a scientific name is an hypothesis, consider that if the bone that a new species is named from is shown to belong to an already-named species, then the hypothesis that the bone represents a new species is rejected. Also, it should be possible to show that any other newly discovered bone belongs to that newly described species if that is indeed the case. An individual fossil bone needs to be both distinctive and sufficiently important for researchers to propose it has come from a species that is new to science. Which is what happened with the description of Maxwell's penguin *Kaiika maxwelli*.



Wing bone (humerus) from the fossil penguin *Kaiika maxwelli* (specimen OU 22402). This humerus bone is slightly S-shaped, which is different to the straight humerus bones of penguins living today. This image is a 3D scan of the fossil and not a photograph. Image credit: DB Thomas.

In the spring of 1998, Phillip (Phil) Maxwell and Ewan Fordyce were searching for fossils along the banks of the Waihao River in South Canterbury when the former found a concretion that was around 30 cm in diameter. He split the concretion into two clean halves using a hammer, revealing a natural mould of a single bone along with a small amount of the original bone material. At the time of discovery these researchers didn't fully realise that they were holding one of the oldest fossil penguin bones that had ever been found, confirming that fossil penguins were living in Zealandia during the early Eocene (between 56 and 52 million years old). This was because they were uncertain about the age of the fossil, and the bone itself had a markedly different shape to other penguin fossils that had been described. The concretion was transported back to the University of Otago for storage in the Geology Museum collections.

By 2009 the significance of the fossil had become clear. Geology Museum paleontology preparator Andrew Grebneff was tasked with removing the remaining bone from the concretion, reattaching the halves of the concretion together, filling the void space with epoxy, and exposing the resulting cast.

The cast was revealed as the uppermost bone (i.e. humerus) from the wing of a penguin that would have been similar in size to a modern emperor penguin *Aptenodytes forsteri*, the largest penguins living today. Aspects of the shape of the fossil humerus had never been seen before in a bone that was so large, and no other penguin fossils had been reported from sediments of this age in the southern Canterbury Basin. For these reasons, researchers were confident that the fossil bone was from an entirely new species, and was distinct enough for future comparisons. This very situation would arise around ten years later with the description of the fossil penguin *Petradyptes stonehousei*. The humerus from *Petradyptes stonehousei* is most similar in shape and size to the fossil penguin that Dr Maxwell had discovered, but is nevertheless clearly distinguishable.

The fossil penguin bone from the banks of the Waihao River was named in honour of Phillip Maxwell as *Kaiika maxwelli*. The article describing the fossil appeared in a special issue of the New Zealand Journal of Geology and Geophysics in 2011 dedicated to Dr Maxwell and the major contributions he had made to New Zealand paleontology across his career.

—Written by Daniel B Thomas

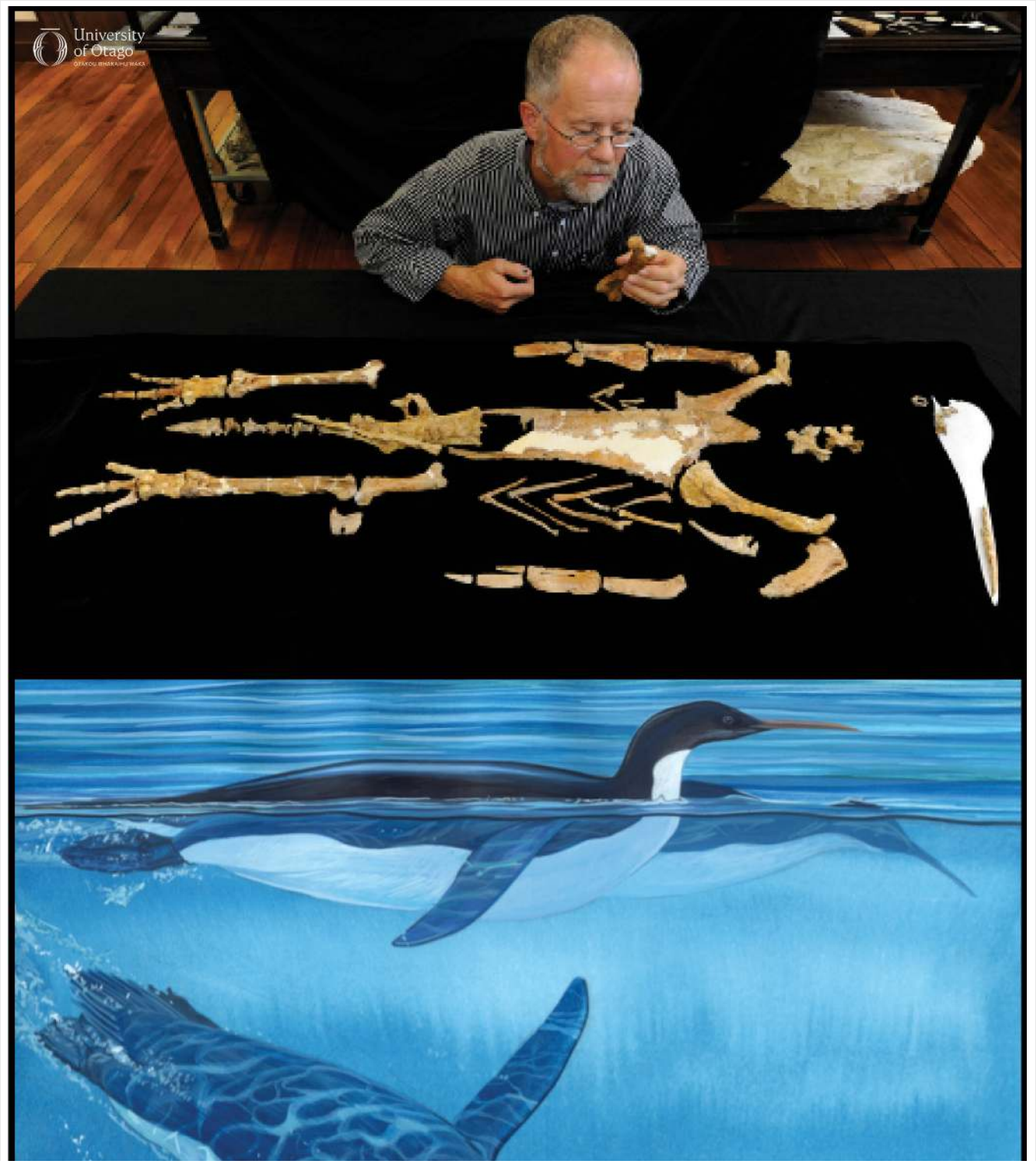
***Specimen number*:** OU 22402	***Age*:** Approximately 53 million years old (early Eocene, Waipawan or Mangaorapan stage)
***Locality*:** Waihao River, Canterbury	***Rock Formation*:** Kauru Formation
***Collected by*:** P Maxwell	
***Citation*:** Fordyce RE, Thomas DB. 2011. *Kaiika maxwelli*, a new Early Eocene archaic penguin (Sphenisciformes, Aves) from Waihao Valley, South Canterbury, New Zealand. New Zealand Journal of Geology and Geophysics 54:43–51. doi.org/10.1080/00288306.2011.536521	

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3.3: When penguins were giants with spear-like bills

Aves, Sphenisciformes: *Kairuku grebneffi* and *K. waitaki*

The emperor penguin *Aptenodytes forsteri* is the largest species of penguin living today at around one metre tall and weighing up to 40 kg. Penguins have a long and relatively detailed fossil record with much of our knowledge of penguin history coming from discoveries made in New Zealand. These include two species of 'giant' fossil penguin first described in 2012, *Kairuku grebneffi* and *Kairuku waitaki*. In life these 'giants' would have been another 30 cm taller than an adult emperor penguin.





In the upper image R. Ewan Fordyce examines a composite skeleton of bones assembled from two species of *Kairuku* fossil penguin. The lower image is a reconstruction of *Kairuku* swimming in late Oligocene oceans. Image credit: RE Fordyce (photograph), C Gaskin (illustration).

At least five partial skeletons of *Kairuku* penguin are housed in the University of Otago Geology Museum. All are from Kokoamu Greensand near Waimate in South Canterbury and Duntroon in North Otago. Each partial skeleton has its own museum accession number. The partial skeleton that became the holotype for *Kairuku waitaki* has the accession number OU 12652, and the partial skeleton that became the holotype for *Kairuku grebneffi* has the accession number OU 22094. The *Kairuku* specimens in the Geology Museum owe their discovery to Ewan Fordyce. In Ewan's words:

"*…I found the first* Kairuku *penguin when I was a PhD student, in 1977, on a field trip looking for Oligocene fossil whales and dolphins near Waimate. One distinctive oval bone was exposed – a broken section through the tibia, or lower leg bone. I collected a few fragments, but realised that the fossil was big, and would take some time to collect – and I didn't have the time or money to do more work. Then I went overseas to study. The penguin stuck in my mind and, when I returned to take up a job at University of Otago, I returned to the site – and found things exactly as I had left them 4 years earlier. So, I excavated the specimen fully…*"

When they were described the *Kairuku* penguins were amongst the most complete fossil penguin skeletons known and included bones from the tip of the bill through to the feet. These specimens allowed researchers to reconstruct the shape of the body of extinct giant penguins and estimate their size.

From a distance, *Kairuku* penguins would have looked similar to modern species like the emperor penguin. Up close though you would see that both *Kairuku waitaki* and *Kairuku grebneffi* had relatively longer bills and a more slender body than living species. The wing was relatively longer than in living species and could flex a little more at the elbow.

There are several possible explanations for large body size in extinct penguins. Large size could have been an adaptation for long-distance swimming and for deep diving. Studies of marine organisms in general suggest that bigger forms can swim more efficiently than smaller forms and thus might be able to feed on rich food resources further from land. Alternatively, large size might have been an adaptation against large predators.

Kairuku penguins probably swam far out to sea, beyond the limits of the wide shallow seas of Zealandia, then dived into deep water to search for prey. Prey was likely fish and squid. The long beak would suggest a spearing and snapping behaviour. In turn, the penguins could have been hunted by early dolphins, especially forms with short, robust, and heavily toothed jaws. Like some species of the shark-toothed dolphins (Squalodontidae) that are also within the collections of the Geology Museum.

—Written by Daniel B Thomas

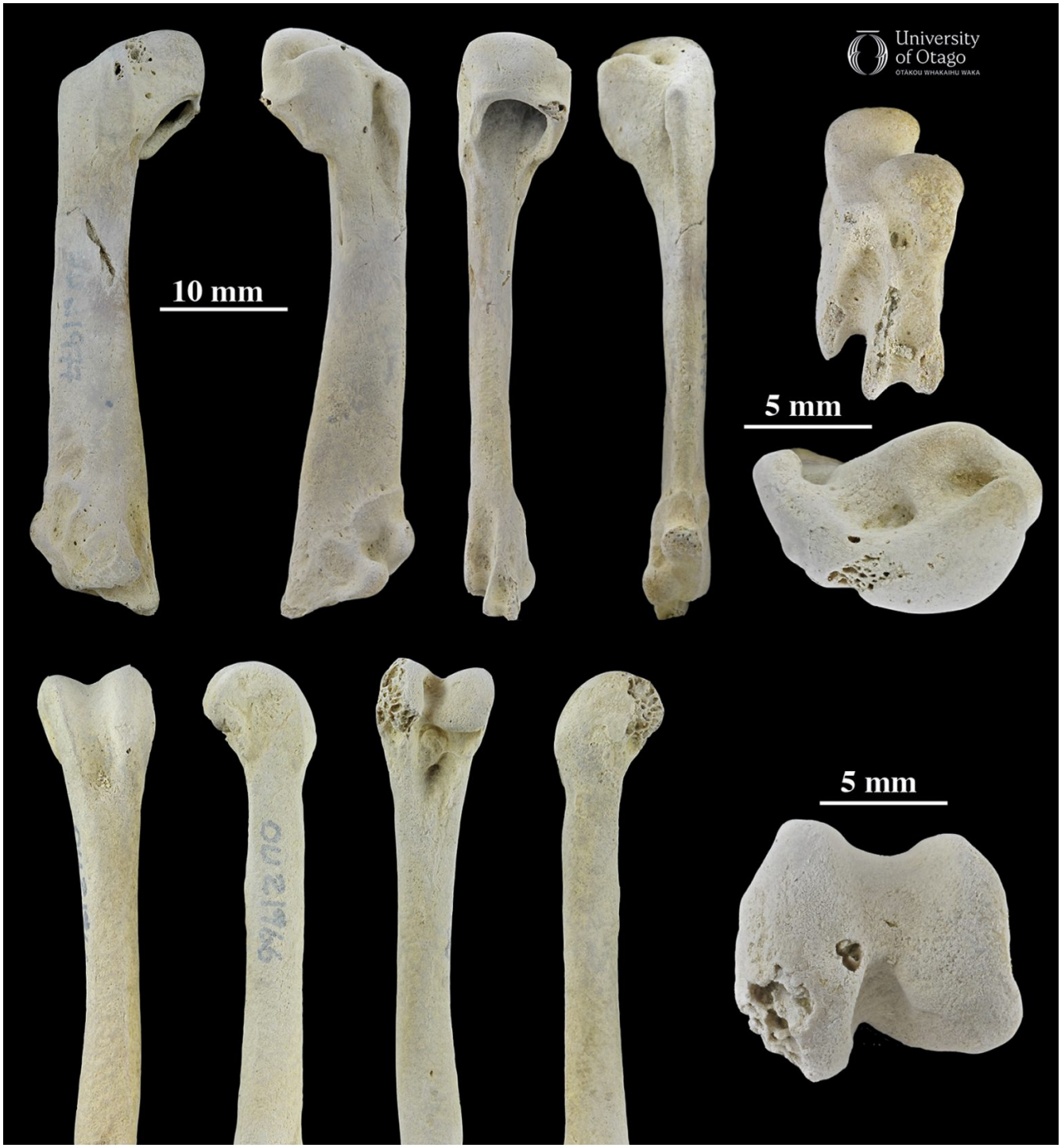
***Specimen number*:** OU 12652, OU 22094	***Age*:** Approximately 26 million years old (late Oligocene, Duntroonian stage)
***Locality*:** Duntroon, North Otago	***Rock Formation*:** Kokoamu Greensand
***Collected by*:** RE Fordyce, MA Fordyce	
***Citation*:** Ksepka DT, Fordyce RE, Ando T, Jones CM. 2012. New fossil penguins (Aves, Sphenisciformes) from the Oligocene of New Zealand reveal the skeletal plan of stem penguins. Journal of Vertebrate Paleontology 32:235–254. doi.org/10.1080/02724634.2012.652051	

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3.4: Small penguin was forerunner of today's tiny divers

Aves, Sphenisciformes: *Pakudyptes hakataramea*

Penguins today range in size from kororā little penguin *Eudyptula minor*, standing around 30 cm tall and weighing one kilogram, up to emperor penguin *Aptenodytes forsteri*, an order of magnitude larger at one metre tall and weighing around 35 kg. Ancient penguins famously reached even larger sizes with *Kumimanu fordycei* (named for Ewan Fordyce) standing more than 1.5 m tall and weighing much more than an emperor penguin. Penguin body size has several important biological and ecological consequences, and researchers have been studying penguin anatomy, ecology and evolution for more than a century to gain insight into how penguins have adapted to life in water.





Bones from the tiny penguin *Pakudyptes hakataramea* (specimen OU 21977). The top row shows different views of the uppermost bone from the wing (humerus). The middle row shows different views of the thigh bone (femur) and the bottom row shows different views of the forearm bone (ulna). *Pakudyptes hakataramea* was a very similar size to living kororā or little penguin (*Eudyptula minor*) from Aotearoa and Australia. Image source: Figure 2 in T Ando, JH Robinson, C Loch, T Nakahara, S Hayashi, M Richards and RE Fordyce (2024) A new tiny fossil penguin from the Late Oligocene of New Zealand and the morphofunctional transition of the penguin wing, which is licensed under CC BY-NC-ND 4.0. Image credit: JH Robinson.

Researchers have discovered that body size influences how a penguin manages heat and finds food. Larger penguins cool down more slowly which means they can endure being in colder water for longer. In contrast, smaller penguins have a reduced risk of overheating in warmer climates. Larger penguins can dive deeper and swim greater distances from shore, whereas smaller penguins can typically meet their energy demands from local food sources closer to shore.

Did you know there is a 3D printable model of this fossil for you to view online and download? Follow this link to learn more: 3D model—Small penguin was forerunner of today's tiny divers.

The correlation between penguin body size and environment gains a new dynamic when we realise that marine environments have experienced radical change over time. The capacity to tolerate environmental change can vary with body size, and so there are many questions about adapting to changing marine environments that are best answered by studying the smallest fossil penguins. While bones from small ancient penguins are generally rare, the University of Otago Geology Museum is fortunate to house fossils from one of the tiniest fossil penguins ever discovered.

In 1987 Craig Jones and Ewan Fordyce collected three small penguin bones (humerus, ulna and femur) from a limestone quarry in South Canterbury, New Zealand. These bones are from a penguin that was approximately the same size as living kororā. The Otekaike Limestone from which these the bones were collected represents an inner- to mid-shelf marine environment, like the type of environment that kororā forages in today. Otekaike Limestone was deposited towards the end of the Oligocene about 24 million years ago. The bones from this tiny fossil penguin were later studied by Tatsuro Ando as part of his doctoral research.

The bones were from *Pakudyptes hakataramea*, a species that was new to science and therefore distinct from the tiny fossil penguin *Eretiscus tonnii* previously identified in South America. Tatsuro Ando observed that the wing bones of *Pakudyptes*

hakataramea featured characteristics found only in ancient penguins, alongside traits that we find today in modern penguins. This means that *Pakudyptes hakataramea* was a capable swimmer but possibly not as effective at generating lift in water as modern penguins. From this we can better understand that the swimming efficiency of penguins has been gradually improving through time.

Pakudyptes hakataramea is the oldest 'tiny' penguin now known, helping to show that the penguins have had a broad range in body sizes for many millions of years.

—Written by Daniel B Thomas

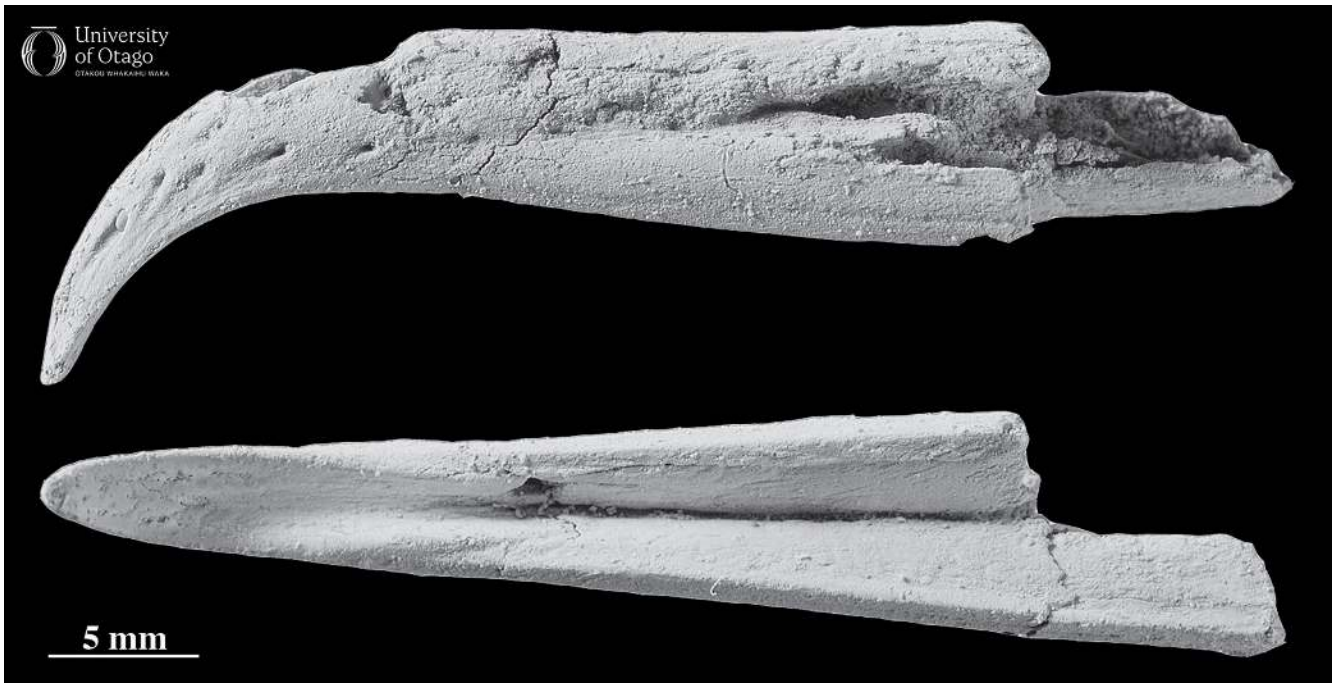
***Specimen number*:** OU 21977	***Age*:** Approximately 26 million years old (late Oligocene, Duntroonian stage)
***Locality*:** Hakataramea Valley, South Canterbury	***Rock Formation*:** Otekaike Limestone
***Collected by*:** CM Jones, RE Fordyce	
***Citation*:** Ando T, Robinson JH, Loch C, Nakahara T, Hayashi S, Richards M, Fordyce RE. 2024. A new tiny fossil penguin from the Late Oligocene of New Zealand and the morphofunctional transition of the penguin wing. Journal of the Royal Society of New Zealand 54:660–681. doi:10.1080/03036758.2024.2362283	

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3.5: Ancient mariner albatross soared over Zealandian oceans

Aves, Procellariiformes: *Plotornis archaeonautes*

Aotearoa New Zealand is a biodiversity hotspot for seabirds with more than a quarter of all seabird species breeding in the New Zealand archipelago today. Indeed, Aotearoa has endemic species within four of the five major seabird groups: Charadriiformes (e.g. tarapirohe, black-fronted tern *Chlidonias albostriatus*), Procellariiformes (e.g. toroa, southern royal albatross *Diomedea epomophora*), Sphenisciformes (e.g. hoiho, yellow-eyed penguin *Megadyptes antipodes*) and Suliformes (e.g. kawau pāteketeke, New Zealand king shag *Leucocarbo carunculatus*). The fifth group, Phaethontiformes, includes a species that is native to New Zealand but not endemic (Amokura or red-tailed tropicbird, *Phaethon rubricauda*). Seabirds are an important link between marine and terrestrial ecosystems by bringing nutrients onshore which then contribute to the growth of plants. The question of how long seabirds have been an important part of the ecosystems of Aotearoa is investigated by studying the fossil record. In 2024 the fossil record for albatrosses in Zealandia was revealed to be at least 22 million years old.



Beak from the ancient mariner albatross *Plotornis archaeonautes* (specimen OU 22690). The ancient mariner albatross was a similar size to some of the smallest albatrosses living today. Image source: Figure 2 in D Ksepka, A Tennyson, M Richards and RE Fordyce (2024) A new species of *Plotornis* (Aves, Pan-Diomedeidae) from the earliest Miocene of New Zealand, which is licensed under CC BY-NC-ND 4.0. Image credit: RE Fordyce.

The partial skeleton of the fossil albatross *Plotornis archaeonautes* was discovered in 2010 during a field trip to a limestone quarry in South Canterbury led by Ewan Fordyce. Preparation of the fossil showed the skeleton was from a bird about the size of the smallest living species of albatross (i.e. Laysan albatross *Phoebastria immutabilis*, with an approximately two metre wingspan). The beak of the fossil albatross was slender compared to living species, which the researchers suggested could correspond with a more fish-intensive diet than the squid-intensive diet of albatrosses today. Recognising the fossil as a new species of *Plotornis* provided the earliest uncontroversial record of albatrosses in the fossil record of the Southern Hemisphere, and greatly increased the known geographic range of *Plotornis* to encompass both hemispheres.

Researchers haven't yet arrived at a consensus on how long the New Zealand archipelago has been a biodiversity hotspot for seabirds. Clear supporting evidence would be needed to show that a diversity of seabird species can be consistently found in the fossil record of Aotearoa across deep time through to modern day. Although just one individual, the discovery of *Plotornis archaeonautes* was an important piece in this much larger story.

—Written by Daniel B Thomas

***Specimen number*:** OU 22690	***Age*:** Approximately 22.0 million years old (earliest Miocene, upper Waitakian stage)
***Locality*:** Hakataramea Valley, South Canterbury	***Rock Formation*:** Mount Harris Formation
***Collected by*:** RE Fordyce and others	
***Citation*:** Ksepka D, Tennyson A, Richards M, Fordyce RE. 2024. Stem albatrosses wandered far. A new species of *Plotornis* (Aves, Pan-Diomedeidae) from the earliest Miocene of New Zealand. Journal of the Royal Society of New Zealand 54:643–659. doi:10.1080/03036758.2023.2266390.	

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CHAPTER OVERVIEW

4: Vertebrates- Marine Mammals

Marine mammals are one of the signature research themes for paleontology at the University of Otago. A particular passion of the late Professor Ewan Fordyce, the discovery of ancient whales and dolphins by Ewan and his research team across the South Island of Aotearoa has changed the global understanding of cetacean evolution. These discoveries are also responsible for much of the international recognition that led to establishing the UNESCO Waitaki Whitestone Global Geopark.

Cetaceans are an important part of the fauna of Aotearoa New Zealand today. Whales, dolphins and porpoises are taoka species with special cultural significance. In this section we introduce several of the ancient whale and dolphin species that have been described by Ewan and his students, revealing the long association between cetaceans and Zealandia.

4.1: Last of the ancient whales- final salute to the old guard

4.2: Archaic dolphin connects oceans of Zealandia to endangered river resident

4.3: Dianne's beautiful dolphin had an unusual smile

4.4: Young hunter from dark age of whale evolution

4.5: Transitional fossil at the dawn of baleen whales

4.6: Small origins for baleen whales, the largest animals to ever live

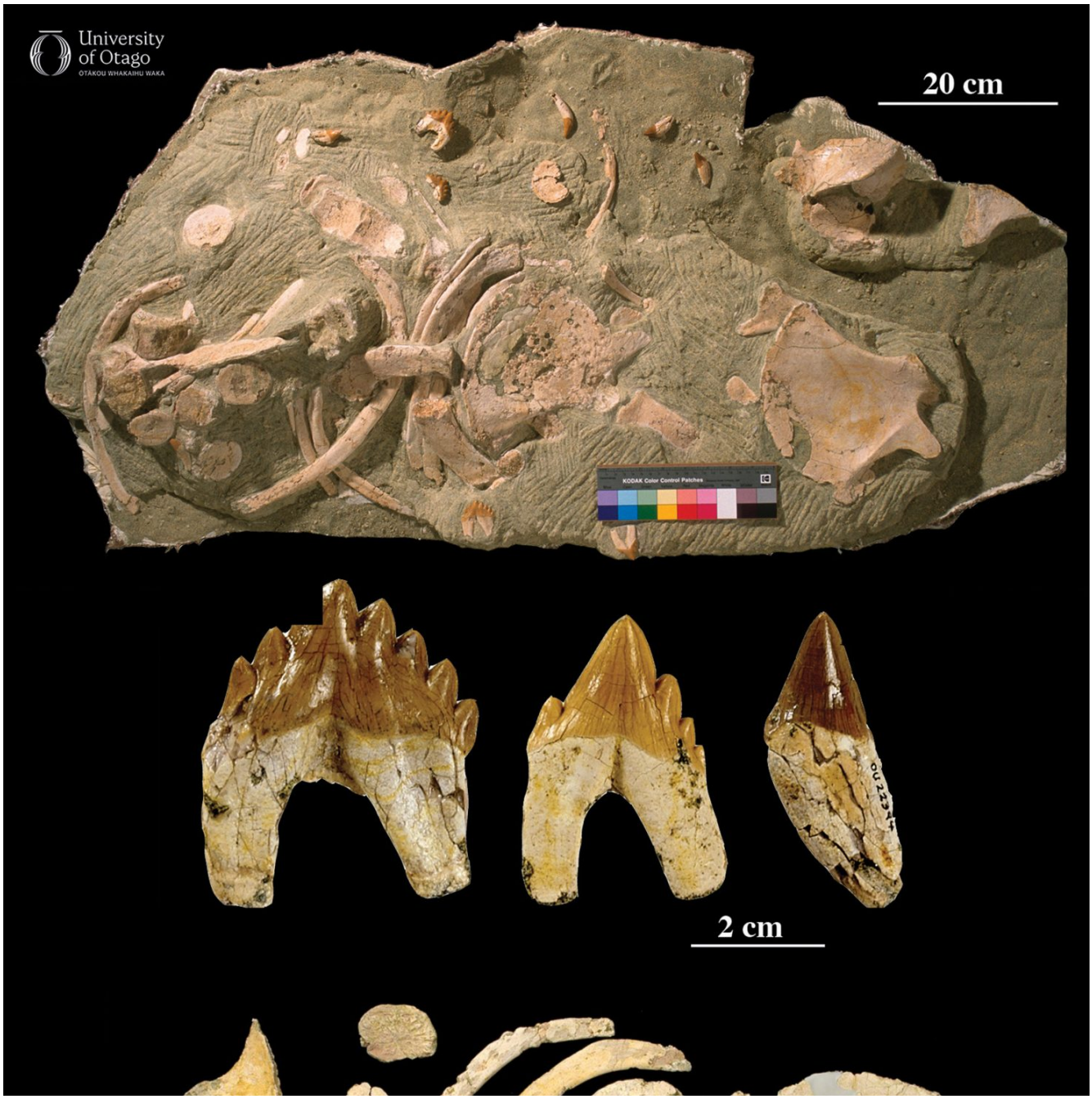
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4.1: Last of the ancient whales- final salute to the old guard

Cetacea, Kekenodontidae: *Tohoraonepu nihokaiwaiu*

Whales first appeared along the shores of the Tethys Ocean in what is now modern-day India and Pakistan around 49 million years ago. As whales began to spread outwards across global oceans they diversified into new lineages. One of these lineages would give rise to today's baleen whales and toothed whales (including dolphins and porpoises). This lineage was named the 'new whales' (Neoceti) by Ewan Fordyce and Christian de Muizon. Whales in every other lineage would all become extinct over time, and have been grouped together under the name 'ancient whales' (Archaeoceti). The extinction of the last species in each of the ancient whale lineages occurred at a different period in the deep past. For a moment in time, however, species in the last of the ancient whale lineages were living alongside the earliest species of the new whale lineages. This last ancient whale lineage is named the Kekenodontidae. Fossils from Kekenodontidae discovered in Aotearoa New Zealand were the focus of Joshua Corrie's doctorate research at the University of Otago.





Bones from the archaic whale *Tohoraonepu nihokaiwaiu* (specimen OU 22394). By studying the worn enamel on the teeth shown here, researchers have discovered that *Tohoraonepu nihokaiwaiu* was a predator. Image source: Figure 3 in J Corrie, and RE Fordyce (2024) A new genus and species of kekenodontid from the late Oligocene of New Zealand with comments on the evolution of tooth displacement in Cetacea, which is licensed under CC BY-NC-ND 4.0. Image credit: RE Fordyce.

Just two species representing Kekenodontidae have been described so far. Fossils from the first species in this lineage were discovered in 1880 in North Otago by Alexander McKay. James Hector described these fossils in 1881 and determined that they belonged to a species that was new to science, *Kekenodon onamata*. Fossils from the second species were also discovered in North Otago more than 100 years later and were described in 2024 by Joshua Corrie and Ewan Fordyce. The second species was named *Tohoraonepu nihokaiwaiu*. Two other fossils have been proposed to belong to the same Kekenodontidae lineage of ancient whales, but these specimens have yet to be formally identified.

Tohoraonepu nihokaiwaiu lived between 27.3 and 25.2 million years ago during a span of time known locally as the Duntroonian Stage. At approximately 2.5 metres in length, *Tohoraonepu nihokaiwaiu* was a similar size to the largest of the common dolphins *Delphinus delphis* living today. However, the fossil bones that were named *Tohoraonepu nihokaiwaiu* were from a young individual, and when it was fully grown it may have reached up to four metres long, closer in size to a large bottlenose dolphin *Tursiops truncatus*.

The name *Tohoraonepu* means sand whale and the origin of the name is from Te Reo Māori, where tohorā is whale and onepū is sand. In Te Reo Māori, niho kai waiū refers to baby teeth, which gives the species name for this ancient whale.

Kekenodon onamata and *Tohoraonepu nihokaiwaiu* shared the oceans with the ancestors of today's dolphins but do not themselves have descendants living today. Together, these kekenodontids probably had a similar ecology to living toothed whales by hunting other marine mammals, seabirds and large fish. Eventually the last species in the Kekenodontidae lineage became extinct, leaving the descendants of the 'new whales' to inherit the oceans.

—Written by Daniel B Thomas

***Specimen number*:** OU 22394	***Age*:** Approximately 26 million years old (late Oligocene, Duntroonian stage)
***Locality*:** Awamoko Valley, North Otago	***Rock Formation*:** Kokoamu Greensand
***Collected by*:** RE Fordyce, A Grebneff	
***Citation*:** Corrie J, Fordyce RE. 2024. A new genus and species of Kekenodontid from the late Oligocene of New Zealand with comments on the evolution of tooth displacement in Cetacea. Journal of the Royal Society of New Zealand 54:722–737. doi.org/10.1080/03036758.2023.2297696	

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4.2: Archaic dolphin connects oceans of Zealandia to endangered river resident

Cetacea, Waipatiidae: *Waipatia maerewhenua*

The seas around Zealandia were rich with a diversity of whale and dolphin species during the Oligocene. The beds of these ancient seas were later uplifted and now form the iconic limestone landscape of North Otago and South Canterbury. In the early 1990s Ewan Fordyce developed a field program supported by the National Geographic Society which sought to learn more about the diversity of life in these ancient seas from the fossils in these Oligocene rocks. By 1994 the bones from a fossil dolphin named *Waipatia maerewhenua* had been described, revealing an incredible connection between the fossils of North Otago and a species living today in the Ganges River, India.



Skull of *Waipatia maerewhenua* (specimen OU 22095). Image credit: RE Fordyce.

The location of the *Waipatia maerewhenua* fossil was first revealed when an earbone and some teeth were found in an outcrop of limestone. Ewan Fordyce, Andrew Grebneff and Bob Connell spent two days excavating the fossil to reveal a skull lying upside down, with the upper jaws crossed over the skull. Many loose teeth were found along with more ear bones and a few fragments of bones from the skeleton behind the head. In the laboratory, it took Andrew Grebneff several months to excavate all the bones from the rock.

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Waipatia maerewhenua has a well-preserved skull that is about 600 mm long. The skull has a long and broad-based snout, small triangular teeth, and a face that is a slightly different shape on the left side compared to the right. The eyes sit on the side of the skull. The blowhole sits above the eyes and in life would have been surrounded by muscles that helped to produce high-frequency

echolocation sounds. Each lower jaw has a region of thin bone by the hinge with the upper skull. In life, this thin pan bone was probably filled with fatty tissue which helped transmit sound from the side of the head towards the ear region.

Waipatia answered some important questions in dolphin evolution. For more than a century, small dolphin teeth had been known from Oligocene rocks around the world. *Waipatia* revealed the sort of skull to which such small teeth belong. Importantly though, *Waipatia* also revealed the existence of a previously unknown taxonomic family within the toothed-whales. The closest living relatives of *Waipatia* appears to be the endangered Ganges River dolphin *Platanista gangetica*.

The unique specimen of *Waipatia maerewhenua* is on loan to Tūhura Otago Museum in Ōtepoti Dunedin and may be seen in the *Southern Land, Southern People* gallery. A cast and interpretive graphics are displayed at the Vanished World Centre, Duntroon, North Otago.

—Written by Daniel B Thomas

***Specimen number*:** OU 22095	***Age*:** Approximately 26 million years old (late Oligocene, Duntroonian stage)
***Locality*:** Waipati Creek, North Otago	***Rock Formation*:** Otekaike Limestone
***Collected by*:** RE Fordyce, A Grebneff, RD Connell	
***Citation*:** Fordyce RE. 1994. *Waipatia maerewhenua*, new genus and new species (Waipatiidae, new Family), an archaic Late Oligocene Dolphin (Cetacea: Odontoceti: Platanistoidea) from New Zealand. Proceedings of the San Diego Society of Natural History 29:147–176.	

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4.3: Dianne's beautiful dolphin had an unusual smile

Cetacea, Platanistoidea: *Aureia rerehua*

The seas surrounding Zealandia during the Oligocene were rich in species that were broadly similar to the biodiversity living in today's oceans, but sometimes possessed obvious differences. We can see clear examples of this amongst the ancient toothed-whales such as *Waipatia* (see Archaic dolphin connects oceans of Zealandia to endangered river resident). These animals had the general body plan we would recognise from dolphins living today but had procumbent incisors.





Dianne Nyhof preparing *Aureia rerehua* (specimen OU 22553). The top right image shows the under-side or ventral surface of the skull after it had been prepared out from the limestone rock. Image credit: RE Fordyce.

The ecology of toothed-whales with procumbent teeth has been a challenge to understand because of the absence of living examples. Fossils of these ancient toothed-whales have been discovered in North Otago and South Canterbury for many decades, and the diversity and ancient ecology of these animals has formed a strong research theme for the Department of Geology at the University of Otago. The hunting behaviour of ancient toothed-whales with procumbent teeth was a focus of Shane Meekin's Master of Science research. Shane and two colleagues explored these insights further when they described *Aureia rerehua*, a new genus and species of ancient toothed-whale discovered in South Canterbury.

The partial skeleton of *Aureia rerehua* was discovered in a limestone quarry in the Hakataramea Valley. The bones included the skull and lower jaws, teeth, ear bones, vertebrae and ribs. The fossil had been collected from Otekaike Limestone and a small sample of the sediment around the fossil helped to confirm that the animal had lived between 22 and 23 million years ago.

Aureia rerehua is described as having 'splayed' teeth. This means that the teeth along both the upper and lower jaws curved outwards before pointing down. And although the procumbent front teeth weren't found attached to the skull, the researchers concluded that they nevertheless protruded horizontally forward (i.e. were procumbent).

The lower jaw of *Aureia rerehua* was slender and the vertebrae of the neck allowed the head to be quite mobile. Taken together with the unusual dentition, the researchers proposed that *Aureia rerehua* hunted by snapping at prey to seize it in a basket of teeth, before sucking that prey deeper into its mouth. A close analogue today might be the endangered living Ganges river dolphin *Platanista gangetica*.

Aureia rerehua was referred to by the name "Dianne's Dolphin" during the preparation and study stages of research, ahead of receiving its scientific name. The name *Aureia* is drawn from aurei, the Te Reo Māori word for cloak pin, referring to the shape of the teeth. In Te Reo Māori *rerehua* is beautiful, referring to its well-preserved face.

—Written by Daniel B Thomas

***Specimen number*:** OU 22553	***Age*:** Approximately 24 million years old (latest Oligocene, Waitakian stage)
***Locality*:** Waimate, South Canterbury	***Rock Formation*:** Otekaike Limestone
***Collected by*:** RE Fordyce, A Grebneff, DB Thomas	
***Citation*:** Meekin S, Fordyce RE, Coste A. 2024. *Aureia rerehua*, a new platanistoid dolphin from the Oligocene of New Zealand with a unique feeding method. Journal of the Royal Society of New Zealand 54:758–777. doi:10.1080/03036758.2024.2314505	

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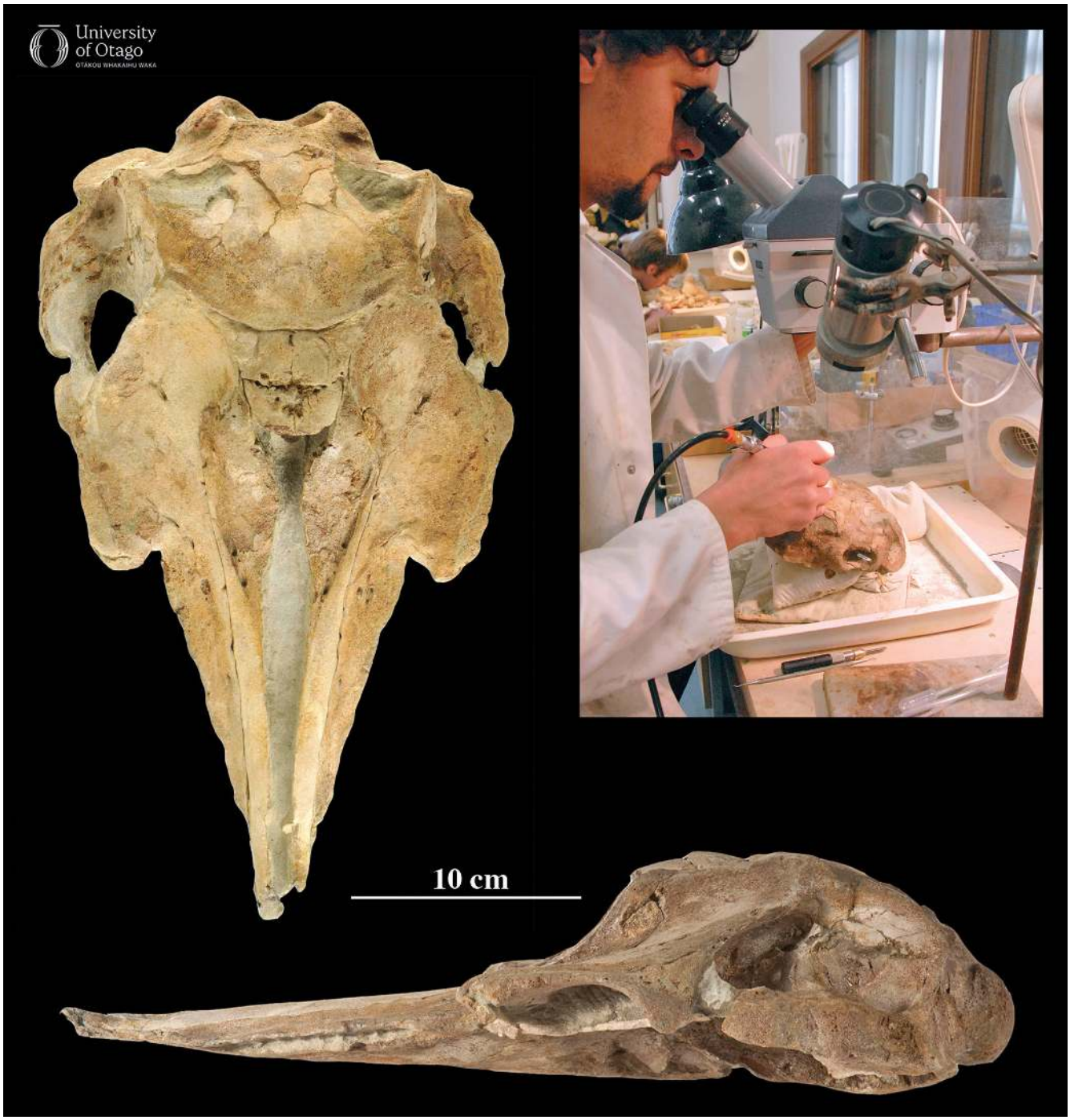
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4.4: Young hunter from dark age of whale evolution

Cetacea, Odontoceti: *Papahu taitapu*

Whales and dolphins are collectively known as cetaceans and arose from an ancestor that was a close relative of the hippopotamus. This cetacean ancestor lived around 50 million years ago during the Paleocene along an ancient coastline of what is now the Indian subcontinent. Cetaceans then began to spread around the world and diversify, and by the end of the Oligocene the two major groups that we recognise today had emerged, baleen whales (mysticetes) and toothed whales (odontocetes, which includes dolphins and porpoises).

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Skull from the ancient dolphin *Papahu taitapu* (specimen OU 22066). Visible lines between bones in the skull (i.e. sutures) show that the skull is from an adolescent. The top right image shows Gabriel Aguirre-Fernández preparing the fossil as part of his doctoral thesis research. Image credit: RE Fordyce.

Crucially though, the cetaceans that lived in these 23 million year old late Oligocene oceans were mostly archaic species that were distantly related to modern species. What follows next in cetacean evolutionary history is something of a mystery, as cetacean fossils are rare in rocks aged between 23 and 20 million years old. This span of time has been described as a global “dark age” in whale evolution. In the times immediately following this “dark age” the oceans became filled with a diversity of whale and dolphin species that appear much more like their living relatives. So how and why did cetacean diversity change so much during this time? One of the ways the fossil record of Aotearoa is important for whale evolution is that it includes cetacean fossils from this “dark

age" and can therefore help to answer these questions. The odontocete *Papahu taitapu* from the northern South Island is one such fossil, dated between 21.7 and 18.7 million years old.

Papahu taitapu is a close relative of modern dolphins but doesn't itself have living descendants. Like living dolphins, *Papahu taitapu* used high frequency sound to navigate and find prey, and had rows of small, conical teeth for seizing this prey.

Only a single specimen of *Papahu taitapu* has been discovered so far. This specimen was collected by Ewan Fordyce and Andrew Grebneff from North West Nelson in 1987. These paleontologists found the fossil exposed on a rock platform at high-tide level. Upon collection and preparation, the fossil was revealed to be a skull that was missing part of the snout (i.e. part of the rostrum). Other bones that were found alongside the skull included an ear bone, a lower jaw, some vertebrae, and a rib.

Ewan Fordyce and PhD student Gabriel Aguirre-Fernández determined that *Papahu taitapu* was around 1.8 m long but was probably still a young individual. At 1.8 m long, *Papahu taitapu* would have been similar in size to some of the smaller living dolphins like the common dolphin, *Delphinus delphis*. When studying the shape of the skull the researchers observed that the blowhole was placed between where it would have been on an archaic odontocete (towards the front-end of the skull) and where it is placed on a modern dolphin (on the top of the head). This intermediate placement is exactly what would be expected from a "dark age" fossil, as it lived in the time following the most archaic cetaceans but before modern species evolved.

—Written by Daniel B Thomas

***Specimen number*:** OU 22066	***Age*:** Approximately 22.5 million years old (latest Oligocene, Waitakian stage)
***Locality*:** North West Nelson	***Rock Formation*:** Kaipuke Formation
***Collected by*:** RE Fordyce, A Grebneff	
***Citation*:** Aguirre-Fernández G, Fordyce RE. 2014. *Papahu taitapu*, gen. et sp. nov., an early Miocene stem odontocete (Cetacea) from New Zealand. Journal of Vertebrate Paleontology 34:195–210. doi:10.1080/02724634.2013.799069	

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4.5: Transitional fossil at the dawn of baleen whales

Cetacea, Mysticeti: *Tokarahia kauaeroa*

Baleen whales are well adapted to life in water where they have evolved specialised feeding adaptations and behaviours. Living baleen whales lack teeth and use baleen to filter food from the water. Amongst living mysticetes, the rorquals are fast-moving predators, right whales are slower-moving grazers that skim the surface of the water to collect food, and gray whales collect their food from the sediment on the sea floor. The evolutionary timing of when ancient whales first developed these baleen-filtering feeding strategies is an important question in cetacean history. One group of ancient whales, the eomysticetids, has been especially important to finding the answer.



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The top left image shows the bones of the fossil whale *Tokarahia kauaeroa* being collected from the North Otago location where it was discovered (specimen OU 22235). The top right image shows the bones of the upper skull and lower jaw after preparation to remove some of the surrounding sediment. The lower image is a reconstruction by artist Chris Gaskin showing what *Tokarahia kauaeroa* may have looked like while swimming in an ancient ocean. Image credits: RE Fordyce (photographs) and C Gaskin (Illustration).

Eomysticetids are an extinct group of whales that occupy a branch in the evolutionary tree between early whales that all had teeth and more modern whales that have baleen. There exists an idea that eomysticetids may have had teeth as adults but not used them for feeding, relying instead on baleen. This idea is challenging to test because baleen is made from keratin and so is highly unlikely to preserve in the fossil record. Instead, researchers use the shape of the jaws of fossil whales to deduce if baleen might have been present when the animal was alive. From there, researchers can also check to see if teeth are preserved with these fossils. Ancient whales with this rare combination of traits (i.e. functional baleen and non-functional teeth) may have lived in the oceans surrounding Zealandia during the Oligocene.

In 1994 a large fossil skull was collected by Ewan Fordyce, Andrew Grebneff and others from the top of a limestone cliff in North Otago. The fossil was dated to between 25 and 26 million years old. The fossil shows a blowhole that is placed about halfway between the front-most end of the skull and the top of the head. The skull also shows a narrow upper jaw or rostrum. These are some of the features that identify the skull as being from an eomysticetid whale and which distinguish it from living modern baleen whales. This large skull would have belonged to an animal that was up to 7 metres long and, based on the shape of the skull, almost certainly had baleen when it was alive. In 2015, the fossil was described as *Tokarahia kauaeroa* by Robert (Bobby) Boessenecker and Ewan Fordyce and was formally determined to be part of the eomysticetid group of ancient whales. As part of this same study these researchers examined other, similar fossils. One of these closely related *Tokarahia* fossils was found as a fragmentary skeleton that included a single, isolated tooth.

The discovery of a tooth as part of this skeleton supports the idea that *Tokarahia* retained adult teeth. The peg-like shape and tiny size of the tooth, coupled with the shape of the skull of *Tokarahia*, suggested to the researchers that the tooth would have had no function in feeding. The delicate bones of the skull in *Tokarahia* further suggested it probably wasn't a lunge feeder like living rorquals. Instead, *Tokarahia* may have used baleen for skim feeding or benthic suction feeding, with its teeth being just a vestigial feature of its jaws.

—Written by Daniel B Thomas

***Specimen number*:** OU 22235	***Age*:** Approximately 24.5 million years old (late Oligocene, Waitakian stage)
***Locality*:** Tokarahi, North Otago	***Rock Formation*:** Otekaike Limestone
***Collected by*:** RE Fordyce, A Grebneff, CM Jones, BVN Black, CM Jenkins, G Curline	

***Citation*:** Boessenecker RW, Fordyce RE. 2015. A new genus and species of eomysticetid (Cetacea: Mysticeti) and a reinterpretation of '*Mauicetus*' *lophocephalus* Marples, 1956: transitional baleen whales from the upper Oligocene of New Zealand. Zoological Journal of the Linnean Society 175:607–660. doi:10.1111/zoj.12297

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4.6: Small origins for baleen whales, the largest animals to ever live

Cetacea, Mysticeti: *Toipahautea waitaki*

The largest animal to have ever lived (that we know about) is the blue whale *Balaenoptera musculus*, which reaches almost 30 metres in length and has a global distribution. The blue whale feeds almost exclusively on krill, which are a collection of jointed-limb animals with external skeletons (species within Arthropoda) that look similar to shrimp. As with all living mysticetes, blue whales capture their food by squeezing a mouthful of water out past plates of keratin that hang from their jaws in the place of teeth. Krill become trapped on the inside of these keratin or baleen plates and the whale uses its tongue to hoover up the food. Baleen plates are clearly important for the success of mysticetes, and so the evolutionary origins of baleen has been an important question in paleontological research. Understanding the early origins of baleen whales has been a major research theme for the Department of Geology at the University of Otago.



The top image shows the incomplete skull of the fossil whale *Toipahautea waitaki* (specimen OU 21981). In this view the snout of the whale is pointing towards the right and we are looking at the top of the head (dorsal surface). The lower left image shows other assorted bones from the fossil and the lower right image shows Cheng-Hsiu Tsai studying the fossil for his doctoral thesis research. Image credit: RE Fordyce.

In 2018 Cheng-Hsiu Tsai and Ewan Fordyce described *Toipahautea waitaki*, the oldest fossil whale ever discovered that did not have teeth. Like all mammals, including their close dolphin relatives, the ancestors of baleen whales had teeth. Baleen would come to replace teeth during the evolutionary history of mysticetes, and so for a time there were ancient whales that had both baleen and teeth (e.g. *Aetiocetus cotylalveus*). This was a transitional time in whale evolutionary history when baleen was becoming more

important for collecting food, beginning when the earliest forms of baleen evolved, and ending when baleen whales no longer had teeth erupting from their jaws. *Toipahautea waitaki* is the fossil whale that currently represents the end of that transitional period.



Did you know there is a 3D printable model of this fossil for you to view online and download? Follow this link to learn more: 3D model—Small origins for baleen whales, the largest animals to ever live.

Toipahautea waitaki is important for helping researchers understand how long the transition from teeth to baleen took and how big ancient whales were when they began to rely only on baleen for food collecting. *Toipahautea waitaki* was discovered in the 1980s in a limestone quarry in the Hakataramea Valley in South Canterbury and was recovered in 1988 by Ewan Fordyce, Andrew Grebneff and Craig Jones. Upon preparation at the Department of Geology the fossil was revealed to be a partial skeleton with bones from the upper skull, lower jaws, vertebrae, scapulae, parts of the flippers, and some ribs. Keratin tends to decompose and not preserve in the fossil record, so no baleen was recovered. Instead, the upper skull preserves grooves that would have housed the blood vessels that supplied the baleen when the animal was living, as in baleen whales today. From these blood vessel grooves and several other features Tsai and Ewan were able to conclude that *Toipahautea waitaki* would have originally used baleen to help with feeding. No teeth were found with the whale and the jaws did not have sockets for teeth.

Toipahautea waitaki lived around 27.5 million years ago and is estimated to have been around five metres long. This is smaller than the adult size of the pygmy right whale *Caperea marginata* which is the smallest baleen whale living today. *Toipahautea waitaki* shows that baleen whales had relatively humble beginnings and that that it would be many millions of years before they approached the size of today's ocean giants.

—Written by Daniel B Thomas

***Specimen number*:** OU 21981	***Age*:** Approximately 27.5 million years ago (late Oligocene, upper Whaingaroan stage)
***Locality*:** Hakataramea Valley, South Canterbury	***Rock Formation*:** Kokoamu Greensand
***Collected by*:** RE Fordyce, A Grebneff, CM Jones	
***Citation*:** Tsai CH, Fordyce RE. 2018. A new archaic baleen whale *Toipahautea waitaki* (early Late Oligocene, New Zealand) and the origins of crown Mysticeti. Royal Society Open Science 5:172453. doi:10.1098/rsos.172453	

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CHAPTER OVERVIEW

5: Vertebrates- Curios

The University of Otago Geology Museum holds fossil, mineral and rock specimens collected over the past 150 years and has gained new specimens across this entire history. Sometimes these specimens are part of a tightly focussed research project, as is the case with the fossil insect collection (see: First beetle named from amber in Aotearoa). Other specimens represent a steadily growing collection that represents a lifetime of achievements in fossil research (see: Small origins for baleen whales, the largest animals to ever live). And still others are discoveries found during student research projects that are yet to be fully analysed (see Predator lizard discovered in the Waipara Valley).

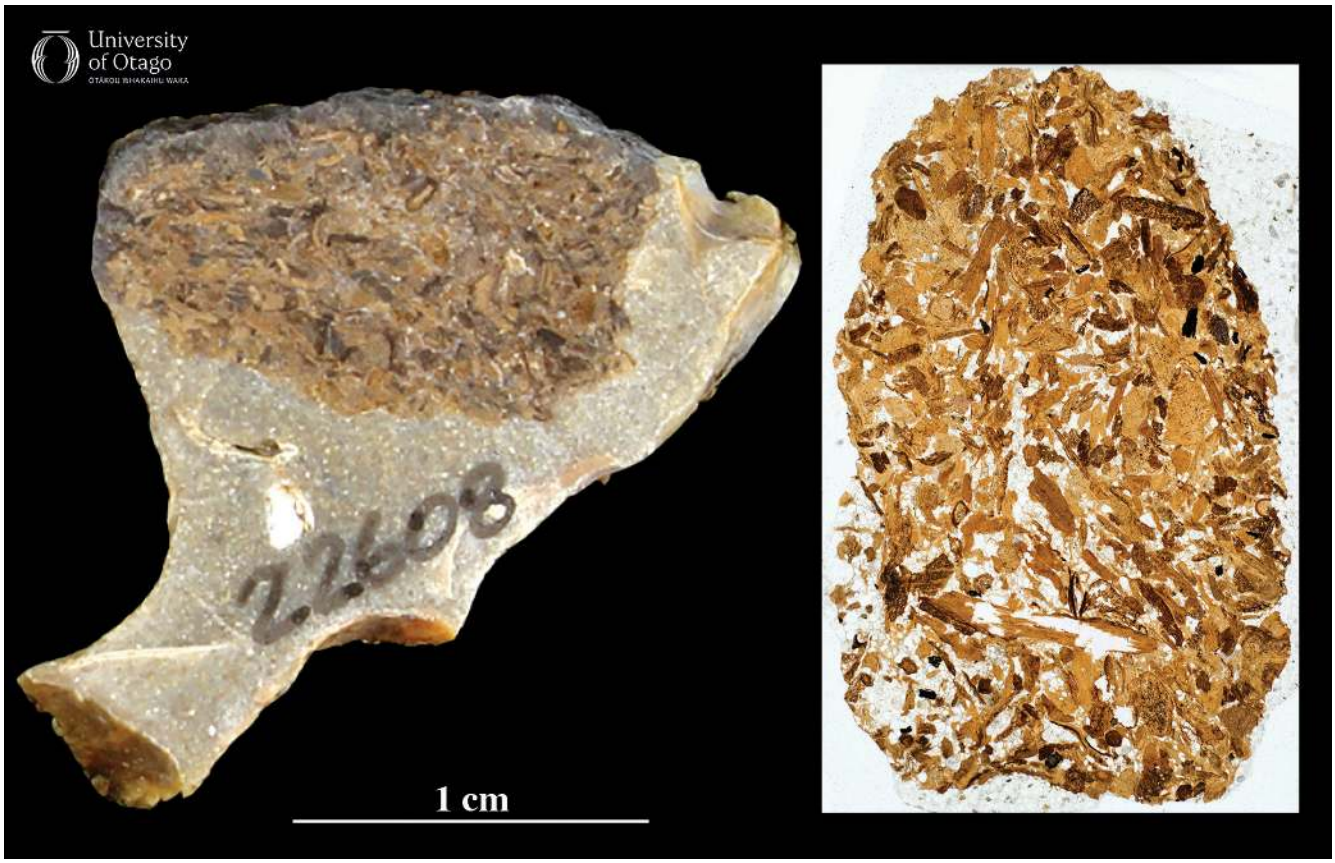
The Geology Museum also holds many other taoka that don't neatly fit into the sections we have presented so far. In this section we introduce some of the curios from among the Geology Museum collections.

5.1: Dinosaur droppings? A bezoar?
5.2: Cast collection hallmark of international connections

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5.1: Dinosaur droppings? A bezoar?

In 2004 a small pebble was collected by one of Ewan Fordyce's students as part of an undergraduate research project. The pebble was found in a sediment horizon in the Waipara Valley in North Canterbury that is densely packed with shells from the Late Cretaceous gastropod *Conchothyra parasitica*. The pebble stood out to the student as a smooth, rounded and brown pebble amongst the mollusc fossils.



The left image shows the coprolite after it was cut through the centre to make a thin section. The right image is rotated 90° clockwise compared with the left image and shows the thin section of the coprolite. Image credits: RE Fordyce, DB Thomas.

The pebble was brought back to the Department of Geology and prepared as a thin section, allowing the internal structure of the pebble to be studied with a microscope. Under the microscope the pebble was revealed to be a mixture of different types of plant fragments all cemented together. These plant fragments may represent the diet of an ancient animal, making the pebble a coprolite. And given that the fragments are from terrestrial plants, and that the coprolite was found in a Late Cretaceous sediment, the small brown pebble may be Aotearoa New Zealand's first discovery of fossilised dinosaur droppings. Another word that could be used to describe this pebble is 'bezoar', a term used for undigested plant material trapped in the digestive system.

The small pebble has yet to be fully analysed and described and so it remains one of the many tantalising potential research projects within the Geology Museum collections.

—Written by Daniel B Thomas

***Specimen number*:** OU 22608	***Age*:** Approximately 75 million years old (Late Cretaceous, Haumurian stage)
***Locality*:** Waipara Valley, North Canterbury	***Rock Formation*:** Charteris Bay Formation
***Collected by*:** DB Thomas	
***Citation*:** Not yet described	

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5.2: Cast collection hallmark of international connections

Fossils curated by the University of Otago Geology Museum capture the incredible diversity of ancient life preserved across the South Island of Aotearoa. The Geology Museum also holds fossil taoka from elsewhere, including fossil fish and other specimens from the Chatham Islands. Among the great opportunities these collections provide to students and other researchers is that they enable comparisons with newly discovered fossils. And even though the fossil record of Zealandia has a wide cross section of biodiversity, sometimes the best specimens for comparison are housed in other museums. To support these comparisons the Geology Museum also holds replicas of a small number of important fossils from around the world.



Ankle bone (tarsometatarsus) from the fossil penguin *Palaeeudyptes antarcticus* (cast of specimen BM A.1048). This cast is one of many similar objects in the Geology Museum collection. Image credit: JH Robinson.

The process of producing and sharing replicas of fossils between museums is a long-standing tradition for promoting research. The most important quality of a replica is its 'fidelity' or faithfulness to the original object. A high-fidelity replica of a fossil captures details at the smallest scale needed to be useful for study. Such replicas have traditionally been created by producing a mould of the fossil using a thin polymer, and then making a cast from that mould. High-fidelity casts of fossils from the Geology Museum can be seen on display at the Vanished World Centre in Duntroon. Similarly, the Geology Museum holds a small collection of high-fidelity casts from several museums around the world.

One especially important example in the Geology Museum collections is the broken ankle bone from a giant penguin. This story about the giant penguin and the cast was written by Ewan Fordyce:

"..The first penguin fossil recognised to science was a dramatically large incomplete ankle bone from Kakanui, on the coast of North Otago. The bone was acquired by Government Agent Walter Mantell during his travels in Otago in late 1848, and was sent to Britain where it was studied by the pre-eminent paleontologist T.H. Huxley. Huxley announced the find in the Quarterly Journal of the Geological Society in March 1859. There he identified the bone as from a new genus and species of penguin which he named Palaeeudyptes antarcticus *– literally, ancient winged diver of the south. The ankle bone or tarsometatarsus is perhaps the single most distinctive bone in penguins and, had he been presented with some other bone, Huxley might have found it more difficult to convince people that the fossil was from a penguin.*

Within a few decades, other fossil penguin bones were reported from New Zealand, both from North Otago and from Westland. Again, the bones clearly represented species larger than those of today. Because of their size, the fossils were thought to represent more individuals of Huxley's new species, Palaeeudyptes antarcticus*. However, no ankle bones were known amongst the new specimens, and it could not be confirmed that all the fossils really did represent the one species. Indeed, despite 150 years of field work, no more material of Huxley's species has been found – the species* Palaeeudyptes antarcticus *is still known from one incomplete bone. So, the name can be used confidently only for the one fossil which resides in a drawer in the Natural History Museum, London. Finally, we aren't even sure of the age of the fossil; it is probably from the soft white Ototara Limestone which, at Kakanui, spans the Eocene/Oligocene boundary – in the range 32-34 million years ago. However, the bone could be from the harder and younger Otekaike Limestone, with an age of perhaps 23-24 million years.."*

The Geology Museum's cast of the tarsometatarsus from *Palaeeudyptes antarcticus* has contributed to the research of postgraduate students and visiting researchers for several decades.

—Written by Daniel B Thomas, with a contribution from R. Ewan Fordyce

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CHAPTER OVERVIEW

6: Invertebrates- Molluscs—Ammonites, Nautiloids, Gastropods and Bivalves

There are tens of thousands of fossil molluscs in the collections of the University of Otago Geology Museum. Most of these fossils are from sites in Otago and Southland, but also other important localities around the South Island. They range in age from the Devonian to the present day, with large numbers from the Permian in Western Southland, Triassic and Jurassic rocks of the Hokonui Hills and the Catlins, a smaller number of Cretaceous age, including from sites around Ōtepoti Dunedin, and many collections from rocks of Paleocene, Eocene, Oligocene, Miocene and Pliocene age around Southland, Otago and South Canterbury. There are also numerous examples of species still living in the seas around Aotearoa New Zealand.

Chitons, limpets, cockles, mussels, oysters, snails, squid and octopus are molluscs – animals with an ancestor that had a muscular 'foot' used for locomotion and a body wall that produced a shell. From the ancestral mollusc body plan has arisen a great amount of biodiversity. For example, in the cephalopod group of molluscs the muscular foot has divided to become a set of arms, and the shell was either lost (as in octopus), was brought inside the body (as in squid, cuttlefish and belemnoids), or grew outwards into a many-chambered structure that is coiled in most species. In the oceans of the Late Cretaceous there were two lineages of cephalopods in which the animal lived in the largest chamber of a multiple-chambered shell. These two lineages were the ammonoids and the nautiloids. Nautiloids generally have less elaborate shells than ammonoids and have survived until the modern day. In contrast, ammonoids tend to have more ornamented shells and became extinct during the same mass extinction event that claimed all non-avian dinosaurs. In addition to being an iconic shape, ammonoid fossils can be useful indicators for the age of a sedimentary horizon.

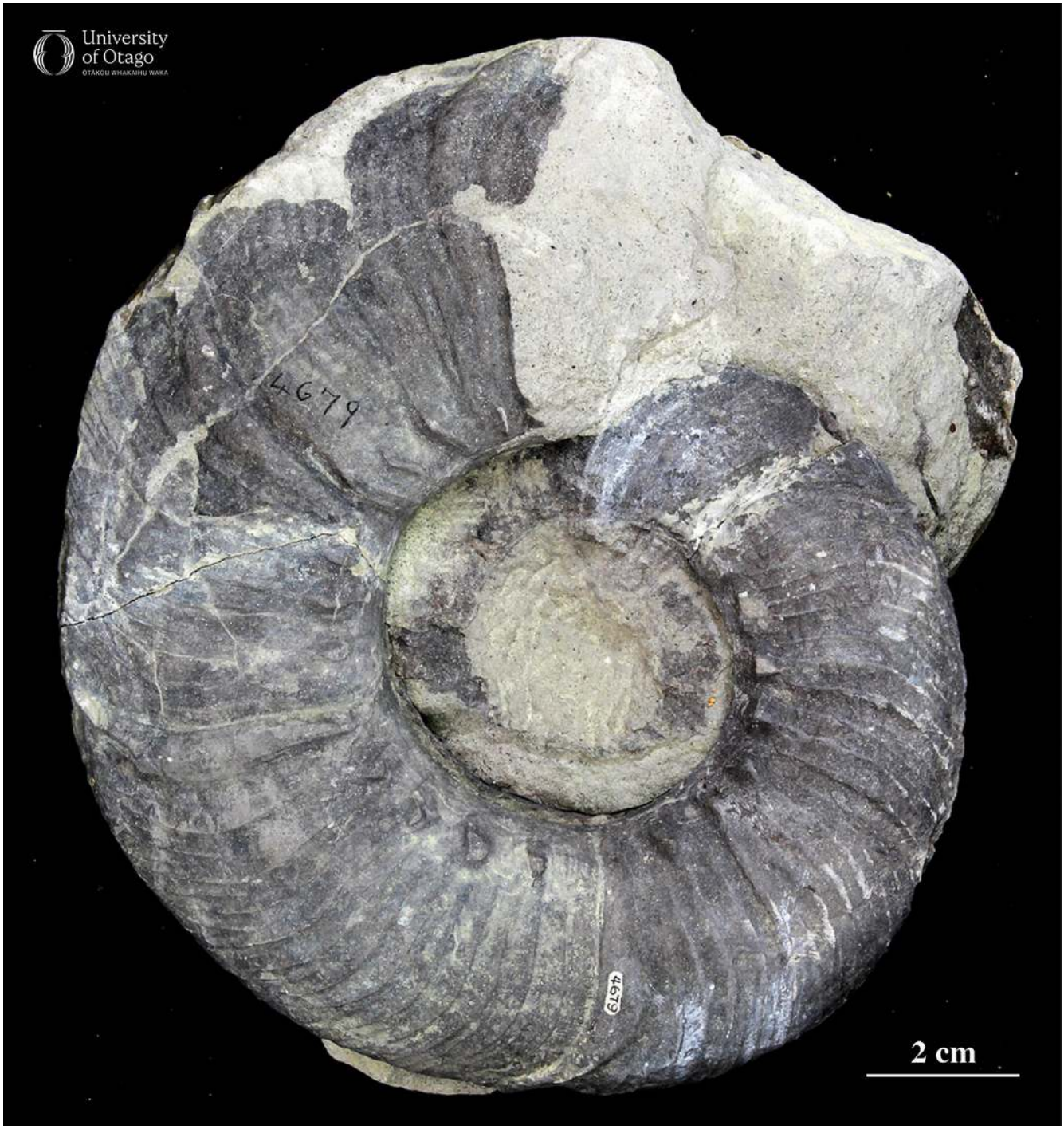
6.1: Dunedin's ammonite named for geology great
6.2: Mystery ammonite from Papatowai needs a name
6.3: Long extinct relative of 'The Chambered Nautilus'
6.4: Marine sandstone with turret shells galore
6.5: Pāua are ancient rocky shore icons
6.6: One-eared floating scallop
6.7: Smooth scallop from the ancient Southern Ocean sea floor
6.8: Carrier shells are snapshots of the sea floor community

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6.1: Dunedin's ammonite named for geology great

Mollusca, Cephalopoda: *Kossmaticeras bensoni*

One of the ammonoids that swam in Late Cretaceous oceans around Zealandia was *Kossmaticeras bensoni*. This large ammonoid had a shell that could reach up to 30 cm in diameter and is locally famous in Ōtepoti Dunedin for two reasons. The first reason is the frequency of discovery in concretions in the Fairfield sand quarry (a privately-owned quarry where access permission must first be sought before entering). The second reason is the name.



Natural mould of the shell from the ammonoid *Kossmaticeras bensoni* (specimen OU 4679). *Kossmaticeras bensoni* can be identified from its large size and the detail on the outside of the shell (i.e. ornamentation). Image credit: JH Robinson.

Kossmaticeras bensoni was named by Robert (Bob) Henderson in 1970 as part of a major study of Late Cretaceous ammonites in New Zealand. The species name *bensoni* was chosen to honour William Noel Benson, Professor and former Head of the Department of Geology at the University of Otago.

The holotype of *Kossmaticeras bensoni* is part of the Geology Museum collections. For every named species of organism on the planet, somewhere in the world there will be a single individual housed within a taxonomic collection that is considered the principal example of that species (the holotype). Every other individual that is identified as belonging to the same species has been compared to the holotype. There are some exceptions to this rule of biological classification, but nevertheless, protecting holotypes is one of the most important roles of the University of Otago Geology Museum, and of many other museums and taxonomic collections around the world.



Did you know there is a 3D printable model of this fossil for you to view online and download? Follow this link to learn more: 3D model—Dunedin's ammonite named for geology great.

Kossmaticeras bensoni can be identified from its large size and a combination of features ornamenting the shell including the approximately 70 ribs (i.e. radial ridges) on each half turn (i.e. half whorl) of the shell. In the well-cemented concretions in Fairfield Greensand at Fairfield quarry, *Kossmaticeras* and other molluscs are preserved as carbonised and three dimensional structures from which all original calcareous shell has been leached away. Accordingly, while surface details are preserved, none remain for internal structures – the septa, chambers and semiporous tube. Clusters of up to five individuals have been preserved together, suggesting that this species was abundant in these shallow seas. On one memorable field trip, a quarry digger driver dug out a row of concretions, lined them up at the foot of the quarry face and proceeded to crack them open for watching students. Dozens of such concretions, many with ammonites, are housed in the research collections in the South Basement, awaiting further study.

Species of *Kossmaticeras* have now been recognised in each of the former fragments of Gondwana and also in Canada, revealing *Kossmaticeras* to have had a broad distribution across Late Cretaceous oceans.

—Written by Daniel B Thomas

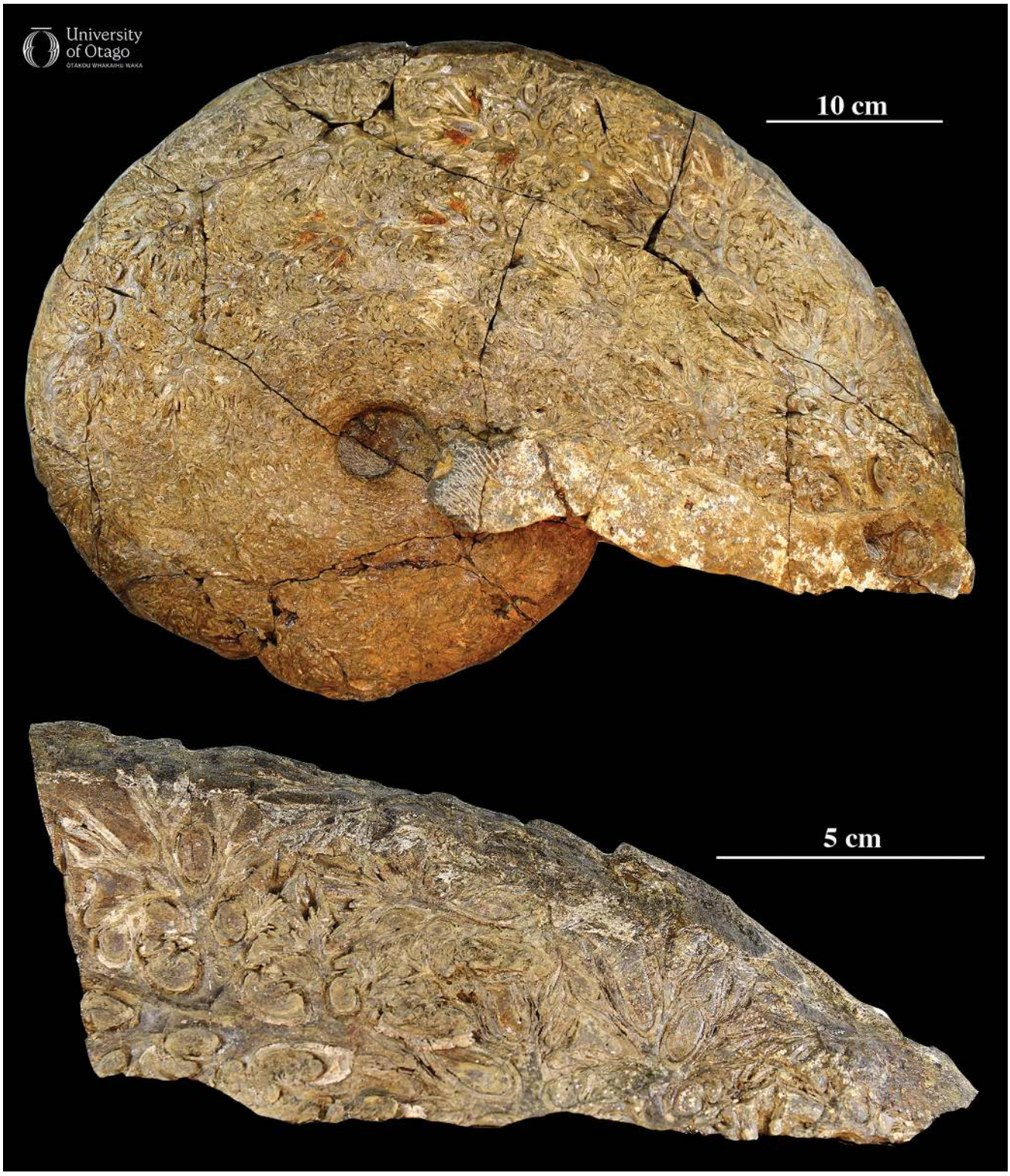
***Specimen number*:** OU 4679	***Age*:** Approximately 69 million years old (latest Cretaceous, Haumurian stage)
***Locality*:** Ōtepoti Dunedin, Otago	***Rock Formation*:** Fairfield Greensand member, Saddle Hill Formation
***Collected by*:** Information not recorded	
***Citation*:** Henderson RA. 1970. Ammonoidea from the Mata Series (Santonian-Maastrichtian) of New Zealand. Special Papers in Palaeontology 6:1–82.	

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6.2: Mystery ammonite from Papatowai needs a name

Mollusca, Cephalopoda: Phylloceratidae

The Geology Museum has hundreds of specimens of ammonites in addition to *Kossmaticeras*. Many of them are from rocks of Mesozoic age from the folded strata of the Southland Syncline (Murihiku Terrane), from the Hokonui Hills and from the Catlins area in South Otago.



Natural mould of the shell from an unidentified ammonoid (specimen OU 48255). The tree-like and round shapes across this fossil are the ornamentation left by the internal walls (i.e. sutures) that would have separated the internal chambers of the shell during life. Image credit: JH Robinson.

The largest ammonite specimen on display in the Geology Museum is labelled “Zetoceras”. However, the identity of this fossil is uncertain as it has not yet been studied in detail. About 50 cm by 30 cm across (bigger than a large dinner plate), this handsome,

laterally flattened ammonite is distinguished by complex suture lines which are only visible because the otherwise smooth exterior of the shell has been eroded away. It probably belongs in the family Phylloceratidae, a group of ammonites characterised by very complex sutures. These mobile carnivores would have possessed excellent vision, roaming the seas around what is now South Otago to feast on small fish, possibly crustaceans or other molluscs.



Did you know there is a 3D printable model of this fossil for you to view online and download? Follow this link to learn more: 3D model—Mystery ammonite from Papatowai needs a name.

Mesozoic fossils discovered in the North and South islands of Aotearoa have a special connection, which ammonite discoveries help to reveal. The first ammonites reported from Aotearoa were discovered by Ferdinand von Hochstetter in 1859, and these come from the Kawhia Harbour region of the west coast of the North Island. The fossil record for ammonites from Aotearoa would soon be joined by new discoveries from the Hokonui Hills in Southland, which were described by Patrick Marshall in 1909. Marshall compared the fossils from both locations and supported an earlier idea from Sir James Hector that the faunas of both locations belonged to the same "…conformable series of rocks as of an age extending from Permian to Jurassic…" Today, we know this to be the case, as the same Murihiku Terrane that crops out in Papatowai and elsewhere in Southland can be discovered forming beach platforms and cliffs at Kawhia. And at each location, it is possible to discover Phylloceratidae ammonites.

Like many other specimens on display in the Geology Museum, this specimen was collected and prepared by the late Andrew Grebneff who was passionately interested in molluscs of all kinds, both living and fossil.

—Written by Daphne E Lee and Daniel B Thomas

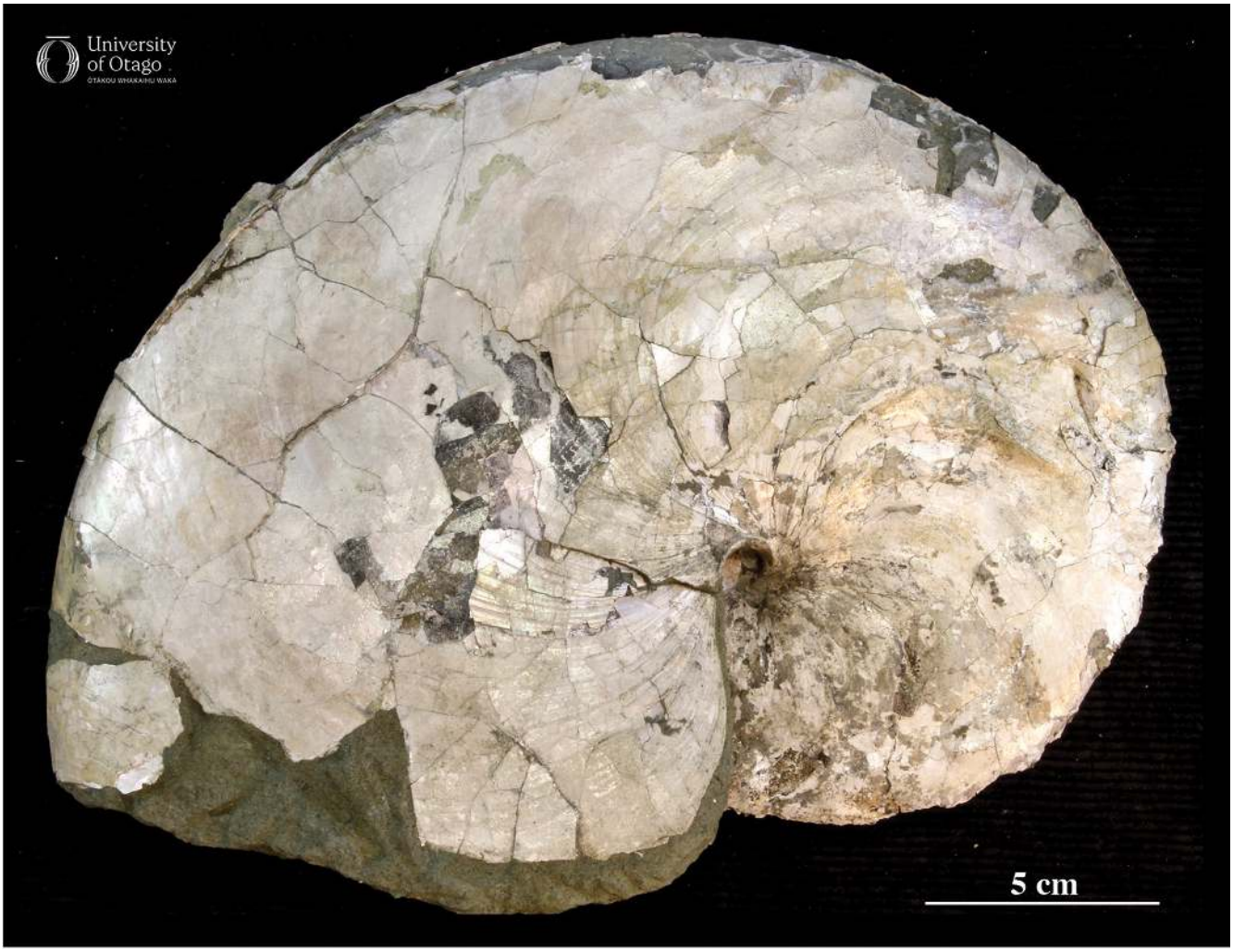
***Specimen number*:** OU 48255	***Age*:** Approximately 190 million years old (early Jurassic)
***Locality*:** Picnic Point, Papatowai, South Otago	***Rock Formation*:** Otekura Formation
***Collected by*:** Andrew Grebneff and others	
***Citation*:** Specimen not yet described.	

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6.3: Long extinct relative of 'The Chambered Nautilus'

Mollusca, Cephalopoda: *Aturia mackayi*

In the introduction to the Mollusca section of the eBook we describe cephalopods with many-chambered and coiled shells. We mention two lineages of these cephalopods, the ammonoids and the nautiloids. Nautiloids have simple septa and sutures inside the shell and usually a central siphuncle in contrast to the often very complex septa and sutures and ventral siphuncle of the extinct ammonites. All ammonoids globally died out at the same time as the last of the non-avian dinosaurs, around 66 million years ago. However, the nautiloids survived this mass extinction and a few are still swimming in modern oceans, mostly in seas around the southwest Pacific. The fossil diversity of nautiloids is therefore much larger than the living diversity and includes some truly spectacular discoveries.



A spectacular example of nacreous shell of the nautiloid *Aturia mackayi* (specimen OU 39928). Image credit: JH Robinson.

The Geology Museum collections display many extinct nautiloids including this nacreous specimen which is a very large, and nearly complete example of the extinct genus *Aturia*.

This handsome and well-preserved specimen was collected in 1990 by Andrew Grebneff and Ewan Fordyce from a locality of Bortonian (Late Eocene) age near Evans Crossing, Pareora River in South Canterbury. Andrew identified it as *Aturia mackayi*, a species named by Charles (later Sir Charles) Fleming in 1945.

There are currently three species of *Aturia* recognised from Aotearoa New Zealand: *Aturia mackayi*, which ranges in age from the Paleocene to the Eocene; *Aturia coxi*, which is known from Middle to Late Miocene sites; and *Aturia cubaensis*, with an

overlapping range of Early to Late Miocene.

Living *Nautilus* are scavengers and live on fish, cast-off moults of lobsters, and crabs, and other decaying material. Scientists have suspended the remains of chickens from research vessels as bait when endeavouring to catch live animals for study. It is assumed that fossil nautiloids such as *Aturia* were also ocean scavengers.

Nautilus shells are beautiful examples of logarithmic spirals and, as such, are often used in art works and logos. '*The Chambered Nautilus*' is the name of the school song of Otago Girls' High School in Ōtepoti Dunedin and the school symbol. A 1.8 metre tall bronze sculpture of two hands holding up a chambered nautilus was specially commissioned for the school's 150th jubilee celebrations. It seems appropriate that animals that swam in seas around Zealandia for millions of years are celebrated in this way even though seas around New Zealand are too cold for nautiloids to survive in today.

—Written by Daphne E Lee

***Specimen number*:** OU 39928	***Age*:** Approximately 40 million years age (late Eocene, Bortonian stage)
***Locality*:** Evans Crossing, Pareora River, South Canterbury	***Rock Formation*:** Waihao Greensand
***Collected by*:** A Grebneff, RE Fordyce	
***Citation*:** Fleming CA. 1945. Some New Zealand Tertiary cephalopods. Transactions of the Royal Society of New Zealand 74:411–418.	

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6.4: Marine sandstone with turret shells galore

Mollusca, Gastropoda: *Zeacolpus* sp.

Measley Beach near the coastal South Otago settlement of Wangaloa has been recognised as a fossil hotspot since the geologist James Hector made a small collection of molluscs in the area in 1869. These and many other marine invertebrates, as well as some vertebrates and fossil wood, have been collected over the years from the fossil-rich Wangaloa Formation, a well-cemented quartz sandstone that was deposited in shallow seas, possibly in an inner shelf setting, and with storm-influenced deposits. There are many places within the Wangaloa Formation where shells are concentrated, but these shellbeds don't form a continuous layer throughout the sedimentary horizon. These shell-rich spots can be seen in the cliffs and on the beach. In places, there are *Teredo*-bored logs of araucarian wood and many trace fossils including burrows of shrimp fossils known as *Ophiomorpha*.



Large block of sediment containing *Zeacolpus* turret shells, the long shells were aligned by a tidal current while resting on the ancient sea floor. A single large fossil *Zeacolpus* shell. Image credit: RE Fordyce.

These rocks and fossils were deposited around 63 to 61 million years ago during the Paleocene, not long after the major extinction event at the end of the Cretaceous which wiped out the non-avian dinosaurs, marine reptiles such as mosasaurs and plesiosaurs, and molluscs such as ammonites and belemnites. So, the fossils at Wangaloa are of particular interest as they represent the survivors who made it through to the Cenozoic.

Some beds are covered with huge numbers of turret-shaped turritellid gastropods which are aligned by current activity but many other invertebrate fossils are present. They include dozens of large bivalves such as *Lahillia* and *Glycymerita* and gastropods such as *Conchothyra* and *Globisinum.* Some of the species found at Wangaloa have close relatives in rocks of similar age in the Antarctic Peninsula but others are found nowhere else. Other fossils include shark teeth, a small toothplate of a chimaeroid fish (sometimes known as ghost sharks) and rare fragments of turtles.

A large boulder collected from a shellbed at Measley Beach is set on a plinth in the Quadrangle outside the Department of Geology Building. It shows dozens of turritellid gastropods, mostly *Zeacolpus.*

—Written by Daphne E Lee

***Specimen number*:** OU 47954 (block), OU 47985 (shell)	***Age*:** Approximately 62 million years old (Paleocene, early Teurian stage)(block), Approximately 23 million years old (late Oligocene to early Miocene, Waitakian stage)(shell)
***Locality*:** Wangaloa, South Otago (block), Hakataramea Quarry (shell)	***Rock Formation*:** Wangaloa Formation (block), Otekaike Limestone (shell)
***Collected by*:** Unknown collectors	
***Citation*:** Marwick J. 1971. New Zealand Turritellidae related to *Zeacolpus* Finlay (Gastropoda). New Zealand Geological Survey Paleontological Bulletin 44:1–87.	

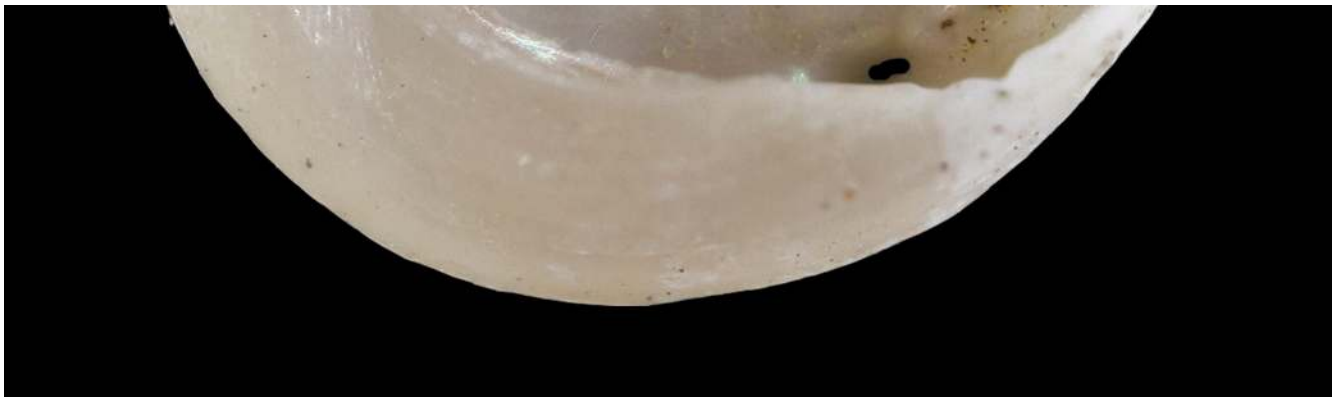
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6.5: Pāua are ancient rocky shore icons

Mollusca, Gastropoda: *Haliotis* sp.

Pāua are iconic inhabitants of rocky shores around Aotearoa New Zealand. Known formally as *Haliotis*, there are three species of pāua living in New Zealand today. And although they have a global fossil record dating back to the Cretaceous, *Haliotis* is an uncommon discovery in the New Zealand fossil record. Importantly though, the small number of *Haliotis* fossils that have been found locally reveal that pāua has a long history in Zealandia.





External and internal views of a tiny fossil pāua shell from Cosy Dell. Note the row of tiny pores (tremata) and the iridescent colour still preserved after 25 million years. This fragile shell floated out from its protective ‘cave’ inside a larger gastropod when the shell was washed in water. Image credit: Yutong Wu.

The Cosy Dell fossil locality in Southland preserves a rare rocky shore environment from between 25.4 and 24.4 million years ago. Several incomplete specimens of *Haliotis* have been discovered at Cosy Dell but the one shown here is a perfectly-preserved fragile juvenile, just 3 mm long, which displays the row of tiny pores (tremata) characteristic of pāua and retains traces of iridescent pearly nacre.

Pāua cling to a rock substrate with a strong muscular foot and graze on seaweed. The fossils at Cosy Dell occur with a wide range of intertidal and subtidal animals such as barnacles and algal grazers such as chitons. The pāua and chiton fossils therefore provide indirect evidence for a diverse seaweed flora. This is amazing, as soft and fragile seaweeds are rarely, if ever, preserved in the fossil record.

—Written by Daphne E Lee

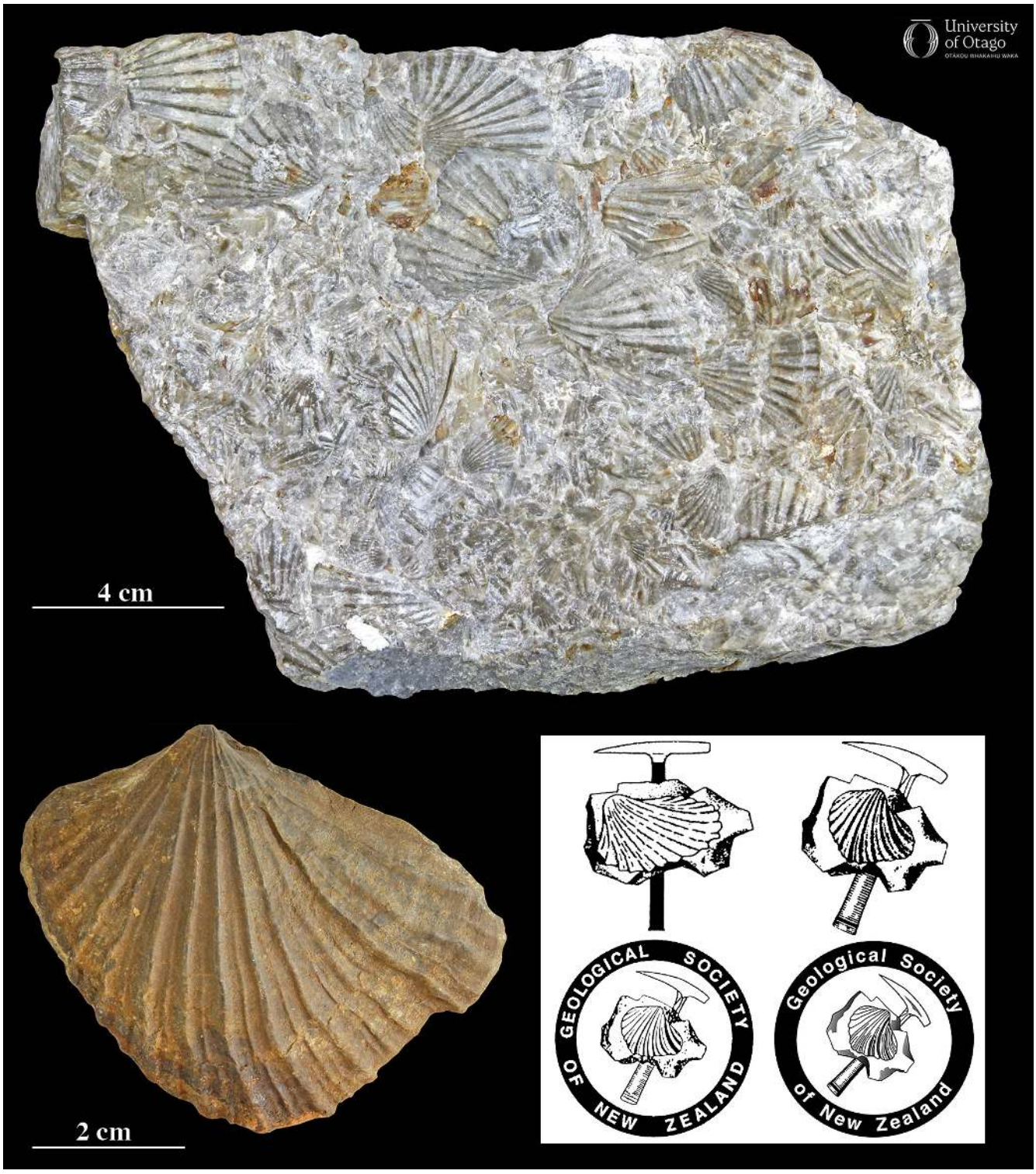
***Specimen number*:** OU 44922	***Age*:** 25.4 to 24.4 million years ago (late Oligocene, boundary between the Duntroonian and Waitakian stages)
***Locality*:** Waimumu, Southland	***Rock Formation*:** Chatton Formation
***Collected by*:** DE Lee	
***Citation*:** Lee D, Lindqvist J, Beu A, Robinson J, Ayress M, Morgans H, Stein J. 2014. Geological setting and diverse fauna of a Late Oligocene rocky shore ecosystem, Cosy Dell, Southland. New Zealand Journal of Geology and Geophysics 57:195–208. doi.org/10.1080/00288306.2014.898666	

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6.6: One-eared floating scallop

Mollusca, Bivalvia: *Monotis* spp.

Monotis is an extinct group of scallops that had a worldwide distribution in the Late Triassic. *Monotis* shells have a distinctive shape with a spoon-shaped ear separated from the anterior wing by a deep byssal notch and strong ribs interspersed with finer ones. The species of *Monotis* had quite thin shells relative to their size and probably lived attached to floating seaweeds at the ocean surface. *Monotis* has a cosmopolitan distribution and often occurs in dense shell beds. It must have been very common in suitable environments where the dead shells settled and thickly covered the sea floor.



The top image shows a section of a shellbed composed almost entirely of fossil *Monotis intermedia* shells. The image along the bottom left shows an individual *Monotis subcircularis* shell. The bottom right shows former logos of the Geological Society of New Zealand showing *Monotis* in a block of sandstone against a geology hammer. Image credit: JH Robinson (photographs), J Koster, D Gregg, G Warren, P Suggate, K Kingma, G Coates (GSNZ logo). Permission to include the logo designs kindly provided by the Geoscience Society of New Zealand. For a history of the logo please see "Origin of the Geological Society of New Zealand's logo" by Don Gregg and David Smale, page 47 in Hayward BW (2005) Geological Society of New Zealand 1955-2005: Our first 50 years. Geological Society of New Zealand Miscellaneous Publication 118. 74pp.

The first European professional geologist to work in New Zealand, Ferdinand von Hochstetter, collected *Monotis* fossils from the Nelson area during his short but productive visit in 1859 and took them back to Austria where they were described by paleontologist KA Zittel. Once all placed in *Monotis richmondiana*, later research has recognised five genera and up to 14 different species but it is challenging for a non-specialist to tell them apart.

Monotis is possibly the best-known and most widely recognised fossil in New Zealand. Tens of millions of individual specimens form shellbeds that can sometimes be traced for many kilometres at localities from South Otago through Southland to Nelson and the Waikato. The Warepan Stage has its type locality near the tiny settlement of Warepa in South Otago and rocks can be immediately identified as of Warepan age (217 to 208.4 million years when the *Monotis* shellbed is present. Isolated shellbeds are also found in rocks of the Torlesse terrane in Canterbury and Wellington.

The Geological Society of New Zealand (now Geoscience Society of New Zealand) was set up in 1955. Seven years later the fledgling society decided it needed a logo, and in 1964 the first version of the logo was published: a block of rock with a stylised *Monotis* shell resting on a geological hammer.

—Written by Jeffrey H Robinson

***Specimen number*:** OU 47986 (block), OU 14294 (shell)	***Age*:** Approximately 212 million years ago (late Triassic, Warepan stage)
***Locality*:** Lees Pass, North Canterbury (block), Taringatura Hills, Southland (shell)	***Rock Formation*:** Torlesse Supergroup (block), Murihiku Supergroup (shell)
***Collected by*:** JD Campbell (block), GGC (shell)	
***Citation*:** Grant-Mackie JA. 1985. The Warepan Stage of the Upper Triassic: Redefinition and subdivision. New Zealand Journal of Geology and Geophysics 28:701–724. doi.org/10.1080/00288306.1985.10422542; Grant-Mackie JA. 2015. Taxonomy of the Late Triassic bivalve *Monotis*. New Zealand Journal of Geology and Geophysics 58:244–251. doi.org/10.1080/00288306.2015.1021819	

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6.7: Smooth scallop from the ancient Southern Ocean sea floor

Mollusca, Bivalvia: *Lentipecten hochstetteri*

On display in the foyer of the Geology Museum is a block of fossil-rich sandy limestone exhibiting an array of beautifully preserved fossils belonging to at least a dozen different phyla. This block, and a dozen more like it, were initially cut out with a chainsaw from a shell bed in a limestone quarry in South Canterbury and brought back to the Department of Geology for further study. Over many weeks, students painstakingly prepared the fossils for display as part of their "Evolution of the New Zealand Biota" GEOL 200/300 level laboratory classes. Grains of sand were removed under binocular microscopes using fine needles and paintbrushes to display the fossils.



A shark's eye view of what the sea bed of the Southern Ocean inland from Oamaru would have looked like 26 million years ago. *Lentipecten hochstetteri* is the smooth-shelled scallop scattered among the other fossils. Photo: JH Robinson.

The fossil diversity is remarkable, and the excellent preservation suggests the shells were not moved far from life position after death. The most conspicuous fossils are molluscs: dozens of bivalve and gastropod species, two species of tusk shells, smooth *Dentalium* and finely ribbed *Fissidentalium*, and one example of the nautilus-like *Aturia* (see: Long extinct relative of 'The Chambered Nautilus'). Some bivalves such as the robust ark shells *Cucullaea* have both valves preserved, while examples of the file clam *Lima* still display traces of their original colouration.

Perhaps one of the most iconic fossils in the section of ancient sea floor is the smooth scallop *Lentipecten hochstetteri*. *Lentipecten* is a palm-sized scallop shell that is a common sight in limestones and greensands from North Otago and South Canterbury. In addition to its two smooth shells, *Lentipecten hochtetteri* is also identified from its auricles, which are smooth along the hinge end in the left valve, and mostly smooth but sometimes slightly ridged for the right valve. These are scallops were clearly an important part of the benthic community on the ancient continental shelf.

Other fossils found alongside *Lentipecten hochtetteri* in these ancient shell beds include bones and teeth of vertebrates, like the upper and lower jaw of a billfish (see: Game fish have ancient history in South Pacific). Microscopic foraminifera that help to date the rock as 26 to 23 million years old are abundant. Corals, bryozoans, brachiopods, barnacles, the conspicuous elongate tapering tubes of the fan tubeworm *Protula*, isolated spines of sea urchins and occasional entire echinoids (heart urchins) attest to the rich fossil ecosystem preserved here.

These fossils are from the Otekaike Limestone which accumulated in shallow shelf waters some distance off the eastern coast of Zealandia when much of the land area of what is now New Zealand was submerged. The limestone was deposited in fairly quiet conditions at depths of between 50 to 100 m. After death, most shells and skeletons were broken apart by scavengers and current activity to form billions of grains of limey sand. Over time the sediments were buried by younger rocks and gradually consolidated into limestone, sometimes well-cemented, sometimes hardly cemented at all (as occurred at the source of this block) allowing the fossils to be carefully extracted.

Over the past 5 million years, uplift has brought these ancient marine rocks up to the surface where modern erosion and weathering has produced the distinctive limestone outcrops and landforms characteristic of much of North Otago and South Canterbury and the UNESCO Waitaki Whitestone Global Geopark. Similar fossils are on display at the Vanished World Centre in Duntroon.

—Adapted by Daphne E Lee and Jeffrey H Robinson from text originally written by R Ewan Fordyce

***Specimen number*:** OU 47987	***Age*:** Approximately 26 million years old (late Oligocene, Duntroonian stage)
***Locality*:** Hakataramea Quarry, South Canterbury	***Rock Formation*:** Otekaike Limestone
***Collected by*:** RE Fordyce	
***Citation*:** Specimen not published	

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6.8: Carrier shells are snapshots of the sea floor community

Mollusca, Gastropoda: *Xenophora* sp.

The Geology Museum has many fossil specimens of the carrier shell, *Xenophora* in its collections. The example illustrated here comes from the sandy limestone in South Canterbury which is described in the chapter Smooth scallop from the ancient Southern Ocean sea floor.



An example of a fossil carrier shell from the sandy limestone in the Hakataramea Valley, South Canterbury. Note the shell debris and concave-up bivalve shells that increase in size as the fragile shell grows. Image credit: JH Robinson.

These well-named marine gastropods camouflage themselves by cementing other mollusc shells, small pebbles or other debris to their shell as they grow. These shell ‘decorations’ serve several functions: as well as helping the animal avoid potential predators, they add strength and lift the animal higher above the substrate to avoid smothering in the soft sediment on/in which these deposit feeders lived.

The decorations which often include concave-up bivalve shells are small at the top, and become larger as the shell grows.

A species of *Xenophora* is found in seas around New Zealand today at depths of 10 to 150 metres. The animals move in jerky leaps across the soft seabed and then stay still, looking to any potential predators like a small heap of shell gravel. They are deposit feeders, sifting through the surface layer of muddy silt to take in diatoms and other microscopic organic material. They give us a picture of the dynamic sea floor that was once occupied by fossil *Xenophora* in a region of South Canterbury and North Otago that is now several hundred metres above sea level.

—Written by Daphne E Lee

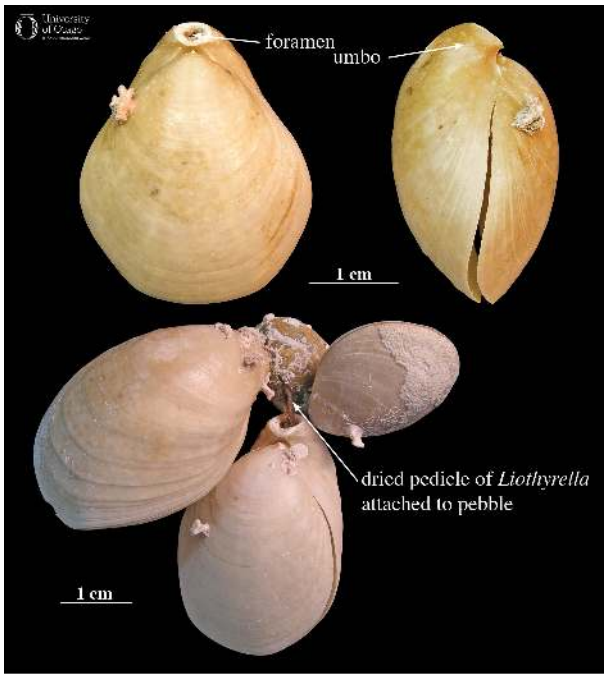
***Specimen number*:** OU 43374	***Age of specimen*:** Approximately 26 million years old (late Oligocene, Duntroonian stage)
***Locality*:** Hakataramea Valley, South Canterbury	***Rock Formation*:** Otekaike Limestone
***Collected by*:** A Grebneff	
***Citation*:** Beu AG. 1977. New Zealand Cenozoic gastropods of the genus *Xenophora* Fischer, 1807. Journal of the Royal Society of New Zealand 7:229–241. doi.org/10.1080/03036758.1977.10427161	

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CHAPTER OVERVIEW

7: Invertebrates- Brachiopods

Although they look at first glance like bivalve molluscs, brachiopods belong to a quite different phylum of marine animals. Sometimes called lampshells because of a fancied resemblance to a Roman oil lamp, brachiopods are solitary marine invertebrates that possess two valves of slightly different sizes. They are usually attached to the sea floor by a pedicle, although they may be cemented, free-lying or burrowers. They have bilateral symmetry, and are generally small, from 2 mm to 100 mm in length. The shell is usually calcareous or rarely phosphatic, and many brachiopods have tiny punctae in the shell. The main distinguishing feature of brachiopods is their method of feeding. They are suspension feeders, filtering minute plankton and organic particles from the surrounding seawater. The feeding organ, the lophophore, is supported inside the shell by short prongs (crura) or delicate short or long ribbon-like loops.



A visual guide to some of the terms used to describe brachiopods. Image credit: JH Robinson.

They are found through the world's oceans today, generally in small numbers – about 100 genera and 350 species are known. However, in the distant past, millions of brachiopods placed in 4,500 genera were some of the most abundant animals on the seabed – especially in the Paleozoic and Mesozoic.

Aotearoa New Zealand has some of the most studied living brachiopods because they are found in very shallow water, including in Otago Harbour, around Stewart Island and in the fiords. However, they have an excellent, though patchy fossil record here too, with specimens known from Cambrian rocks in the Cobb Valley, Devonian sediments near Reefton and in North West Nelson, the Permian of Western Southland, and Triassic and Jurassic strata in the Catlins, Hokonui Hills, and the western North Island between Port Waikato and Awakino. The Oligocene and Miocene limestones and greensands of the Canterbury Basin are also important where shellbeds made up entirely of brachiopods can occasionally be found.

7.1: Wing-like brachiopods endemic to a future Zealandia
7.2: Large brachiopod that easily forms attachments
7.3: Massive free-lying brachiopod
7.4: Free-living, unattached brachiopod

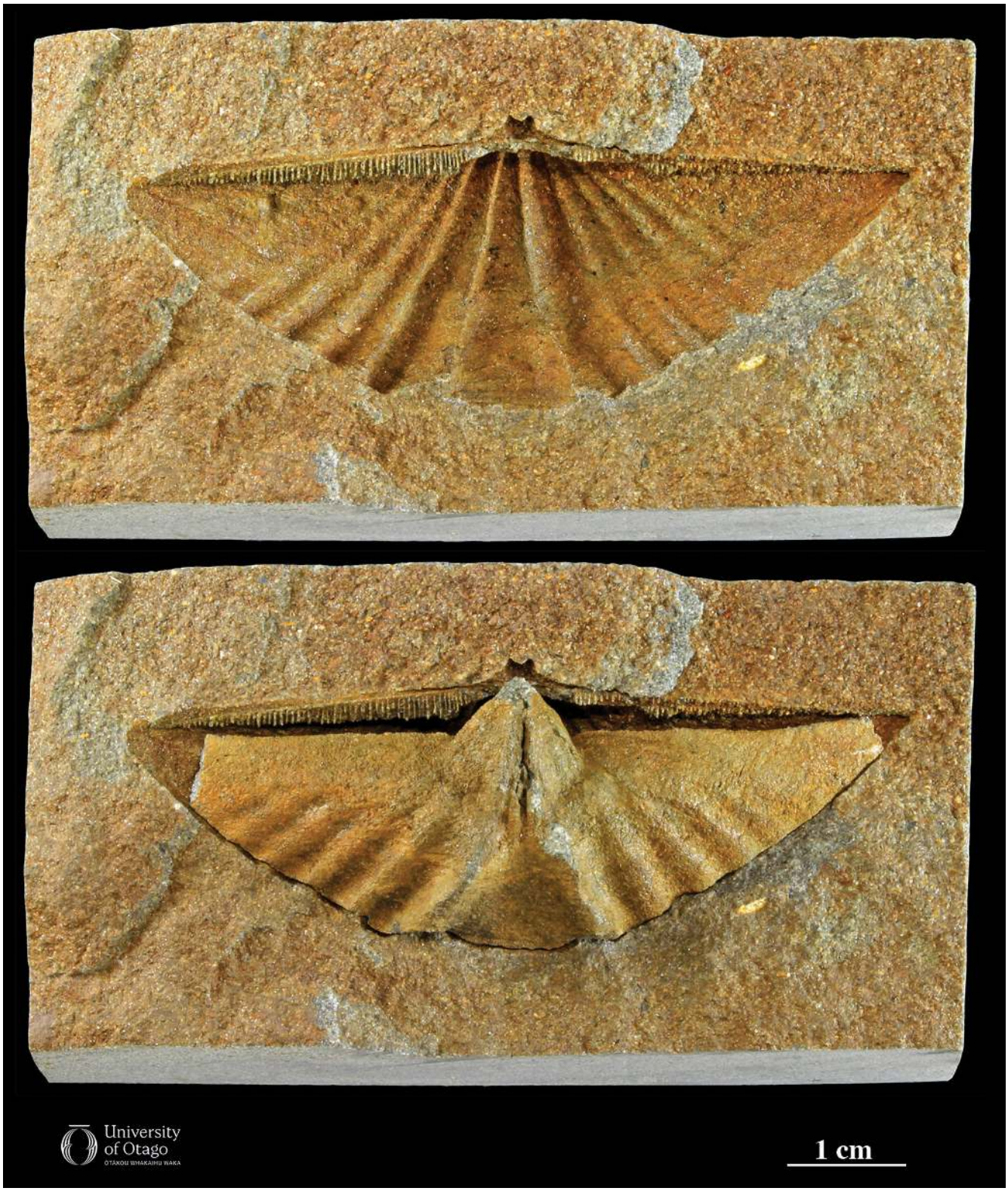
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7.1: Wing-like brachiopods endemic to a future Zealandia

Brachiopoda, Spiriferinida: *Rastelligera* sp.

During the Triassic and Jurassic about 200 species of brachiopods were present in the seas around southern Pangaea and the newly-forming Gondwana (future Zealandia). One particularly unusual group of brachiopods known as *Rastelligera* is well-represented in the University of Otago Geology Museum collections. This is a genus of spiriferinid brachiopods (these have a coiled spiralium which supported the lophophore during life) that are distinguished by a very long, wing-like hingeline. Around eight species are known and all are endemic to Zealandia. The first of these species was named in 1913. Most of the others were named in 1968 by JD (Doug) Campbell, a paleontologist and botanist who was on the staff of the Department of Geology from 1959 until his death in 2001.



Part, counterpart and steinkern (internal mould) of a specimen of the extinct brachiopod, *Rastelligera*. The calcareous external shell has been completely dissolved away. Image credit: JH Robinson.

These distinctive brachiopods are found throughout a 2000 metre thick sequence of Triassic rocks in Southland and South Otago from the Hokonui Hills to Nugget Point. They became extinct at the end of the Triassic, a time when many other brachiopods also disappeared from the fossil record.

The name *Rastelligera* refers to the distinctive “comb-teeth” and was coined by James Hector in 1878 (in Latin, rastellus refers to the teeth on a rake). Some of these brachiopods are also described as mucronate, an unusual word which means to end abruptly in a point. The elongate, wing-like shape may have helped to anchor the brachiopods on the seabed and the many teeth ensured the animal could securely hold its valves closed. Because the shell material has usually been dissolved away over time, the fossils are often moulds showing the interior structures. The shape and morphology of the actual shell can be recreated by using a rubber or silicone mould and then more replicas can be made.

—Written by Jeffrey H Robinson and Daphne E Lee

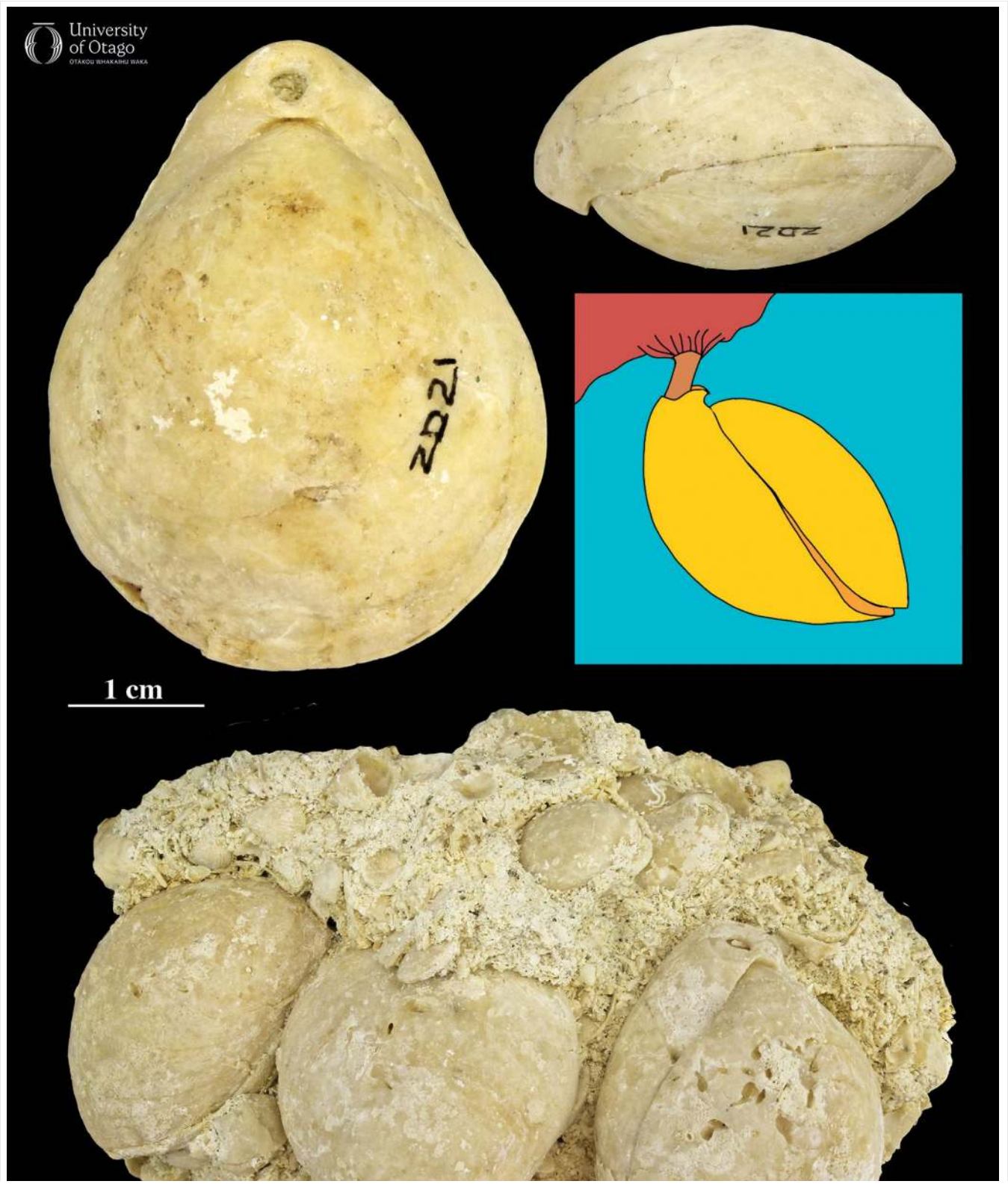
***Specimen number*:** OU 19325	***Age*:** Approximately 204 million years old (late Triassic, Otapirian stage)
***Locality*:** Otamita Stream, Hokonui Hills, Southland	***Rock Formation*:** Murihiku Supergroup
***Collected by*:** Student on a Geology field trip in 2001	
***Citation*:** Campbell JD. 1968 *Rastelligera* (Brachiopoda) of the upper Triassic of New Zealand. Transactions of the Royal Society of New Zealand 6:23–37.	

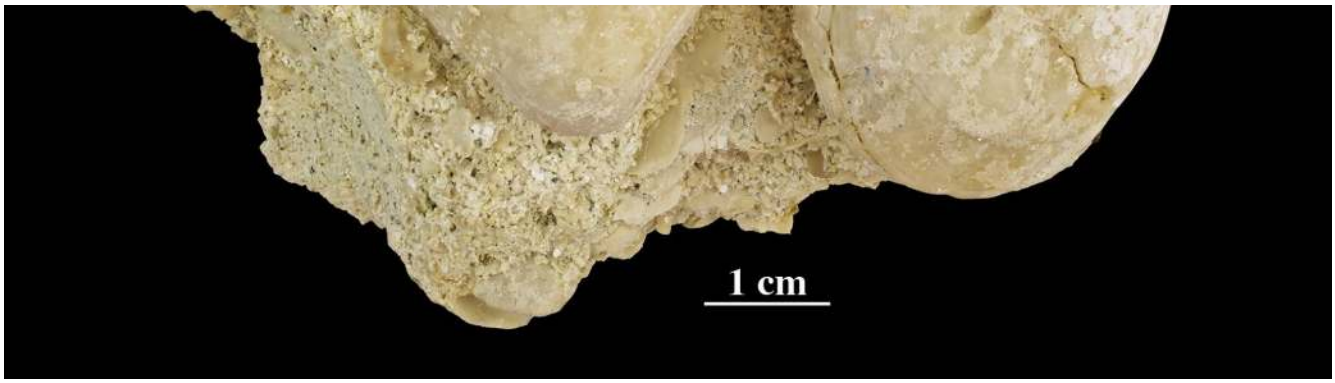
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7.2: Large brachiopod that easily forms attachments

Brachiopoda, Terebratulida: *Liothyrella* sp.

Liothyrella are medium to large-sized, short-looped brachiopods. Fossils are known from the Eocene and Oligocene of Aotearoa New Zealand and living species are known from New Zealand, Antarctica and South America.





Liothyrella brachiopods as individual fossils and as a cluster preserved together in limestone. An illustration shows how the brachiopod would have attached to a rock by its pedicle. Image credit: JH Robinson, with illustration adapted from Richardson (1981).

Liothyrella is invariably attached to a hard substrate. Living individuals are often found in large clusters, all attached to each other. We know this also happened in fossil populations as well as the pedicle attachment to the shells leave a distinctive trace (a trace fossil known as a podichnus).

In the Ototara Limestone of North Otago, *Liothyrella* shells are sometimes very common in certain horizons. Their large shells, both live and dead, provided a substrate for many smaller invertebrates to attach to, including bryozoans, tube worms, barnacles, encrusting foraminifera and smaller ribbed brachiopods such as *Terebratulina*.

—Written by Jeffrey H Robinson

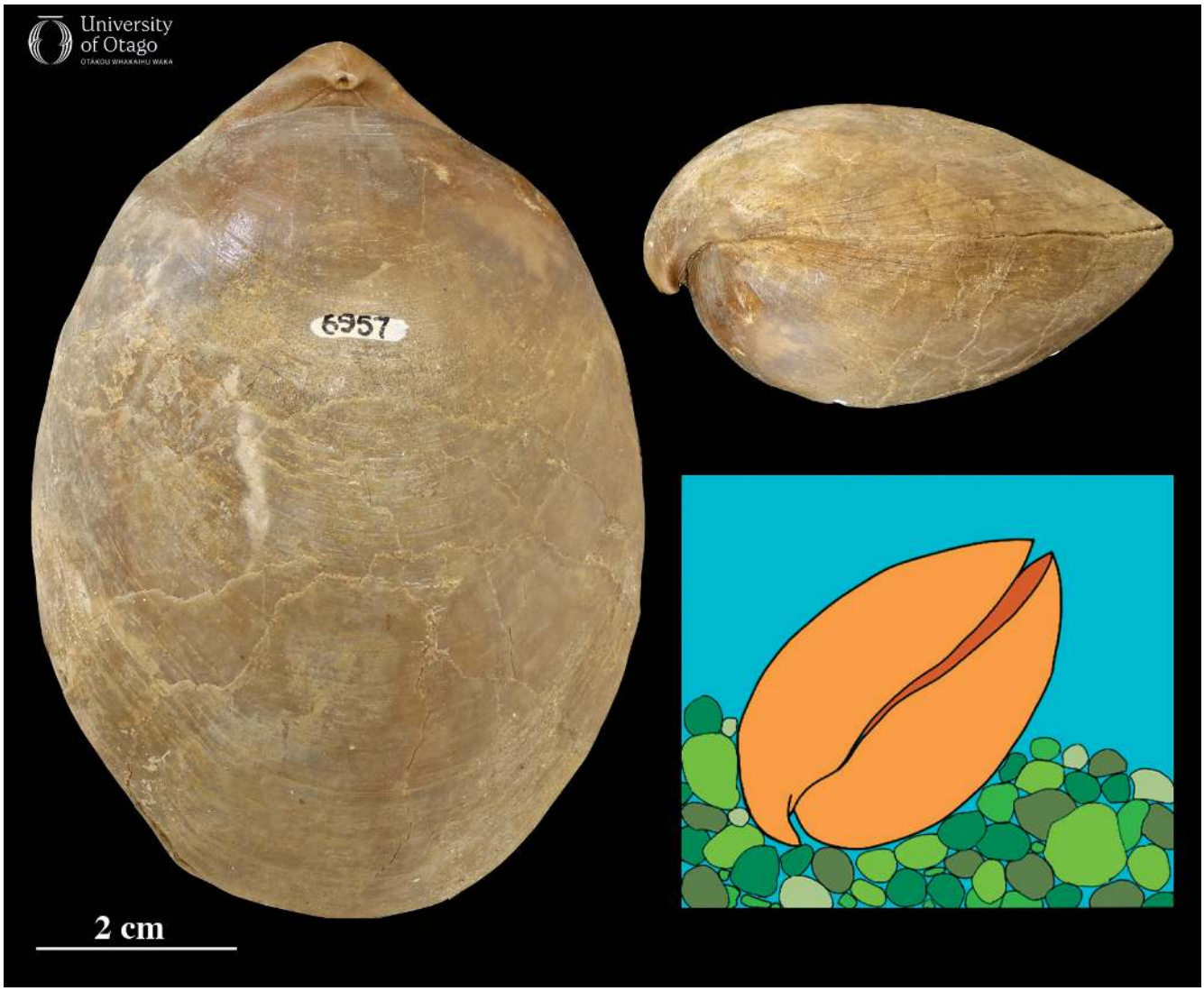
***Specimen number*:** OU 47988 (single shell), OU 47989 (small block with 3 shells)	***Age*:** 34.6 million years old (late Eocene, Whaingaroan stage)
***Locality*:** Kakanui, North Otago	***Rock Formation*:** Ototara Limestone
***Collected by*:** ZD Bowen and JD Campbell	
***Citation*:** Robinson JH. 2004. Brachiopod and molluscan faunas of Everett's Quarry, Kakanui. Unpublished MSc thesis, Department of Geology, University of Otago.	

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7.3: Massive free-lying brachiopod

Brachiopoda, Terebratulida: *Erihadrosia epsilon*

One of the variety of life habits that brachiopods have evolved is known as ‘free-lying’. While juveniles of free-lying brachiopods are probably always attached to a hard substrate (ie a shell or pebble) by their pedicle, as these species get larger they allow their pedicle to wither and they lie on the sea floor on soft sediments. The foramen is tiny in adults.



An example of the brachiopod *Erihadrosia epsilon* in different views, including a reconstruction of how it would have sat on the sea floor (specimen OU 6957). Image credit: JH Robinson with illustration adapted from Richardson (1981).

Brachiopods must open their shells (at the ‘anterior’ end) in order to feed by filtering tiny food particles out of the sea water. Free-lying brachiopods thicken the posterior end of the shell so it is much heavier and sinks a little into the soft sediment, raising up the anterior end.

Many different genera and species of brachiopod have adopted this free-lying habit over their 500 million year history. In New Zealand the most impressive species is *Erihadrosia epsilon* (originally called *Stethothyris epsilon*); single specimens can be up to 10 cm long.

Erihadrosia lived in shallow shelf environments around New Zealand during the Middle Miocene.

—Written by Jeffrey H Robinson

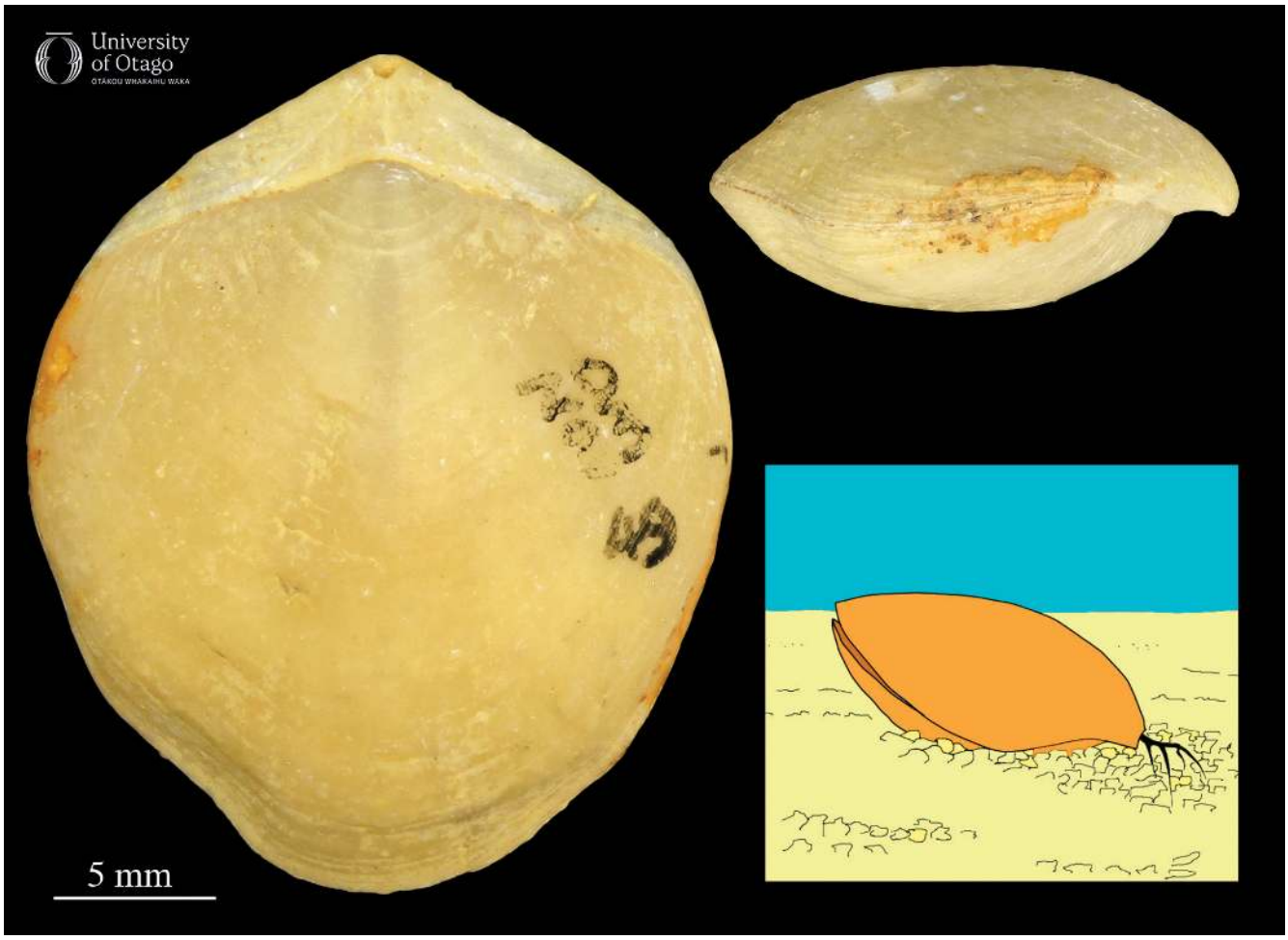
***Specimen number*:** OU 6957	***Age*:** Approximately 14 million years old (middle Miocene, Lillburnian stage)
***Locality*:** *Cucullaea* Shellbed, Clifden, Southland	***Rock Formation*:** Clifden Limestone
***Collected by*:** JD Campbell and others	
***Citation*:** Hiller N, MacKinnon DI. 2000. A reappraisal of the systematics of the *Stethothyris* group of brachiopods from the Cenozoic of New Zealand and Australia. New Zealand Journal of Geology and Geophysics 43:59–81. doi.org/10.1080/00288306.2000.9514870	

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7.4: Free-living, unattached brachiopod

Brachiopoda, Terebratulida: *Rhizothyris* spp.

Rhizothyris was a genus of brachiopods with a life habit known as ‘free-living’. These brachiopods are not attached to anything (see: Large brachiopod that easily forms attachments) or are passively free-lying on the sea floor (see: Massive free-lying brachiopod), but have a ‘motile’ pedicle that they can move in and out to reorient themselves.



An example of the brachiopod *Rhizothyris* in different views, including a reconstruction of how it would have sat on the sea floor. Image credit: JH Robinson with illustration of the motile pedicle, adapted from Richardson (1981).

In brachiopods that attach to the substrate the umbo curves, the end of the pedicle has ‘roots’ that attach to the substrate (see Brachiopods) and the pedicle muscles allow the shell to be rotated.

Having a motile pedicle has involved modification of the umbo and foramen and the muscles controlling the pedicle. The umbo is straight and the foramen points posteriorly. The tip of the pedicle has small branches that can be pushed against exterior objects.

The free-living *Rhizothyris* lived on sandy and shelly sediments of the wide, shallow marine shelf around New Zealand from the latest Eocene to the Middle Miocene.

—Written by Jeffrey H Robinson

***Specimen number*:** OU 47990	***Age*:** Approximately 28 million years old (Oligocene, late Whaingaroan to Waitakian stages)
***Locality*:** Weka Pass, Canterbury	***Rock Formation*:** Mount Brown Limestone

***Collected by*:** ZP Bowen, JD Campbell, and others

***Citation*:** Bowen ZP, Campbell JD. 1973. Systematics and evolution of the brachiopod genus *Rhizothyris* in the Oligocene—Miocene of New Zealand. Journal of the Royal Society of New Zealand 3:141–160. doi.org/10.1080/03036758.1973.10430597

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CHAPTER OVERVIEW

8: Invertebrates- Arthropods

The name, arthropod, means jointed foot, and all of the many and varied groups with Phylym Arthropoda are characterised by jointed limbs and jointed bodies. The body of an arthropod has a jointed exoskeleton that is mostly made up of chitin. There are more species of arthropods on Planet Earth, and more individual animals belonging to the phylum than any other group of animals. They occupy a huge range of habitats from the tops of the highest mountains to the deepest parts of the ocean and everywhere in between.

There are many different ways of classifying arthropods but we follow that used in Species 2000, the New Zealand Inventory of Biodiversity: Kingdom Animalia. Edited by Dennis Gordon and published in three volumes between 2009 and 2012, this inventory attempted to catalogue every plant and animal living in the New Zealand region, including estimates of organisms that have not yet been identified and described. In the Introduction to Arthropoda, the modern New Zealand fauna is estimated to include 3000 species living in marine environments, 1250 species in freshwater and a huge 18,000 occupying terrestrial habitats. Around 800 fossil arthropods are listed as of 2009; however, research on newly discovered spiders and insects housed in the Geology Museum collections at the University of Otago is steadily increasing this number.

We follow Species 2000 in assigning the fossils to one of four Subphyla: Trilobitomorpha (trilobites); Chelicerata (arachnids: spiders and mites); Crustacea (shrimps, crabs, lobsters, barnacles and their kin) and the biggest group by far, Hexapoda (insects of a myriad different kinds).

Arthropods have a very long fossil history, extending back to the earliest times of multicellular life. The earliest arthropod fossils found in New Zealand are the extinct trilobites which date back to the Cambrian.

Fossil Chelicerata in the Geology collections include several spiders, one selected as a treasure, a few pseudoscorpions and many minute mites, mainly trapped in amber, that are yet to be formally described.

The best-known fossil crustaceans are decapods (the word means 10-footed) – examples are lobsters, crayfish, crabs and shrimps. A few live on land or in freshwater but most of the 10,000 living species occupy a wide range of environments in the ocean. About 500 living species of decapods are known from New Zealand and about 100 fossil species have been recorded.

The Geology Museum has fine examples of holotypes of four different groups of decapods. Those described and illustrated here include a freshwater crayfish (koura) from Central Otago, a species of hermit crab from Southland preserved in its gastropod home, a large crab, and and a palinuran or spiny lobster from South Canterbury.

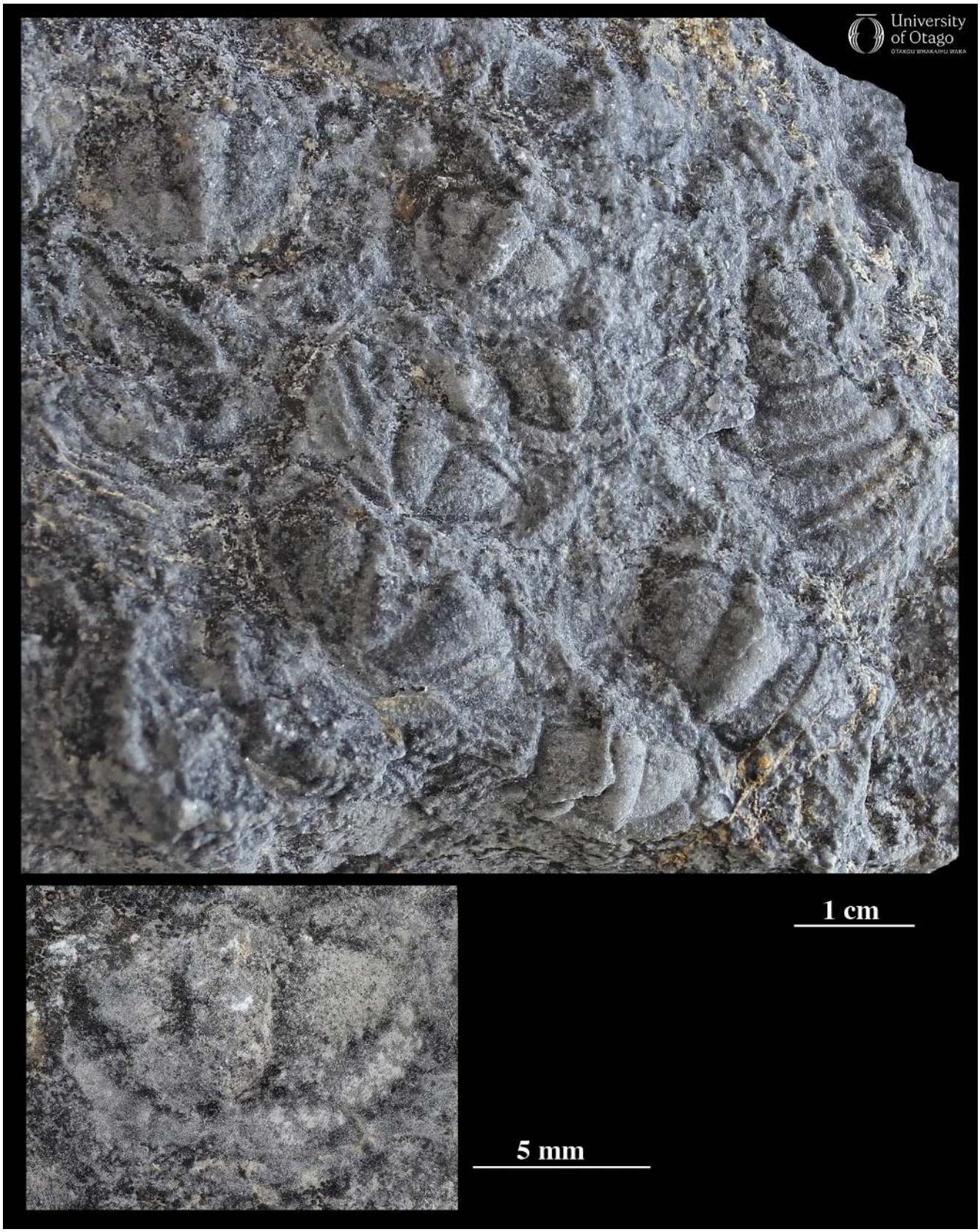
8.1: Valley of trilobites, our oldest fossils
8.2: Juvenile armoured trapdoor spider
8.3: Assembling the food basket- freshwater crayfish are deeply connected to Zealandia
8.4: Diverse primitive termites are Aotearoa's lost social insects
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8.1: Valley of trilobites, our oldest fossils

Arthropoda, Trilobitomorpha

Within the Cambrian display in the University of Otago Geology Museum there is a palm-size grey rock which is unremarkable at first glance. Look a little closer though and you will soon notice it is covered in small round structures. Lean in a little closer and take a longer look at one of those round structures. You will see it is a group of body segments that may remind you of a slater or pillbug (an isopod). These body segments are from the carapace of an armoured marine ‘bug’, a trilobite. And now that you know what to look for, take another look at that grey rock. The entire block of grey limestone is made up of trilobites.



Upper image shows detail from a hand sample of ‘Trilobite Rock’ from Cobb Valley, Nelson. The surface features on this rock are carapace segments from many individual trilobites (specimen OU 8258). The lower image shows a closer and more detailed view of one carapace segment. Image credit: JH Robinson.

The trilobites in this display case are among the oldest fossils known from Aotearoa. They lived during the middle Cambrian, during a time before there were plants on land and when all animals lived in the ocean.

The discovery of Trilobite Rock in Cobb Valley is one of Aotearoa's great fossil stories. In 1948 local student Malcolm Simpson joined a field trip into the Cobb Valley that was being led by Professor William Noel Benson from the Department of Geology at the University of Otago. During the trip 14-year-old Simpson collected a piece of limestone and passed it Benson, who initially described the fossils it contained as 'indistinguishable molluscan remains'. It was only later, back in Ōtepoti Dunedin, that Benson determined what had actually been found. After receiving confirmation, Professor Benson phoned the young explorer to let him know that his discovery contained trilobites, the first Cambrian fossils ever recognised in New Zealand.

We encourage you to read 'The Discovery of the New Zealand Cambrian' by Alan Mason and Bill Watters for the detailed account.



Did you know there is a 3D printable model of this fossil for you to view online and download? Follow this link to learn more: 3D model—Valley of trilobites, our oldest fossils.

Trilobites are an entirely extinct group of jointed-limb animals that are distantly related to arthropods living today like crayfish, spiders and flies. Like living arthropods, trilobites had a carapace that they shed and replaced as they grew. The carapace of a trilobite was divided into three major segments, the 'head' (cephalon), 'body' (thorax) and 'tail' (pygidium), with parts from each segment making up the three 'lobes' of the carapace that are the namesake structures of trilobites.

The trilobites from Trilobite Rock in Cobb Valley include members of Agnostida, which are distinguished by having a cephalon segment that was a similar size to their pygidium segment. Also, most agnostid trilobites lacked the compound eyes found on other trilobites. So when you are studying the palm-size grey rock in the Geology Museum, take a look to see if you can spot the tri-lobed, symmetrical, and eyeless carapace of an agnostid trilobite!

—Written by Daniel B Thomas

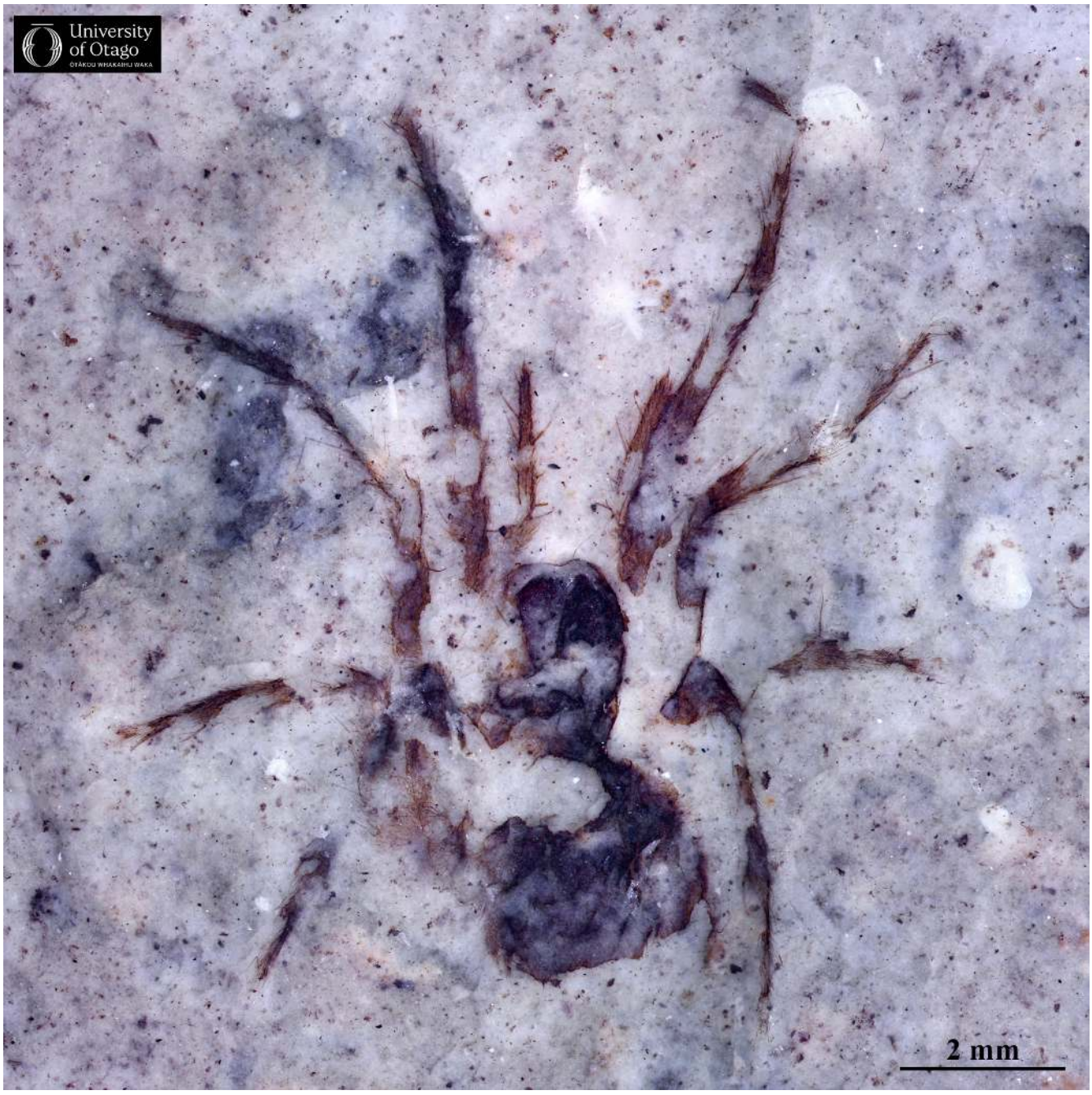
***Specimen number*:** OU 8258	***Age*:** Approximately 502 million years ago (middle Cambrian, Undillan or early Boomerangian stage)
***Locality*:** Cobb Valley, Nelson	***Rock Formation*:** Tasman Formation
***Collected by*:** WN Benson	
***Citation*:** Cooper RA. 1979. Lower Palaeozoic rocks of New Zealand. Journal of the Royal Society of New Zealand 9:29–84; Mason A, Watters B. 1999. The Discovery of the New Zealand Cambrian. Geological Society of New Zealand Newsletter 118: 15–20.	

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8.2: Juvenile armoured trapdoor spider

Arthropoda, Arachnida

Spiders are usually the top invertebrate predators in forest ecosystems in Aotearoa New Zealand. All produce silk for their webs (although not all spiders have webs) and to aid travel, and all use venom to subdue their prey.



This small juvenile armoured trapdoor spider (OU 45208) may have been washed out of its burrow near the shoreline into the Foulden Maar lake during heavy rain. Image credit: U Kaulfuss.

New Zealand today has more than 1600 known endemic species of spider placed in 137 genera or subgenera, in 57 different families.

Spiders are rare as fossils, having no hard parts to be preserved. And, until 2018, no spider fossils were known from New Zealand. But that year, two important research papers based on newly discovered fossils housed in the University of Otago Geology Museum collections allowed the first glimpses of New Zealand fossil spiders. The first was an overview of discoveries in New Zealand amber mainly from Harliwich's Coalmine, near Roxburgh. Here arachnid remains include several well-preserved, though undeterminable juvenile spiders which appear to represent web-builders, rather than free-living hunters. Well-preserved spider web filaments also occur with trapped insect remains, fecal pellets, fungi and stellate plant hairs. These spiders lived in an ancient kauri forest and were trapped in sticky resin that has now become amber.

But, more important were four spiders discovered by Uwe Kaulfuss in the Foulden Maar diatomite. Two of these had their original spider cuticle replaced by or covered over by pyrite. These pyritised specimens could not be given species names as important details of their anatomy cannot be seen but one is likely to be a male orb weaver spider.

The other two specimens belong to the Mygalomorphae, a group of powerful predators with robust bodies, stout legs and strong jaws with fangs that inject venom into their prey. One specimen in particular is especially well-preserved and is identified as a juvenile armoured trapdoor spider (family Idiopidae).

—Written by Daphne E Lee and Uwe Kaulfuss

***Specimen number*:** OU 45208	***Age*:** 23 million years old (early Miocene, Waitakian stage)
***Locality*:** Middlemarch, Otago	***Rock Formation*:** Foulden Hills Diatomite
***Collected by*:** U Kaulfuss	
***Citation*:** Selden PA, Kaulfuss U. 2018. Fossil arachnids from the earliest Miocene Foulden Maar Fossil-Lagerstätte, New Zealand. Alcheringa: An Australasian Journal of Palaeontology 43:165–169. doi.org/10.1080/03115518.2018.1450446	

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8.3: Assembling the food basket- freshwater crayfish are deeply connected to Zealandia

Arthropoda, Decapoda: *Paranephrops fordycei*

Kōura, freshwater crayfish, are found in streams, rivers, lakes and sometimes swamps throughout Aotearoa today. But how long have they been here?



Ancient freshwater crayfish, *Paranephrops fordycei* (specimen OU 39695). In this view the head and legs are to the left of the image, the tail is to the right, and the body is bent into a V shape. Image credit: RE Fordyce.

A specimen in the Geology Museum can help answer this question – at least since the early Miocene.

Collected in 1994 from near Bannockburn, this incomplete specimen shows the general body shape of modern kōura as well as some finer details like gills. This specimen was determined to be a new species and was named *Paranephrops fordycei*, in honour of Ewan Fordyce. Today kōura can live to be 25 years or more in age, growing up to 8 cm long. Occupying crevices and living under rocks, they are scavengers, living on insects or decaying leaves.

Like all crustaceans, they grow by moulting.

—Written by Daphne E Lee

***Specimen number*:** OU 39695	***Age*:** Approximately 18.7 to 15.1 million years ago (early or middle Miocene, Altonian or Clifdenian stage)
***Locality*:** Bannockburn, Central Otago	***Rock Formation*:** Dunstan Formation
***Collected by*:** M Pole	
***Citation*:** Feldmann, RM, Pole M. 1994. A new species of *Paranephrops* White, 1842: A fossil freshwater crayfish (Decapoda: Parastacidae) from the Manuherikia Group (Miocene), Central Otago, New Zealand. New Zealand Journal of Geology and Geophysics 37:163–167. doi.org/10.1080/00288306.1994.9514611	

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8.4: Diverse primitive termites are Aotearoa's lost social insects

Arthropoda, Blattodea: *Stolotermes kupe*

Some of the unexpected insect finds at Foulden Maar in the past two decades are isolated wings from a diverse range of termites.



Isolated forewing of the dampwood termite, *Stolotermes kupe* (OU 44560). Image credit: U Kaulfuss.

Termites, formerly placed in the order Isoptera but now included in Blattodea with the closely related cockroaches, have the longest fossil record of any eusocial insects. In modern temperate and tropical ecosystems, termites are very important recyclers of organic matter.

Aotearoa New Zealand today has a very low diversity of termites: just three native species in two genera and families. In contrast, Australia has about 270 species in five extant termite families.

Although termites have a bad press, known for eating through wooden structures, the three New Zealand natives cause little damage. The two species of *Stolotermes* live in dampwood such as dead and decaying stumps and logs of a variety of native trees including kauri, rimu, beech and broadleaf and can also be found in exotic trees such as radiata pine and macrocarpa. The distantly related *Kalotermes brouni* makes its habitat in drywood. All three are inconspicuous components of the New Zealand fauna, forming small colonies of up to a few hundred individuals, in both native and exotic trees, mostly in the North Island.

The first termite fossil found at Foulden was an isolated complete forewing of a species of the primitive dampwood genus *Stolotermes*, showing that these termites have probably been in New Zealand for the past 23 million years. It was different enough from the living species to be given a new name, *Stolotermes kupe*. This was the first direct evidence for fossil termite in New Zealand, although Joan Sutherland, a former Otago Geology graduate, described and illustrated silicified hexagonal-shaped fecal pellets 'similar to those of *K. brouni*' from specimens of silicified wood of Early Miocene age from near Auckland.

But this was just the beginning. Since 2010, another five genera and species of termites have been described from Foulden Maar. All are isolated wings, preserved as part and counterpart (meaning one half of the fossil is on one split block and the other half on the opposite side) – both are needed to fully understand the characteristics of the fossils.

Four of these new termites proved to be so different from all other living and fossils termites known that they have been placed in new genera as well as new species. Named from the area around Foulden Maar, the taxa are called *Waipiatatermes matatoka* (from the Waipiata Volcanic Field in which the maar is located); *Taieritermes krishnai* (from the nearby Taieri River); *Otagotermes novazealandicus* from Otago; and *Pterotermopsis fouldenica* for Foulden Maar.

They add a new component to what we know of the ecology of the rainforest that once surrounded Foulden Maar – there must have been plenty of dead and decaying trees able to support a diverse range of termites that have since become extinct, probably due to changing climates over millions of years.

—Written by Daphne E Lee and Uwe Kaulfuss

***Specimen number*:** OU 44560	***Age*:** 23 million years old (early Miocene, Waitakian stage)

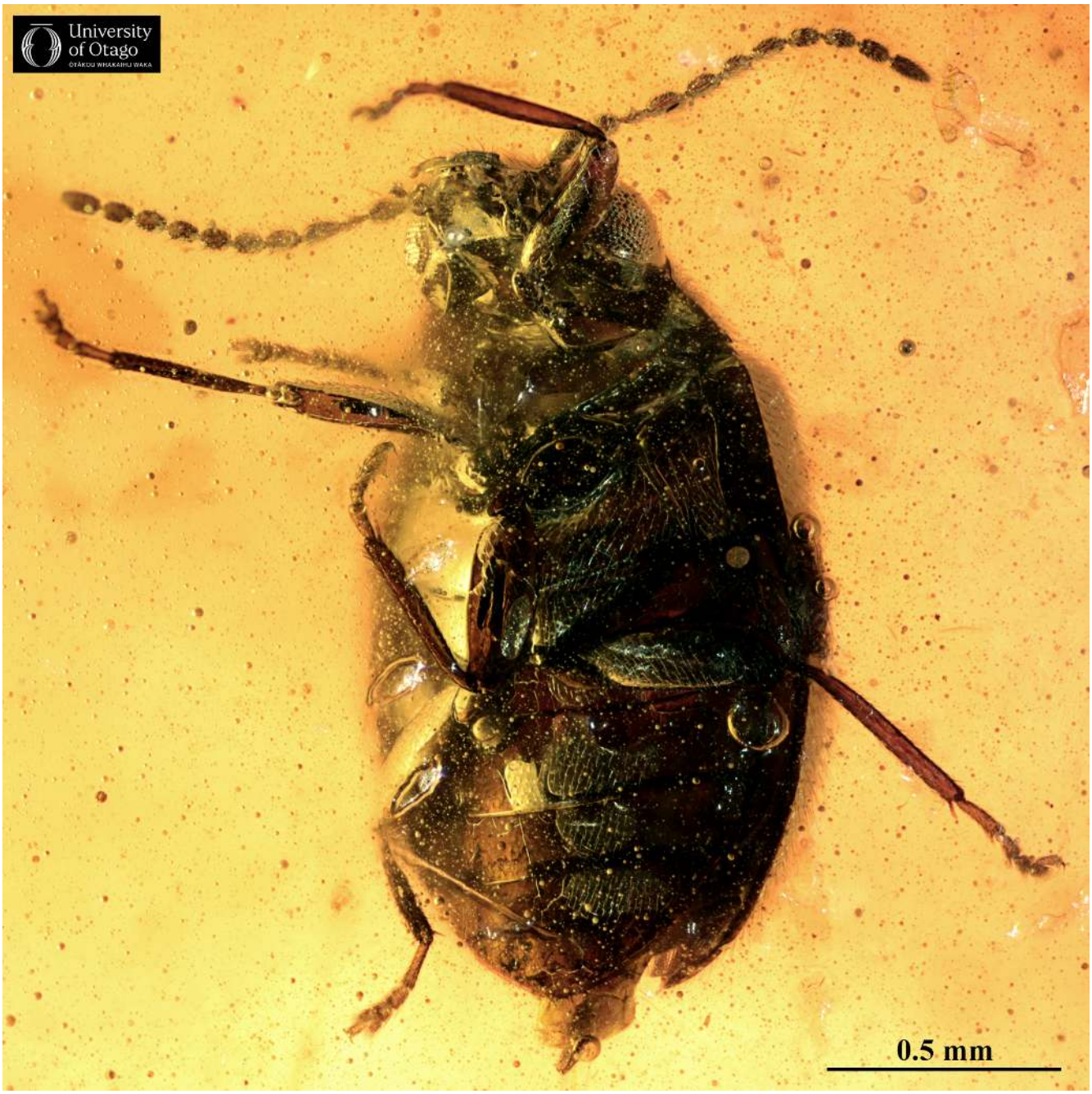
***Locality*:** Middlemarch, Otago	***Rock Formation*:** Foulden Hills Diatomite
***Collected by*:** U Kaulfuss	
***Citation*:** Kaulfuss U, Harris AC, Lee DE. 2010. A new fossil termite (Isoptera, Stolotermitidae, *Stolotermes*) from the Early Miocene of Otago, New Zealand. Acta Geologica Sinica 84:705–709. doi.org/10.1111/j.1755-6724.2010.00275.x	

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8.5: First beetle named from amber in Aotearoa

Coleoptera, Scirtidae: *Contacyphon pomahakaensis*

Fossils discovered in New Zealand amber include a wide range of invertebrates including mites, spiders, beetles, flies and ants. The first to be found, as recently as 2011, was a tiny mite, just 2 mm across. Previously it was assumed that New Zealand amber, often called ‘kauri gum’, lacked fossils, in contrast to the famous Baltic amber of northern Europe. The reason is that most amber from Aotearoa is dark brown or gold in colour, and almost opaque, full of tiny air bubbles which make it almost impossible to see anything inside it. Everything changed in 2011, when Daphne Lee sent a few small samples to Professor Alexander Schmidt at Göttingen University in Germany. Alexander embedded small pieces of amber in epoxy resin, placed them in a vacuum to stabilise the amber and then polished the embedded amber very carefully to reveal details of the creatures within. This discovery has opened up a huge new window into New Zealand’s past biodiversity.



Fifteen images stacked together provide a three dimensional view of this tiny marsh beetle, *Contacyphon pomahakaensis*, from amber in a Pomahaka Formation lignite seam (OU 47547). Image credit: U Kaulfuss.

We now know that New Zealand amber hosts a very diverse invertebrate and fungal biota that provides the first glimpses into the fossil ecosystems of the ancient forests that once covered much of Zealandia.

The first beetle from amber to be given a formal name is this well-preserved marsh beetle from a lignite seam near Pomahaka, in South Otago. It is tiny, just 1.7 mm long, with every segment of the antennae visible. As the name suggests, it lived in a coastal kauri forest in a swampy or marshy environment around 27 million years ago. There are 50 species of *Contacyphon* recorded from New Zealand today and many more still to be described.

Larvae of these tiny beetles are filter-feeding detritivores in shallow stagnant water whereas adults are found on shrubs or trees in wet forests. The finding of this minute marsh beetle in amber tells us that these beetles have had a very long history in the New Zealand region.

—Written by Daphne E Lee and Uwe Kaulfuss

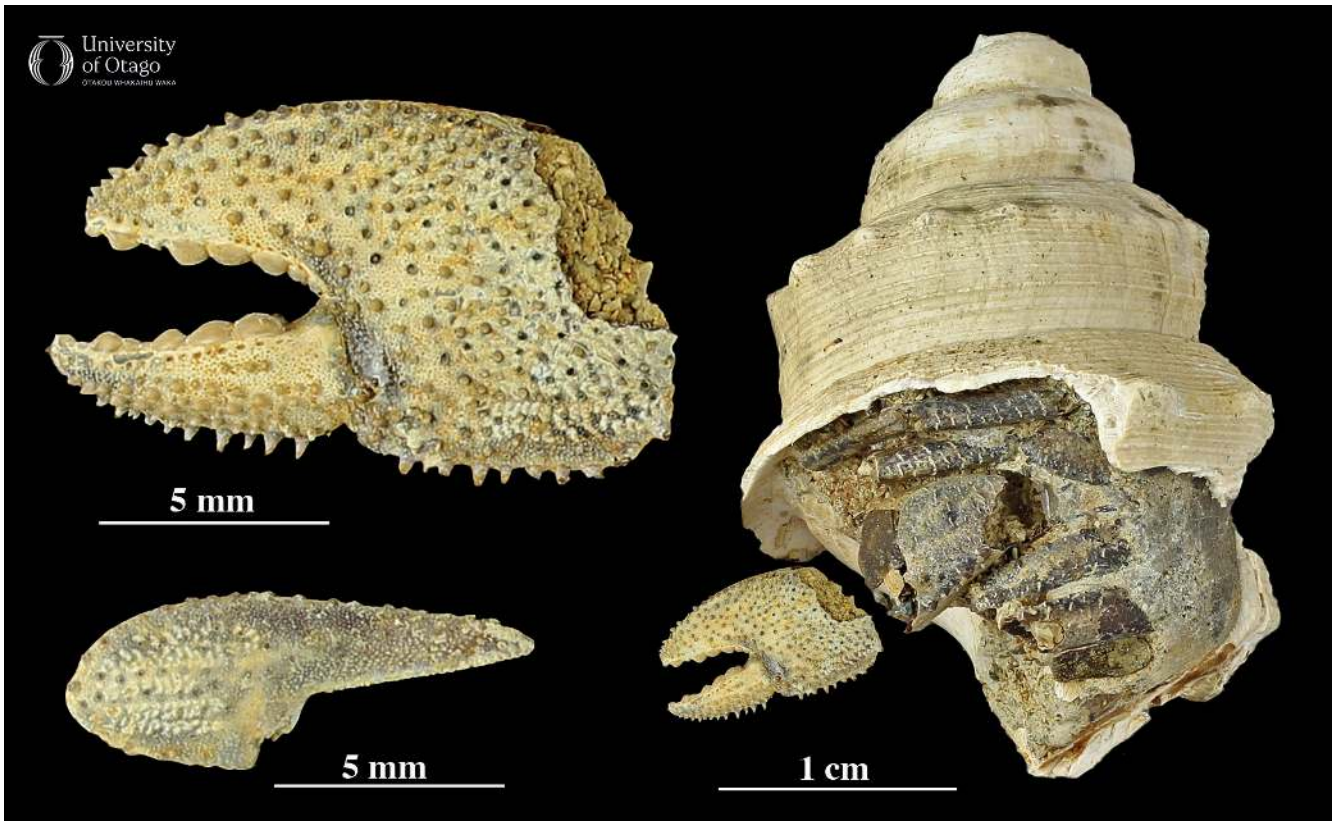
***Specimen number*:** OU 47547	***Age*:** 27.3 to 25.2 million years old (Oligocene, Duntroonian stage)
***Locality*:** Pomahaka, South Otago	***Rock Formation*:** Pomahaka Formation
***Collected by*:** U Kaulfuss	
***Citation*:** Kaulfuss U, Szawaryn K, Lee DE, Ruta R. 2024. The first beetle species described from Oligocene New Zealand amber (Coleoptera: Scirtidae). Palaeoentomology 7:529–538. doi:10.11646/palaeoentomology.7.4.12	

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8.6: Hermit crab inside its gastropod home

Arthropoda, Decapoda: *Diacanthurus clifdenensis*

Crab fossils are quite common in Aotearoa New Zealand, often preserved within calcareous concretions. Examples of the large, extinct species of stone crab *Tumidocarcinus* are frequent discoveries at various fossil sites around New Zealand.



Ancient hermit crab *Diacanthurus clifdenensis* (OU 11797) discovered in its last gastropod home. Image credit: JH Robinson.

But one fossil crab in the Geology collections was a serendipitous, rare and exciting discovery – an entire, beautifully preserved hermit crab still hiding inside its gastropod home.

Found by Fiona Hyden in the Calamity Point Sandstone near Clifden, Western Southland during her PhD research on the limestones of the Southland region it was formally described as a new species of *Pagurus* (since moved to a new genus, *Diacanthurus*). The right cheliped of the fossil crab is larger than the left, and both are covered with large, cone-shaped tubercles all over the dorsal surface. There are conspicuous teeth along the opposable faces of the right chela.

Such hermit crabs belonging to the family Paguridae are a specialised group of decapod crustaceans that are mostly found in shallow-water, often rocky-shore, environments. Because their bodies are soft, they avoid predators by occupying the empty shells of gastropod molluscs, moving from smaller to larger shells (house-hunting) as they grow and moult. Crabs obviously need to have a reliable supply of suitable dwellings and at Calamity Point in the Early Miocene, there was a diverse fauna of around 90 species of gastropods, although not all would be suitable second homes for crabs.

The host shell for the hermit crab is *Struthiolaria subspinosa*, a turreted gastropod whose living relations, known as ostrich foot shells, are common inhabitants of sandy shores around New Zealand today. Similarly, the close living relative of *Dicanthurus*, *D. spinulimanus*, is common on muddy sand substrates around New Zealand at depths of 20 to 120 metres.

One reason why hermit crabs are rarely found as fossils is that they vacate their homes before death and usually only the heavily calcified chelipeds (claws) survive. Few such examples have been described from anywhere in the world and even fewer are well-enough preserved to be given a formal name.

—Written by Daphne E Lee

***Specimen number*:** OU 11797	***Age*:** Approximately 17 million years ago (early Miocene, Altonian stage)
***Locality*:** Clifden, western Southland	***Rock Formation*:** Calamity Point Sandstone, Nga Pari Formation
***Collected by*:** F Hyden	
***Citation*:** Hyden FM, Forest J. 1980. An in situ hermit crab from the Early Miocene of southern New Zealand. Palaeontology 23:471–474.	

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8.7: Long-snouted weevils from ancient volcanic fields

Arthropoda, Coleoptera, Curculionidae

Beetles (Coleoptera) are the most common insect fossils found in the Hindon Maar Complex, making up 70% of the 250 insect fossils found so far in small excavations in the maar lake deposits near Hindon, 30 km west of Ōtepoti Dunedin. Of these, small weevils are the most abundant kinds of beetles in the black carbonaceous sediments. Easily recognised by their elongated snouts, most of the weevils are preserved as laterally compressed specimens (lying on their sides). This happened because their stout, rounded long-legged bodies tipped over on their sides as they sank through the water column to lie on the lakebed.





Two examples of fossil weevil collected from Hindon Maar. The upper image shows specimen OU 45421 and the lower image shows specimen OU 45429. The exceptional level of preservation allows us to see fine details like tiny pits and grooves on the carapace (external skeleton). Image credit: U Kaulfuss.

Several kinds of spined weevils are present, some closely related to endemic modern genera (found only in New Zealand). Many specimens such as these two examples are almost three-dimensional, with fine details of ornamentation and sometimes structural colour still present.

Weevils are mostly herbivores, often closely associated with just a few plant types. Their abundance at Hindon and Foulden maars indicate that they were ecologically important components of forest ecosystems in early and mid Miocene forests in Aotearoa, just as they are today. Other insects found at Hindon include a cicada wing (*Tettigarcta)*, a damselfly, jumping plantlice, stinkbugs, wasps, ants, and, most recently, a bee.

—Written by Daphne E Lee and Uwe Kaulfuss

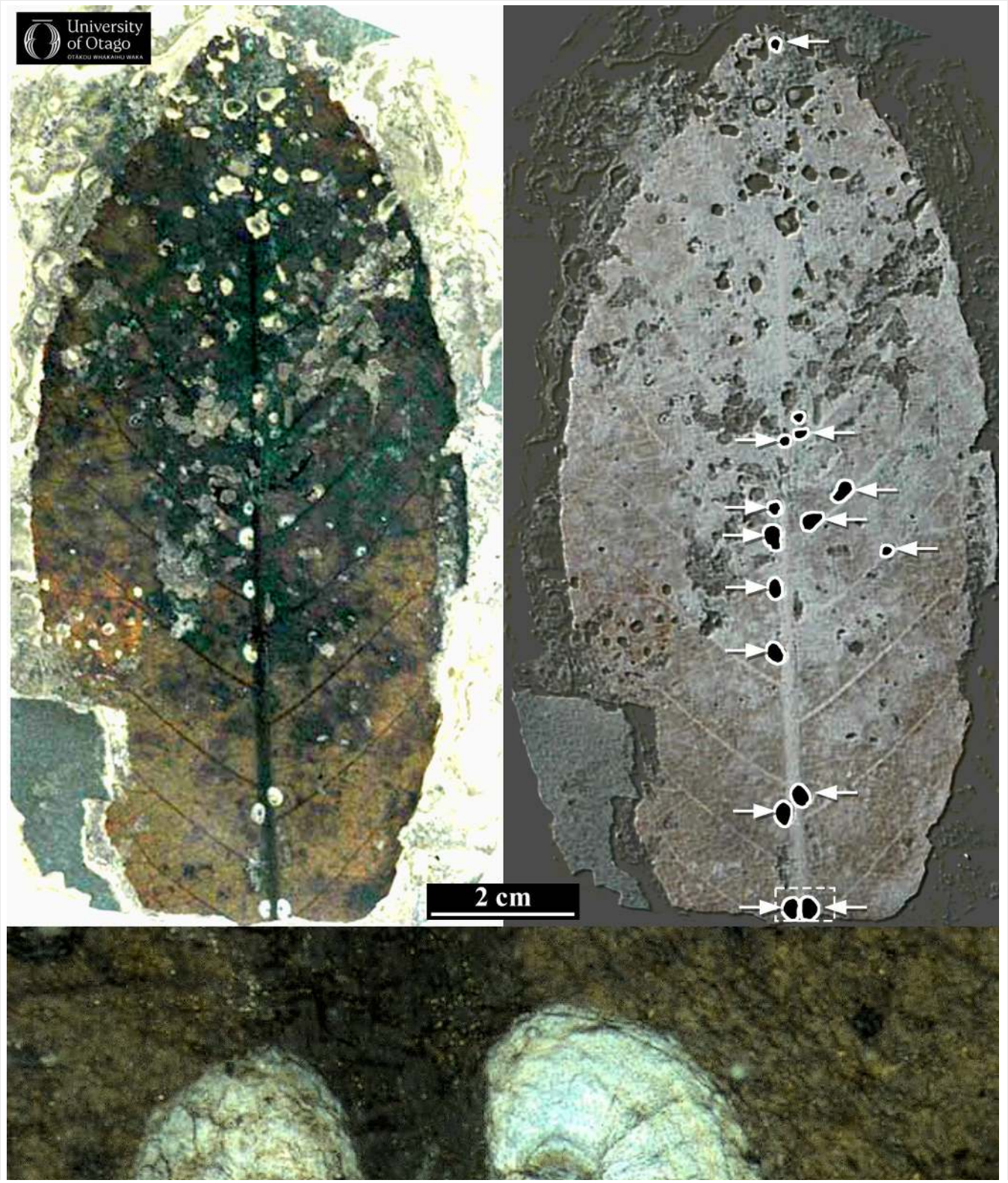
***Specimen numbers*:** OU 45421 and OU 45429	***Age*:** 14.6 million years ago (middle Miocene, Lillburnian stage)
***Locality*:** Hindon, Otago	***Rock Formation*:** Dunstan Formation
***Collected by*:** U Kaulfuss	
***Citation*:** Kaulfuss U, Lee DE, Wartho J-A, Bowie E, Lindqvist JK, Conran JG, Bannister JM, Mildenhall DC, Kennedy EM, Gorman AR. 2018. Geology and palaeontology of the Hindon Maar Complex: a Miocene terrestrial fossil Lagerstätte in southern New Zealand. Palaeogeography, Palaeoclimatology, Palaeoecology 500:52–68. doi.org/10.1016/j.palaeo.2018.03.022	

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8.8: Tiny scale insects in life position

Arthropoda, Hemiptera

Fossils preserved in life position are very uncommon. Typically, after death, the plant or animal will become detached from its position in life – leaves fall off trees, pollen is blown away, and fish sink to the bottom of the lake.



https://geo.libretexts.org/@go/page/45102



The image to the top and left shows 14 female scale insects still in life position on an angiosperm leaf. Each little waxy scale is about 2.5 mm long and displays the original nacreous colouring. The image to the top and right is a diagram with white arrows showing the location of the scale insects on the leaf. The region towards the bottom of this diagram identified by the dashed white line is expanded to show the scale insects in the bottom image. Image credit: JM Bannister and A Harris. Image re-use permission kindly provided by Otago University Press and originally published in: DE Lee, U Kaulfuss and J Conran, *Fossil Treasures of Foulden Maar*, Otago University Press, 2022.

In the Geology Museum collections we have several examples of creatures ‘frozen’ in life position. Some particularly spectacular examples include insects which spend part of their life cycle firmly attached to a living leaf.

One of the best examples is a single, medium-sized leaf from Foulden Maar which has 14 individual scale insects still attached to it. One of few such examples known globally, each little scale has the long axis of its body parallel to the main or secondary veins on which they were feeding. All the scales are female, and they range from nine large, mature adult females (up to 2.55 mm in diameter) to five smaller young adult females that had not long moulted into their third and final instar. The larger, mature females were occupying the basal part of the leaf, while the smaller, younger individuals were on the apical part of the leaf, including one right at the tip.

Remarkably, the original nacreous, pale whitish-green colouration of the waxy scales is preserved.

Scale insects generally occur on plants that live for more than a year, and, although we can’t identify the leaf for certain, it is from an evergreen flowering plant and is probably a species in the family Elaeocarpaceae that grew near the margin of the small volcanic lake at Foulden Maar (see: World’s oldest whitebait swam in volcanic lake).

These scales are placed in the family Diaspididae (armoured scales) and subfamily Aspidiotinae. The common name refers to the wax-like, fibrous scale that is formed by the insect and which covers it. However, although these tiny fossils do not closely resemble any living species, the lack of characters needed to place them in a genus (and species) mean they cannot be given a new scientific name.

In armoured scales such as these the adult males are fragile, short-lived (a matter of hours) and lack mouthparts. The first instar immatures (termed crawlers), occur under the female’s scale cover and disperse over the leaves and stems of the host plant to colonise new leaves or are blown by the wind to other plants. Once landing on a suitable host, the crawler inserts its piercing mouthparts onto the plant to access food and begins to produce a waxy cover. The limited dispersal abilities of these armoured scales and the disappearance of their host plant from the flora of Aotearoa New Zealand likely led to their extinction.

Over 2400 species of Diaspididae occur worldwide, with 39 species still native to New Zealand that are confined to native host plants. However, there are many exotic scale insects now that are serious plant pests and are regarded as major biosecurity risks in New Zealand.

—Written by Daphne E Lee

***Specimen number*:** OU 31745	***Age*:** 23 million years old (Early Miocene, Waitakian stage)
***Locality*:** Middlemarch, Otago	***Rock Formation*:** Foulden Hills Diatomite
***Collected by*:** JM Bannister	

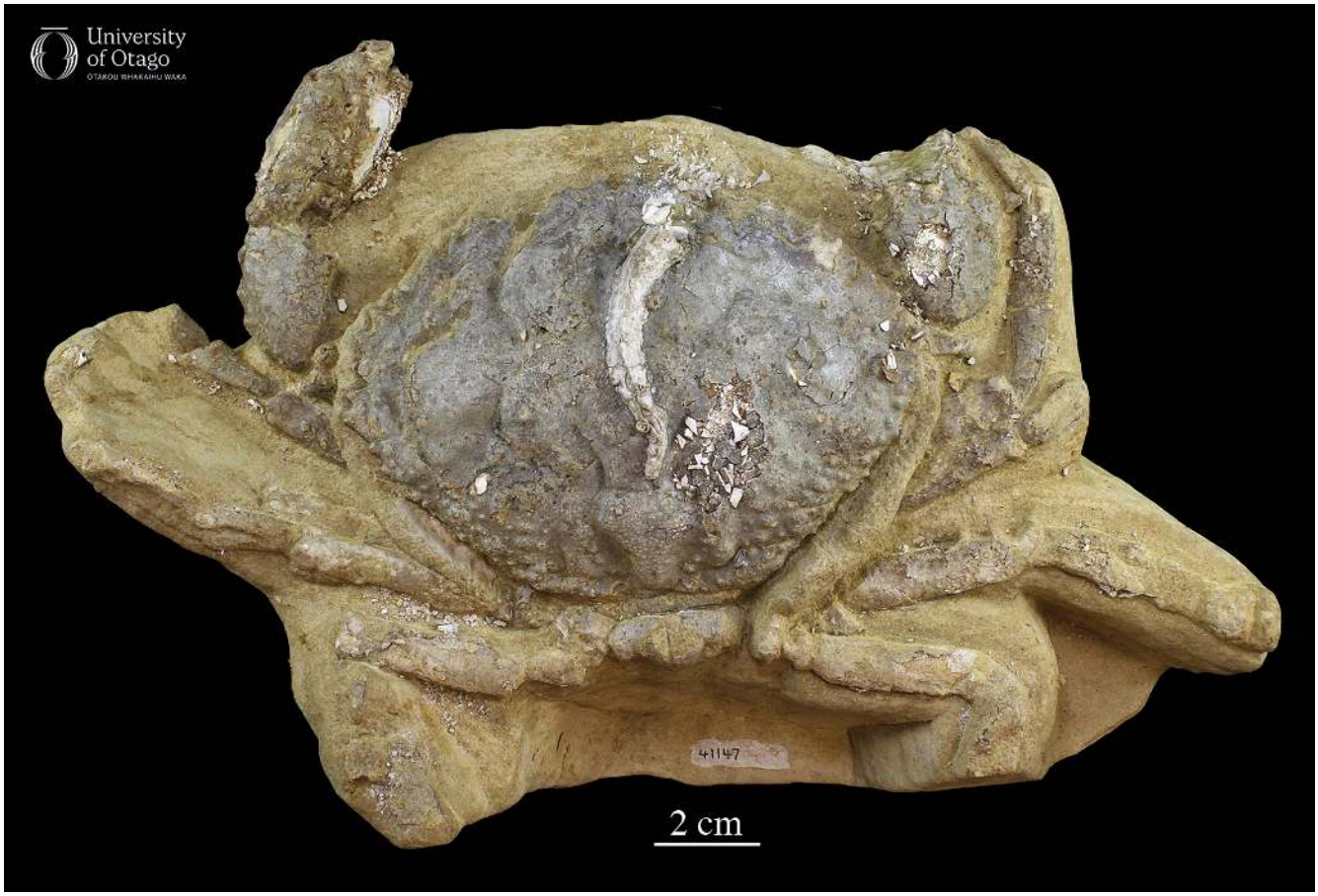
***Citation*:** Harris AC, Bannister JM, Lee DE. 2007. Fossil scale insects (Hemiptera, Coccoidea, Diaspididae) in life position on an angiosperm leaf from an early Miocene lake deposit, Otago, New Zealand. Journal of the Royal Society of New Zealand 37:1–13. doi.org/10.1080/03014220709510531

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8.9: Spectacular crab from Caversham Sandstone

Arthropoda, Decapoda: *Lobocarcinus pustulosus*

This large crab was initially found with just the worn tips of the chelae poking out on the surface of a fallen block of Caversham Sandstone at the base of a cliff near Cornish Head, Waikouaiti, Otago. Careful preparation was required to uncover the rest of the crab and reveal details of what turned out to be a nearly complete, fully articulated specimen of a new species of a crab not previously reported from the Pacific region.



Dorsal view of the Waikouaiti fossil crab *Lobocarcinus pustulosus* (specimen OU 41147). In this view bubbly detail on the carapace for which the crab is named can be clearly seen. The white structure down the midline of the carapace is a serpulid worm that attached to the crab while it was buried on the sea floor. Image credit: JH Robinson.

The family Cancridae in which the crab is placed is characterised by having a carapace that is wider than it is long, three or four spines on the frontal region, and up to 10 spines on the long convex anterolateral margin,. These are all features seen on the Waikouaiti specimen. Named *Lobocarcinus pustulosus* because of the strongly pustulose ornament on the pentagonal carapace, the body of the dead crab must have lain on the sea floor for some time as it is encrusted by a large serpulid worm tube as well as several tiny coiled *Spirorbis* serpulids.

The Caversham Sandstone is a thick, generally well-cemented calcareous sandstone that forms spectacular cliff outcrops on the coast north and south of Ōtepoti Dunedin. Macrofossils are not particularly common and are generally scattered randomly throughout the 120 metre thick formation. The fallen block from which the crab was extracted is from a poorly cemented, silty to sandy limestone bed probably tens of metres above the base. This was the first crab fossil to be reported from this formation although a few more examples have been collected since 1996.

—Written by Daphne E Lee

***Specimen number*:** OU 41147	***Age*:** Approximately 18 million years ago (early Miocene, Altonian stage)
***Locality*:** Waikouaiti, Otago	***Rock Formation*:** Caversham Sandstone
***Collected by*:** RE Fordyce (discovery), A Grebneff, R Köhler (collection)	
***Citation*:** Feldman RM, Fordyce RE. 1995. A new cancrid crab from New Zealand. New Zealand Journal of Geology and Geophysics 39: 509–513. doi.org/10.1080/00288306.1996.9514729	

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8.10: Spiny lobster preserves sound-producing structures

Arthropoda, Decapoda: *Linuparus korura*

Three species of spiny or spear lobster in the genus *Linuparus* within the family Palinuridae live in the Indo Pacific region today. In contrast, 32 fossil species from this genus, ranging in age from the Cretaceous to the Oligocene, are recorded from many places around the world.



Dorsal view of the ancient spiny lobster *Linuparus korura* (OU 12842) showing the rectangular carapace. Image credit: JH Robinson.

One of these fossils is housed in the University of Otago Geology Museum collections and was the first example of the genus to be discovered in Aotearoa New Zealand. Collected by Bob Carter from the Otaio Gorge in 1978, the lobster is more-or-less undistorted and still retains antennae, articulated eyestalks and pereiopods. The excellent preservation suggests that this fossil represents an actual animal that was buried in sediment on the sea floor, rather than just a moulted carapace (see: Valley of trilobites, our oldest fossils).

Modern palinurid lobsters produce rasping sounds by rubbing together their flexible antennae as a means of deterring predators. Remarkably, the Geology Museum specimen still possesses these sound-producing structures because the frontal region of the cephalothorax is complete and the basal segments of the antennae are exposed. This was the first time the structures responsible for sound production had been observed in a fossil palinurid lobster.

Modern *Linuparus* lobsters inhabit mid- to outer-shelf waters at depths of between about 30 and 500 m. Molluscan fossils from the same locality suggest a mid-shelf environment of around 100 to 200m, in moderately warm seas. This fossil *Linuparus* lobster, like its modern counterparts, probably ate fish and other crustaceans. The species was named *Linuparus korura* with the species name adapted from kōura, the te reo Māori name for lobster or marine crayfish.

—Written by Daphne E Lee

***Specimen number*:** OU 12842	***Age*:** Approximately 40 million years ago (late Eocene, Bortonian stage)
***Locality*:** Otaio Gorge, South Canterbury	***Rock Formation*:** Little Pareora Silt
***Collected by*:** RM Carter	
***Citation*:** Feldmann RM, Bearlin RK. 1988. *Linuparus korura* n. sp. (Decapoda: Palinura) from the Bortonian (Eocene) of New Zealand. Journal of Paleontology 62:245–250.	

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CHAPTER OVERVIEW

9: Invertebrates- Other Amazing Organisms

The tree of life has many branches! In this section we explore some of the amazing biodiversity preserved the fossil record of Aotearoa New Zealand that we haven’t introduced elsewhere in this book.

9.1: Floating colonies of 'rock writing'

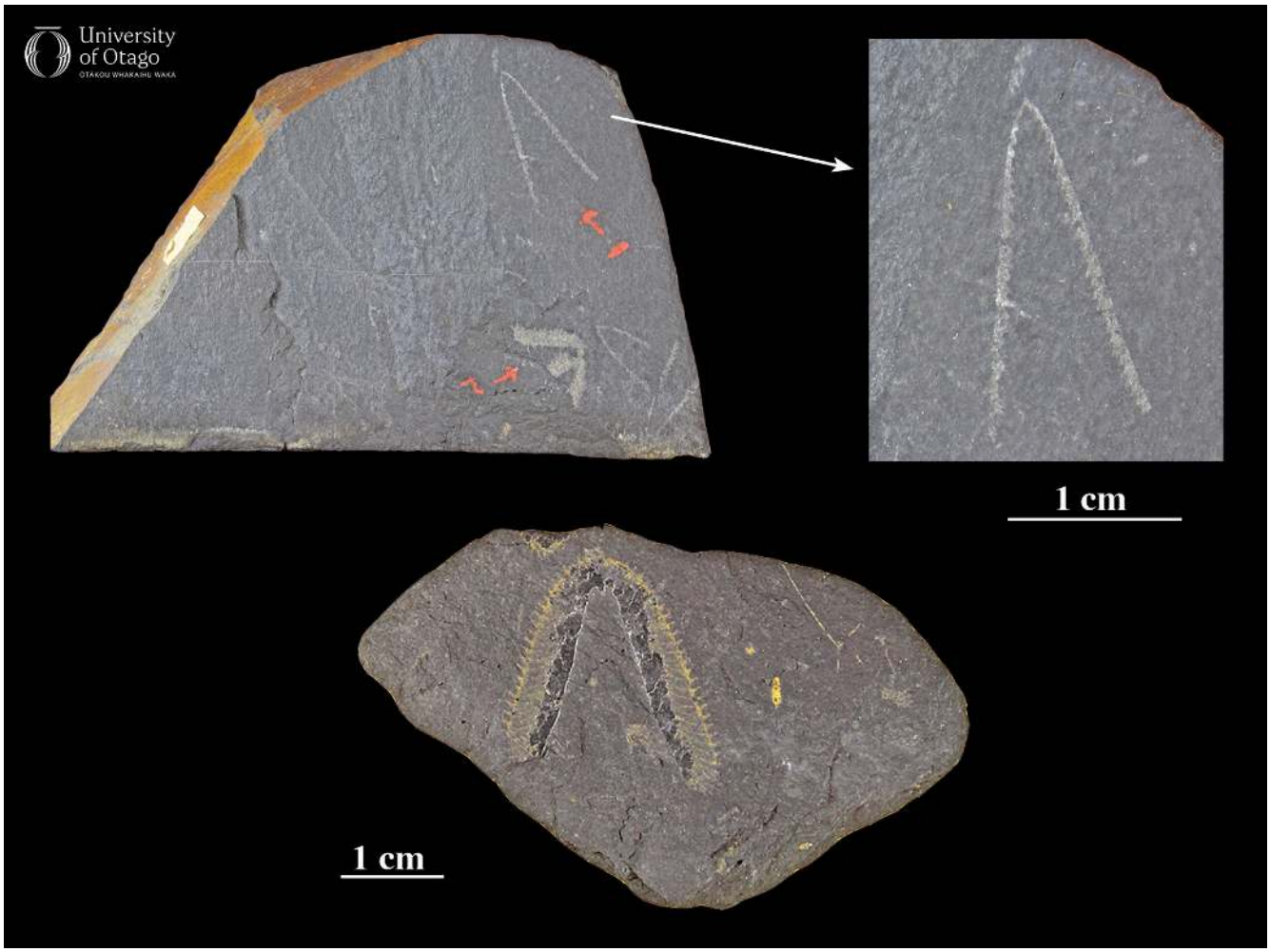
9.2: Small boulders of fossil bacteria

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9.1: Floating colonies of 'rock writing'

Hemichordata, Graptolithina

The Geology Museum has dozens of trays and hundreds of specimens of the small strange-looking animals known as graptolites (the name, meaning ‘written on the rock’, comes from their similarity to pencil markings on the slate rock in which they are preserved).



Examples of graptolite fossils. Image credit: JH Robinson.

It takes a closer look to recognise that these are flattened fossils of floating graptolite colonies that dominated the surface waters of the world’s oceans between 500 and 400 million years ago. All the examples in the Geology collections are of Ordovician age – about 450 million years old, and many come from remote areas in southwestern Fiordland near Preservation Inlet and Cape Providence.

The colour of the fossils and the dark grey to black colour of the rock are due to carbonaceous (once organic) material in the sedimentary rocks.

Graptolites are small, filter feeding, colonial animals. They were most common in the Ordovician and Silurian periods. The earliest forms (from the Middle Cambrian) were benthic and lived on the sea floor. In the Early Ordovician some graptolites became planktic, living their entire lives floating near the surface of the ocean.

Although small, flattened and seemingly nondescript, myriads of floating graptolites occupied the surface waters of the global oceans for tens of millions of years, carried far and wide by currents. After death, the small animals drifted down through the water column and came to rest on the soft mud and silt on the deep sea floor. Here, conditions were anoxic (low in oxygen) and this

helped preserve these fragile fossils in sedimentary rocks which were eventually deeply buried and transformed into shale and slate.

Each graptolite fossil is in fact a small colony, like an apartment block, with each little theca providing a home for a single tiny animal.

Planktic organisms can be very useful when determining the age of rocks. Because they live in the ocean, a particular species of graptolite might have lived over a very wide area. The dead bodies of that species would sink to the ocean floor and some would be fossilised. If that species occurred for a short period of time, geologically speaking, before going extinct then (for example, five million years), then whenever that species is found as a fossil in a rock, that rock can be dated to that time period.

Professor William Noel Benson, head of the Department of Geology at the University of Otago from 1916 to 1949, made large collections of New Zealand planktic graptolites from Fiordland and North West Nelson. With the help of graptolite expert RA Keble, Benson established the succession of graptolite species for the Early Ordovician in New Zealand. Benson described five new species or subspecies and recognised the close correlations between rocks in New Zealand with rocks in Victoria, Australia.

Until recently, graptolites were considered to be long extinct. However, research in the 2010's has shown that an encrusting living organism known as *Rhabdopleura* is possibly a living graptolite. Living in small secreted tubes, a *Rhabdopleura* colony is about 2 cm long with each individual about 0.5 mm long.

—Written by Jeffrey H Robinson and Daphne E Lee

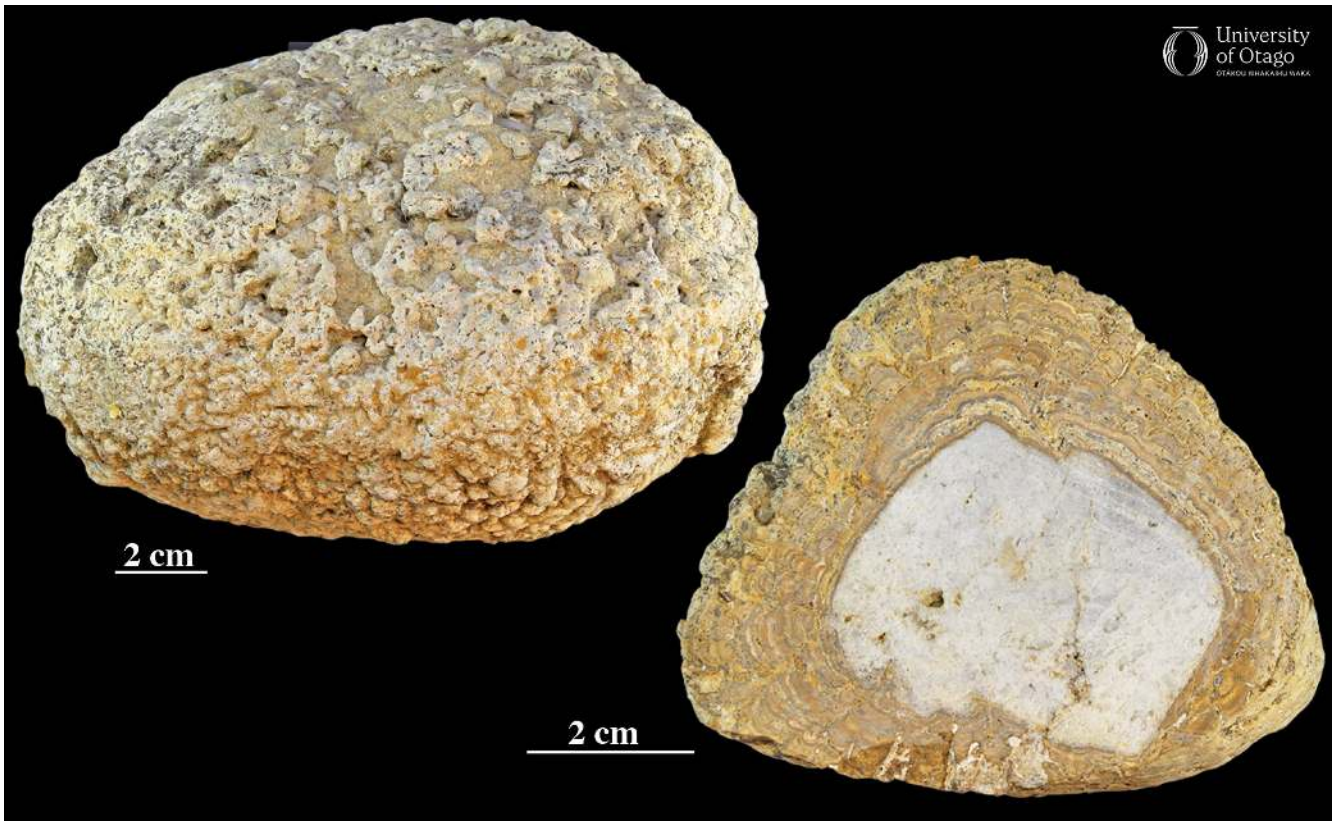
***Specimen number*:** OU 852 (upper) & OU 850 (lower)	***Age*:** 487 to 443 million years old (Ordovician)
***Locality*:** OU 852: Preservation Inlet, Fiordland, & OU 850: Aorangi Mine, Northwest Nelson	***Rock Formation*:** Slaty Creek Formation
***Collected by*:** WN Benson and others	
***Citation*:** Benson WN, Keble RA, King LC, McKee JT. 1936. The Ordovician graptolites of north-west Nelson, New Zealand, second paper; with notes on other Ordovician fossils. Transactions of the Royal Society of New Zealand. 65:357–382.	

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9.2: Small boulders of fossil bacteria

Prokaryota, Cyanobacteria

Stromatolites are some of the oldest fossils known on Earth. They date back to the Precambrian, around 3.5 billion (yes, billion) years ago and are still living in some part of the world today, generally in quite unusual environments. The best-known modern examples can be seen at the World Heritage site at Shark Bay, on the northeastern coast of Western Australia.



An example of a calcareous stromatolite formed by cyanobacteria encrusting an angular quartz pebble. Image credit: JH Robinson.

We have no stromatolites of this vast age in Aotearoa New Zealand, but we have some remarkable examples from the Miocene of Central Otago. They lived during the Early Miocene near what is now St Bathans. These stromatolites formed in shallow waters at the margin of a very large freshwater lake, Lake Manuherikia (see: Crikey! Lake crocodilian from Central Otago).

These stromatolites look like a rock cauliflower on the outside, but when sliced through, their unusual finely layered structure is revealed. They begin when a hard nucleus of some kind, in this case, a small quartz pebble from the Otago schist, is coated with a sticky layer of cyanobacteria, sometimes known as blue-green algae. Over time, new layers are added, together with fine calcareous sediment, so the stromatolite increases in diameter. If it is growing on a large rock, it will form a layered mat. However, if it has encrusted a smaller pebble such as in this example, waves can roll it around on the lake shore in stormy conditions to form a nearly spherical stromatolite. They can only live in very shallow-water (less than 4 metres deep) as the cyanobacteria need sunlight for photosynthesis.

—Written by Daphne E Lee

***Locality*:** Near St Bathans, Central Otago	***Age*:** 18.7 to 15.1 million years ago (early or middle Miocene, Altonian or Clifdenian stage)
***Collected by*:** J K Lindqvist	***Rock Formation*:** Bannockburn Formation

***Citation*:** Lindqvist JK. 1994. Lacustrine stromatolites and oncoids: Manuherikia Group (Miocene), New Zealand. Pp. 227-254 in: J Bertrand-Sarfati, C Monty (eds.). Phanerozoic Stromatolites II (Springer, Dordrecht). doi.org/10.1007/978-94-011-1124-9_9

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CHAPTER OVERVIEW

10: 3D models

A selection of fossils from the University of Otago Geology Museum have been 3D scanned to make digital replicas. 3D scanning is an increasingly important tool in paleontology as it allows people all over the world to study fossils that are physically located in a museum collection. 3D scanning also allows us to take measurements and examine details directly from the digital replica, meaning that the original can stay safe and sound.

10.1: 3D model—Exceptional mega shark- distant ancestor of Jaws
10.2: 3D model—Ghostly trace of an egg capsule
10.3: 3D model—Game fish have ancient history in South Pacific
10.4: 3D model—Marine reptile from oceans ancient before Zealandia formed
10.5: 3D model—Fossil from the Discworld? Giant turtle named for famed author
10.6: 3D model—Most complete dinosaur-aged reptile from Aotearoa
10.7: 3D model—Small penguin was forerunner of today's tiny divers
10.8: 3D model—Archaic dolphin connects oceans of Zealandia to endangered river resident
10.9: 3D model—Small origins for baleen whales, the largest animals to ever live
10.10: 3D model—Mystery ammonite from Papatowai needs a name
10.11: 3D model—Dunedin’s ammonite named for geology great
10.12: 3D model—Valley of trilobites, our oldest fossils

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10.1: 3D model—Exceptional mega shark- distant ancestor of Jaws

From the chapter Exceptional mega shark: distant ancestor of Jaws.

Tooth from *Otodus* (*Carcharodon*) *anguistidens* (specimen OU 22261).

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10.2: 3D model—Ghostly trace of an egg capsule

From the chapter Ghostly trace of an egg capsule.

Impression of an egg capsule from an unidentified species of chimeroid (specimen OU 22689). The egg capsule is recognised from a trace fossil and the ichnotaxon for the trace fossil is *Chimaerotheca reperepe*.

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10.3: 3D model—Game fish have ancient history in South Pacific

From the chapter Game fish have ancient history in South Pacific.

Bill (maxilla and premaxilla) from *Aglyptorhynchus hakataramea* (specimen OU 22396).

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10.4: 3D model—Marine reptile from oceans ancient before Zealandia formed

From the chapter Marine reptile from oceans ancient before Zealandia formed.

Natural mould of the snout from an unidentified species of ichthyosaur (specimen OU 3859).

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Cast made from the natural mould of the snout from an unidentified species of ichthyosaur (specimen OU 3859).

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10.5: 3D model—Fossil from the Discworld? Giant turtle named for famed author

From the chapter Fossil from the Discworld? Giant turtle named for famed author.

Rib from *Psephophorus terrypratchetti* (OU 22177). The rib and associated bones and sedimentary matrix are shown in light grey. The fossil is resting on a base made from plaster and is shown here in dark grey.

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10.6: 3D model—Most complete dinosaur-aged reptile from Aotearoa

From the chapter Most complete dinosaur-aged reptile from Aotearoa.

Skull from *Kaiwhekea katiki* (specimen OU 12649).

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10.7: 3D model—Small penguin was forerunner of today's tiny divers

From the chapter Small penguin was forerunner of today’s tiny divers.

Humerus (upper-most wing bone) from *Pakudyptes hakataramea* (specimen OU 21977).

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10.8: 3D model—Archaic dolphin connects oceans of Zealandia to endangered river resident

From the chapter Archaic dolphin connects oceans of Zealandia to endangered river resident.

Cast of the skull from *Waipatia maraewhenua* (specimen OU 22396).

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The size of the bounding box for this object is: 192.5 mm tall by 554.9 mm long by 242.2 mm wide.

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10.9: 3D model—Small origins for baleen whales, the largest animals to ever live

From the chapter Small origins for baleen whales, the largest animals to ever live.

Vertebra from *Toipahautea waitaki* (specimen OU 21981).

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10.10: 3D model—Mystery ammonite from Papatowai needs a name

From the chapter Mystery ammonite from Papatowai needs a name.

Shell of an unidentified ammonite (OU 48255).

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The size of the bounding box for this object is: 469.1 mm tall by 326.0 mm wide by 109.0 mm deep.

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10.11: 3D model—Dunedin’s ammonite named for geology great

From the chapter Dunedin’s ammonite named for geology great.

Natural mould of *Kossmaticeras bensoni* (specimen OU 4679).

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10.12: 3D model—Valley of trilobites, our oldest fossils

From the chapter Valley of trilobites, our oldest fossils.

Sample of trilobite fauna from Tasman Formation, Nelson, New Zealand (specimen OU 8258).

One or more interactive elements has been excluded from this version of the text. You can view them online here: pb.libretexts.org/geology/?p=220

The size of the bounding box for this object is: 102.5 mm tall by 117.6 mm wide by 51.8 mm deep.

Follow this link to Sketchfab to download a print-ready version of the 3D model: https://skfb.ly/ptErJ.

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Index

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Glossary

Adipose fin | A small, fleshy fin between the dorsal fin and the tail.

Alveoli (teeth) | Sockets in the mandible and maxilla (i.e. jaw bones) where teeth are set.

Amniota | A group of vertebrate animals that hatch from a complex egg with extra-embryonic membranes and an outer shell (e.g. reptiles), or are the descendants of an animal that hatched out of such an egg (e.g. mammals).

Anapsida | A group of reptiles that have no openings in the sides of their skull posterior to the orbit. Contrast with Diapsida. Turtles are the only living anapsids.

Anoxic | An environment that lacks oxygen.

Antirostrum (otolith) | The antirostrum of an otolith is a beak-like projection that is on the opposite side of an excisura to the rostrum. Typically smaller than the rostrum.

Apex predator | An animal that hunts other animals for food and which holds a position in a food web where it has no natural predators.

Araucariaceae | A family of conifer trees. A living example of an araucarian is kauri, *Agathis australis*.

Archaeoceti | Ancient close relatives of living whale and dolphin species. In taxonomic terms, 'archaeocetes' are all species within Cetacea that are not within Neoceti.

Articulated | Body structures like bones or shells are positioned as they would have been in life.

Auricle (bivalve) | Also called an 'ear', auricles are the often rounded structures along the edge that forms the hinge in each valve (shell).

Balaenidae | A family of cetaceans with four living species including the southern right whale *Eubalaena australis*.

Balaenopteridae | A family of cetaceans with nine living species including the blue whale *Balaenoptera musculus*.

Baleen | Cartilage plates suspended from the upper jaw in the mouth of mysticete whales. Used to strain prey from sea water.

Bannockburn Formation | Poorly bedded, light green to brown siltstones and mudstones.

Benthic | Relating to the bottom of a body of water.

Bilateral symmetry (biology) | A body plan where an organism has a left side and a right side that are generally mirror images of one another.

Binocular vision | Vision using two eyes with overlapping fields of view, allowing good perception of depth.

Biodiversity | The variety of life.

Biogeography | The geographic distribution of species.

Bioturbation | Disturbance of sedimentary deposits by living organisms.

Blowhole (odontocete anatomy) | Where the nostrils open on the top of the head, enabling the animal to breathe.

Bounding box | A bounding box for a 3D object is the smallest rectangular box that surrounds an object in 3D space.

Calcareous | Composed of calcium carbonate.

Cambrian Period | 538.8 to 486.85 million years ago.

Canterbury Basin | A sedimentary basin on the South Island of New Zealand.

Carapace (invertebrate) | Outer shell.

Carapace (turtle) | Shell on the upper (i.e. dorsal) surface.

Cartilage | Firm, flexible connective tissue found. One of two major components in the skeleton of all vertebrates (with the other being a calcium phosphate mineral).

Caversham Sandstone | Calcareous, medium-grained sandstone with local variation.

Cephalon | The head of a trilobite.

Cetacea | A group of marine mammals with around 90 living species across two key clades, Mysticeti (baleen whales) and Odontoceti (toothed whales, including dolphins and porpoises). The fossils of many extinct species of cetacean have been discovered.

Chamber (biology) | An enclosed space.

Charadriiformes | An order of birds with more than 390 living species. Includes seabirds and shorebirds.

Chelae (Arthropoda) | Pincer-like claws at the anterior limbs of an arthropod, like a crab or lobster. Used for defence and to gather food.

Chitin | A tough polymer made of sugar molecules by insects and other organisms. Like a 'biological plastic'.

Collagen | A protein that is important for the structure of connective tissues. A key component of cartilage.

Colonial (organisms) | A collective form of life where many individual organisms live in close association with one another.

Concretion | Sedimentary rock cemented into a solid structure through the gradual precipitation of minerals into the pore spaces between sedimentary grains.

Continental margin | The outer edge of the continental crust where it meets oceanic crust.

Continental shelf | The extended margin of a continent which is submerged under relatively shallow seas. While the width of the shelf varies between continents, most shelf seas are generally less than 100 metres deep.

Continental slope | The slope between the outer edge of the continental shelf and the deep ocean floor.

Coprolite | Fossilised faeces.

Cretaceous Period | 145 to 66 million years ago.

Crocodilian | The general term for the group of reptiles that includes all living species of crocodile, alligator, caiman and gharial. Crocodilians are also all of the extinct species that are more closely related to living crocodiles, alligators, caimans and gharials than they are to any other group.

Decomposed | The process by which organic structures like animal bodies or tree trunks are broken down into simpler organic matter.

Dentition | The arrangement, types and shape of teeth.

Devonian Period | 419.6 to 358.9 million years ago.

Diadromous | An animal that migrates between freshwater and seawater during different stages of their life cycle. Special cases include anadromous fish, which spend most of their life in freshwater but migrate to the sea, and catadromous fish, which migrate from the ocean to freshwater.

Diapsida | A group of animals that have two openings in each side of their skull, posterior to the opening for the eye (orbit). Examples of diapsids include lizards, crocodiles, birds and other dinosaurs.

Diatom | A group of algae where many species in that group have a cell wall made of hydrated silicon dioxide (silica) which forms a shell called a frustule.

Diatomite | Sedimentary rock composed of the frustules (shells) of diatoms, a type of algae.

Discworld (media) | See: Discworld - Sir Terry Pratchett.

Dolphin | A smaller species within Cetacea, and one that has teeth. The precise taxonomic definition for dolphin is any species within Delphinidae, Platanistidae, Iniidae, Pontoporiidae and Lipotidae. However, dolphin is also used for close extinct relatives of living dolphins that are not included in these families.

Duntroonian Stage | 27.3 to 25.2 million years ago.

Early Eocene | 56.0 to 48.07 million years ago. The late Eocene is more formally known as the international Ypresian Stage.

Early Miocene | 23.03 million to 15.97 million years ago. The Early Miocene is a sub-epoch that spans the international Aquitanian and Burdigalian stages.

Echolocation | The use of sound to determine the location of objects.

Ecological niche | The role or position of an organism in an ecosystem, including the interactions that organism has with other organisms.

Ectothermy (biology) | Organisms that rely on external sources of heat to regulate their body temperature, also known as cold-blooded.

End-Cretaceous extinction event | A mass extinction event that occurred around 66 million years ago. An asteroid impact is generally considered to have been the cause.

Endemic | Species that are native to and found only within a specific geographic area.

Eocene epoch | 56 to 33.9 million years ago.

Epoch (geological time) | A unit of geological time that is smaller than a period and larger than a stage. An epoch usually spans several million years.

Eschrichtiidae | A family of cetaceans with a single living species, the gray whale *Eschrichtius robustus*.

Eusocial (biology) | An advanced level of social organisation.

Evolutionary relationships | The degree of relatedness between species.

Excisura (otolith) | The excisura of an otolith is a deep groove or notch.

Exoskeleton | Structural support that is on the exterior surface of an animal.

Fauna | The animals of a particular geographic region (e.g. the fauna of New Zealand), environment (e.g. the marine fauna) or geological period (e.g. the Oligocene fauna).

Femur | A bone in the hindlimb of a vertebrate (i.e. back leg) that connects with the pelvis. Commonly known as the thigh bone.

Food web | The connection of all food chains in an ecosystem. A food web represents which organisms consume which other organisms in an ecological community.

Foot (mollusc) | A muscular organ that is part of the body plan of all molluscs. Used in different species for locomotion, grasping or digging.

Foramen | The hole in the umbo that the pedicle passes through.

Fossil | Evidence of life from a past geological age. Remains like bones, shells or wood, or an impression like a footprint, or some other evidence of life, from something that was alive more than 11,700 years ago.

Fossil mould | An impression of part of an organism preserved in sediment.

Fossil record | A collection of fossils that document the history of life. Reference might be made to the history of life in a particular place ('the fossil record of New Zealand'), or the history of a particular group of organisms ('the fossil record of penguins'), or simply the global history of all life ('the fossil record').

Foulden Maar | A former crater lake with abundant diatoms, and now a fossil site known for diatomite and famous for high-quality fossil preservation. Located near Middlemarch in Otago, New Zealand. See: Fossil Treasures of Foulden Maar.

Genus (biology) | The taxonomic rank that groups together closely related species. The genus forms the first part of the binomial species name.

Geological time scale (GNS Science Te Pū Ao) | See: GNS Science Te Pū Ao: New Zealand's geological timescale (includes link to download NZ Geological Timescale poster) And: GNS Science Te Pū Ao: The 100-million-year evolution of our continent

Geological time scale (Wikipedia) | See: Cambrian Also: New Zealand geologic time scale

Geoscientists | Scientists who study the Earth, including its composition, structure, processes, and history. Paleontologists are a type of geoscientist.

Glauconite (mineral) | A hydrated iron-rich silicate mineral made up of potassium, iron, aluminum, magnesium, silicon, and oxygen. Generally appears green and is most often found in marine sediments.

Global biodiversity hotspot | A geographic region with a higher-than-usual level of species diversity.

Gondwana | An ancient landmass that existed from the late Precambrian to the Jurassic, which upon fragmenting gave rise to Africa, Antarctica, Australia, India, Madagascar, South America, and Zealandia.

Gordon (2009 | Gordon, D.P. (ed.) (2009). New Zealand Inventory of Biodiversity. Volume One: Kingdom Animalia: Radiata, Lopotrochozoa, Deuterostomia. Christchurch, New Zealand, Canterbury University Press. 648 p., Gordon, D.P. (ed.) (2010). New Zealand Inventory of Biodiversity. Volume Two: Kingdom Animalia: Chaetognatha, Ecdysozoa, Ichnofossils. Christchurch, New Zealand, Canterbury University Press. 528 p., Gordon, D.P. (ed.) (2012). New Zealand Inventory of Biodiversity. Volume Three: Kingdoms Bacteria, Protozoa, Chromista, Plantae, Fungi. Christchurch, New Zealand, Canterbury University Press, 616 p.

Gould (1983) | Gould, SJ. 1983. Hen's Teeth and Horse's Toes: Further Reflections in Natural History. New York: W.W. Norton & Company, Inc. Page 363: "*...Some of our most common and comforting groups no longer exist if classifications must be based on cladograms. With apologies to Mr. Walton and to so many coastal compatriots in New England, I regret to report that there is surely no such thing as a fish. About 20,000 species of vertebrates have scales and fins and live in water, but they do not form a coherent cladistic group. Some—the lungfishes and the coelacanth in particular—are genealogically close to the creatures that crawled out on land to become amphibians, reptiles, birds, and mammals...*"

Greensand | A marine sedimentary rock composed mainly of sand-sized quartz and an abundance of the green mineral glauconite.

Hakataramea Valley | An inland location within southernmost Canterbury, New Zealand, where significant fossil discoveries have been made.

Haumurian Stage | 83.6 to 66.0 million years ago.

Hinge (bivalve) | The dorsal edge of the shell of a bivalve mollusc where the two valves (two shells) articulate.

Hingeline | The hingeline is the axis that the two shells open along. Brachiopods have teeth on one valve and sockets on the other.

Hokonui Hills | A range of hills that rise to 600 metres above the surrounding Southland Plains. Part of the Southland Syncline geological fold system.

Holocene | 11,700 years ago to present.

Holotype | The individual specimen from which a species is named.

Humerus | The bone in the forelimb of a vertebrate (i.e. wing, arm, flipper) that connects with the shoulder.

Hyden (1979) | Hyden FM. 1979. Mid-Tertiary temperate shelf bioclastic limestones, Southland, New Zealand. Unpublished PhD thesis, University of Otago. download.otagogeology.org.nz/temp/Abstracts/1979Hyden_FM.pdf

Hypothesis | A proposed explanation which can be tested and proven false.

Invertebrate | Any animal that is not a vertebrate (i.e. does not have a backbone). Examples include sponges, molluscs and echinoderms.

Isopoda | An order of crustaceans. There are over 10,000 species of isopod worldwide with around 5,000 terrestrial species, 4,500 species in marine environments, and 500 fresh water species.

Jurassic Period | 201.4 to 143.1 million years ago.

Katiki Formation | Massive, indurated, dark grey sandy siltstone.

Keratin | A protein that provides structural support to many epidermal tissues including hair and nails of mammals, feathers of birds, scales of reptiles.

Kokoamu Greensand | Green-grey, calcareous, glauconitic, quartz sandstone.

Konservat-Lagerstätte | A sedimentary deposit that exhibits extraordinary fossil preservation, often including soft tissues.

Late Cretaceous | 100.5 to 66 million years ago. The final epoch of the Cretaceous Period.

Late Eocene | 37.71 to 33.90 million years ago. The late Eocene is more formally known as the international Priabonian Stage.

Late Oligocene | Approximately 27 to 23.03 million years ago. The late Oligocene is not a formally defined segment of geological time, but instead refers to the final three or four million years of the Oligocene Epoch.

Late Triassic | 237.0 to 201.4 million years ago. The Late Triassic is the final epoch of the Triassic Period.

Lateral cusplets | Points on either side of the primary cusp of a tooth that are small compared to the primary cusp.

Lignified | Plant tissues have have become rigid due to the accumulation of the organic polymer lignin. Wood is an example of a lignified tissue.

Limestone | A sedimentary rock composed mainly of calcium carbonate. Can be formed from the skeletal fragments of marine organisms.

Lophophore | The lophophore of brachiopods is their breathing and food filtering/gathering organ.

Lower Lias | Mesozoic marine sedimentary rocks found in the United Kingdom and elsewhere in western Europe.

Mackerel shark | A type of large, fast-swimming shark belonging to the order Lamniformes. Living examples include great white shark (*Carcharodon carcharias*) and shortfin mako shark (*Isurus oxyrinchus*).

Marine mammal | A mammal that is dependent on offshore marine environments for finding food.

Marl | A muddy sedimentary rock with abundant calcium carbonate.

Meiolaniidae | An extinct family of large turtles that were probably terrestrial herbivores. Known from South America and Australasia.

Mellor Laboratories Clean Lab facility | See: World Class Clean Lab opens at Otago

Mesozoic Era | 251.9 to 66 million years ago. The Mesozoic Era is the section of geological history spanning the Triassic, Jurassic and Cretaceous periods.

Middle Cambrian | 506.5 to 497 million years ago. The middle Cambrian is the international Miaolingian stage.

Middle Eocene | 48.07 to 37.71 million years ago. The middle Eocene spans the international Lutetian and Bartonian stages.

Middle Miocene | 15.97 million to 11.04 million years ago. The Middle Miocene is a sub-epoch that spans the international Langhian and Serravallian stages.

Mineralised tissue | Connective tissues with a high proportion of accumulated minerals, generally a calcium phosphate mineral (bone) or a calcium carbonate mineral (shell). Mineralised tissues including bones and teeth are harder and more durable than cartilage-only skeletal tissues.

Miocene Epoch | 23.03 to 5.33 million years ago.

Moulting (Arthropoda) | The process of shedding an exoskeleton in order to grow. Also known as ecdysis.

Mysticeti | Marine mammals within Cetacea that have large keratin plates (baleen) for filtering food from water. One of two major clades within Neoceti, with the other being Odontoceti. Living examples include blue whale (*Balaenoptera musculus*) and southern right whale (*Eubalaena australis*).

Nacre | Iridescent material constructed from calcium carbonate and organic material.

Nacreous | A pearly appearance with iridescence.

Neoceti | All living species within Cetacea and the descendants of their most recent shared ancestor, including extinct species.

Non-avian dinosaurs | All dinosaurs except birds. Examples include *Deinonychus antirrhopus* and *Tyrannosaurus rex*.

Occlusal surface | The surface of a tooth or tooth plate that comes into contact with another tooth or tooth plate when the jaw is closed.

Odontoceti | Marine mammals within Cetacea that have teeth. One of two major clades within Neoceti, with the other being Mysticeti. Living examples include sperm whale (*Physeter macrocephalus*) and Hector's dolphin (*Cephalorhynchus hectori*).

Oligocene Epoch | 33.9 to 23.03 million years ago.

Orbit (anatomy) | Openings in the skull for the eyes.

Ordovician Period | 486.85 to 443.1 Ma million years ago.

Otekaike Limestone | Coarse-grained, sandy limestone.

Otolith | Sometimes called 'earbones', but more correctly termed 'ear stones', these are accumulations of calcium carbonate minerals in the base of the skull of many vertebrates that help to provide a sense of movement and maintain balance.

Ototara Limestone | Well-sorted bryozoan limestone.

Paleocene Epoch | 66 to 56 million years ago.

Pan bone (odontocete anatomy) | Thin bone in the lower jaw near the jaw hinge that helps transmit sound to the ear.

Pectoral fins | The pair of fins located on either side of the body near the gills.

Pedicle | The stalk that attaches a brachiopod to the substrate.

Pedicle (biology) | A muscular stalk.

Pentagonal | Shaped like a pentagon.

Pereiopoda (Arthropoda) | Jointed walking legs that are also used in food-gathering.

Permian Period | 298.9 to 251.9 million years ago.

Phaethontiformes | An order of seabirds with three living species in a single family (Phaethontidae).

Phosphatic | Composed of calcium phosphate.

Phylum | A level of the classification system used to organise life that is below kingdom and above class. Organisms in one phylum generally have a very different body to organisms in another phylum within the same kingdom.

Planktic | Relating to the part of a body of water that is not along the bottom.

Plaster jacket | Protective coverings made of plaster used to encase and transport fossils.

Plastron | Shell on the lower (i.e. ventral) surface.

Pleistocene | 2.58 to 0.0117 million years ago.

Pliocene Epoch | 5.33 to 2.58 million years ago.

Precambrian | 4.6 billion years ago to around 538.8 million years ago.

Primary cusp | Tall central point of a tooth.

Procellariiformes | An order of seabirds with more than 140 living species across the four families Diomedeidae (albatrosses), Procellariidae (petrels and shearwater), Hydrobatidae (northern storm petrels) and Oceanitidae (southern storm petrels).

Procumbent incisors | Front teeth that point out from the mouth instead of into the jaw.

Puncta | Small opening (the plural is punctae).

Pustulose | Bumpy.

Pyrite (mineral) | An iron sulphide mineral, FeS2. Commonly known as "Fool's gold".

Rangitāhua (Kermadec Islands) | A group of islands in the South Pacific Ocean, northeast of New Zealand, known for their rich marine biodiversity.

Richardson (1981) | Richardson JR. 1981. Distribution and orientation of six articulate brachiopod species from New Zealand. New Zealand Journal of Zoology 8:189–196. doi.org/10.1080/03014223.1981.10427961

Rocky shore (environment) | A marine ecosystem that's found in the intertidal zone, where the ocean meets the land.

Rostrum (otolith) | The rostrum of an otolith is a beak-like projection that is on the opposite side of an excisura to the antirostrum. Typically larger than the antirostrum.

Rostrum (skull) | The region of a skull that holds the teeth, palate, and nasal cavity. Can be elongated into beak or bill.

RV Polaris II | See: Tour of the RV Polaris II (YouTube)

Scales | Small, rigid plates that grow out of an animal's skin to provide protection from the non-living environment and from other organisms. The scales of reptiles are constructed from keratin, but are a mineralised tissue in fish.

Scapula | Bones in the shoulders where muscles from the forelimb are attached. More commonly known as shoulder blade.

Seabird | A bird that is dependent on offshore marine environments for finding food.

Sedimentary horizon | A layer of sedimentary rock with distinct characteristics.

Semiporous (biology) | A surface that is permeable to some substances but not others.

Septum (biology) | Wall that divides a cavity into smaller cavities. Septa is the plural of septa.

Siltstone | A sedimentary rock composed mainly of silt-sized particles (0.002 to 0.063 mm diameter).

Silty fine sandstone | A sedimentary rock that is mostly made up of fine sand (0.02 - 0.20 mm diameter grains) but which also includes an appreciable amount of silt (0.002 to 0.063 mm diameter grains).

Silurian Period | 443.1 to 419.6 million years ago.

Siphuncle (Cephalopoda) | A calcareous tube running through all of the chambers in the shell of an ammonoid or a nautiloid. Allows fluid to be pumped between chambers to adjust buoyancy.

Species (biology | One or more populations of organisms in which any two individuals of the appropriate sexes or mating types can produce fertile offspring. In paleontology, a species is often considered a lineage of organisms that maintains its identity over time and space.

Sphenisciformes | Penguins. An order of seabirds with around 20 living species in a single family (Spheniscidae). Many more extinct species of penguin are known compared with the number of living species.

Spiralium | The internal loop of *Rastelligera* was in the form of two tight spirals.

Stingray | Cartilaginous fish known for their flattened bodies and long, thin tails. Stingrays are all animals within order Myliobatiformes.

Strata | Layers of rock that stack up on top of one other over time. A single layer is a stratum. The different layers can appear in different colours or have other properties that differentiate them when they form under different conditions. For example, a stratum that is mostly made up of sand-sized sedimentary grains might be stacked up on top of a layer that is mostly made up of mud-sized sedimentary grains. Strata are important for understanding geological history and environmental change.

Suliformes | An order of seabirds with more than 55 living species across the four families Fregatidae (frigatebirds), Sulidae (gannets and boobies), Phalacrocoracidae (cormorants and shags) and Anhingidae (anhingas).

Suspension feeding | Feeding by capturing and ingesting food particles that are suspended in water.

Sutherland (2003) | Sutherland JI. 2003. Miocene petrified wood and associated borings and termite faecal pellets from Hukatere Peninsula, Kaipara Harbour, North Auckland, New Zealand. Journal of the Royal Society of New Zealand 33:395–414. doi.org/10.1080/03014223.2003.9517736

Suture (biology) | A join between structures. Examples of sutures include the join between a septum and the shell wall in a nautiloid, or between two bones in a vertebrate.

Taoka | Te reo Māori term originating with Kāi Tahu meaning treasured. The term taonga in te reo Māori is also used for treasured.

Tarsometatarsus | Bone in the hindlimb of a bird. Forms part of the foot. This bone is a fusion of the tarsal and metatarsal elements that would be found as separate bones in some other reptiles or in mammals.

Tasman Sea | The body of water between Australia and Aotearoa New Zealand.

Taxonomy (biology) | Grouping organisms into categories based on shared characteristics gained through inheritance.

Temperate latitudes | Regions of Earth between the tropics and the polar regions (approximately 23.5° to 66.5° north and south of the equator) where the temperatures are mild.

Temporal fenestra | Opening in the skull behind the orbit. A site of muscle attachment.

Terrane | A section of Earth's crust that has a geological history that is distinct from the geological history of the section of crust in the surrounding areas. For example, the Murihiku Terrane is a major geological feature in Aotearoa New Zealand, especially prominent in the Southland and western North Island regions.

Tethys Ocean | An ancient precursor to the modern Indian Ocean, the Mediterranean Sea, and the Black Sea and Caspian Sea.

Thin section | A common method of preparing a very thin slice of a rock or fossil for examination under a microscope.

Tibiotarsus | Bone in the lower leg of a bird. This bone is a fusion of the tibia and elements of the tarsal bones that would be found as separate bones in some other reptiles or in mammals.

Toolkit fossil | A fossil that is particularly useful for identifying and understanding the characteristics of a specific geological period or environment.

Trace fossil | Evidence of an organism from a past geological age but not the preserved remains of the organism itself.

Triassic Period | 251.9 to 201.4 million years ago.

Tropical latitudes | Regions of Earth that surround the equator (approximately 23.5° north to 23.5° south) where there are high temperatures and abundant rainfall.

Type specimen | The specimen on which the description and name of a new species is based.

Tīkapa Moana | Also known as the Hauraki Gulf, a coastal feature of the North Island of New Zealand.

Tūhura Otago Museum | See: Tūhura Otago Museum, Southern Land, Southern People.

Ulna | A bone in the forelimb of a vertebrate (i.e. wing, arm, flipper) that connects with the humerus to form the 'forearm'.

UNESCO Global Geopark | Geographical areas with geology of outstanding societal value, which are community owned and open to everyone. See: UNESCO Global Geoparks Programme.

UNESCO Waitaki Whitestone Global Geopark | See: UNESCO Waitaki Whitestone Global Geopark.

Valve (mineralised shell) | Technical term for each articulating shell part. For example, the shells of bivalve molluscs and brachiopods are each made up of two valves.

Vanished World Centre | Part of the UNESCO Waitaki Whitestone Geopark. See: Vanished World Centre.

Ventral | The surface facing the 'floor'. For example, in a shark this is the opposite surface from the one with the large dorsal fin.

Vertebrae | The series of bones forming the flexible 'backbone' structure of the animals named for possessing these bones, the vertebrates.

Vertebrate | Animals that have bony tissues (e.g. vertebrae, teeth) and are quadroblastic (i.e. four germ-layers: endoderm, mesoderm, ectoderm and neural crest tissue).

Vestigial (biology) | A structure that has lost its original function through evolutionary time.

Waihao Greensand | Massive, glauconitic, dark grey to green silty fine sandstone.

Waipara region | North of Christchurch in the Canterbury district of New Zealand. Notable for the scenic Waipara Valley which has produced internationally-important vertebrate fossils.

Whale | Any species within Cetacea, however, generally reserved for larger species.

Whorl (biology) | One rotation (i.e. an individual circle) in a spiral or concentric pattern. For example, the coiled shell of an ammonite can be constructed from multiple whorls.

Zealandia | The mostly submerged continent of which New Zealand and New Caledonia are a part.

µCT facility | See: Otago Micro And Nanoscale Imaging

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Versioning History

4

This page provides a record of changes made to this eBook.

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Version	Date	Change	Details
1.00	May 2025	First version	Written by Daniel B Thomas, Jeffrey H Robinson and Daphne E Lee, with additional writing contributions from R. Ewan Fordyce and Uwe Kaulfuss. Improved with edits from Richard White and others (see: Acknowledgements).
1.01	June 2025	Revised 3D model descriptions	Note about requiring a Sketchfab account for download access was added to the description of each 3D model.
1.02	June 2025	Front cover	Added a front cover page that is only viewable in exported versions of the eBook.
1.03	July 2025	Mystery ammonite	Added Mystery ammonite from Papatowai needs a name and 3D model—Mystery ammonite from Papatowai needs a name.

Fossil Collections Database

2

The University of Otago Geology Museum holds more than 60,000 catalogued fossils in three main collections: vertebrates, invertebrates and plants. These fossils have been given OU numbers and carefully logged into hand-written catalogue books for more than 100 years. Now, these catalogue books are being digitised into three searchable databases for all to access.

The fossil vertebrate collection

An internationally-significant collection of mostly marine vertebrates, varying from largely complete skeletons to single or partial bones and otoliths. Highlights include Late Cretaceous plesiosaurs and mosasaurs and numerous specimens of whales, dolphins, penguins, turtles, bony fish and sharks of Paleocene to Miocene age.

Access database: the Fossil Vertebrate Collection

The fossil invertebrate collection

Most of the Geology Museum's 60,000 specimens are marine invertebrates. Of particular note are Ordovician graptolites, Permian, Triassic and Jurassic molluscs and brachiopods, a diversity of Eocene to Miocene foraminifera, corals, crustaceans and echinoderms, and Miocene insects from Foulden Maar and other sites.

Access database: Fossil Invertebrate Collection

The fossil plant collection

A collection of spectacular plant fossils that have been critically important for understanding the evolution of southern landscapes. Fossils especially represent Otago and Southland localities including Pikopiko Fossil Forest, Foulden Maar, Hindon Maar, Newvale Mine, Lake Manuherikia and diatomaceous leaf beds around Ōtepoti Dunedin. The material includes fossil leaves, wood, flowers, fruits, seeds, pollen and fungi.

Access database: Fossil Plant Collection

How to search the databases

Each of the three collections has its own database within the Specify Web Portal. Please see the "Access database" links above to get started.

Search methods

The left hand side of the Specify Web Portal contains the Search Tools. There are two options for searching: Express and Advanced.

Below the 'Search Tools' heading are two check boxes. If you tick the **Geo Coords** box, only records from defined localities (latitude and longitude) will be shown. If you click on the **Images** box, only records with images will be shown.

Express search

The Express search allows you to enter a single word or number and the search engine will show all Records in the collection that include that word or number.

The word might be the 'common name' for:

- an animal (e.g. whale);
- a locality (e.g. Hakataramea);
- a rock formation name (e.g. Kokoamu);
- a rock type (e.g. limestone);
- a geological stage (e.g. Duntroonian);
- the type status (e.g. holotype);
- the name of a researcher (e.g. Fordyce or Lee).

Advanced search

The Advanced search option allows you to be more specific. Clicking on the + symbol opens the column of data fields. On the far left is the name of the field, then a space where you can type a word or number and then a small downward arrow. This arrow gives you several options – it is best to use ‘contains any’.

As an example, if you put ‘Whale’ into the **Common name** field and ‘Holotype’ into the **Type Status** field and Duntroonian into the **Stage/Age** field and hit the Search button (bottom left), the records of holotype specimens of Duntroonian age whales will be shown. Note that the Advanced search is case sensitive, using ‘Holotype’ and ‘Whale’ will work but using ‘holotype’ and ‘whale’ will not work.

Results

The main window of the Specify Web Portal displays the results of your search.

Each numbered line of information is one Record, which includes its catalogue number and information about a specimen or specimens. There is quite a lot of information included on the most important specimens.

If you double-click on a Record (a numbered line on the Results page) a pop up box (Detail) will open to show all the information on that specimen in a more readable format. The Detail box contains two tabs: Images and Map. These display any Images of the specimen and a Map with the locality it was found.

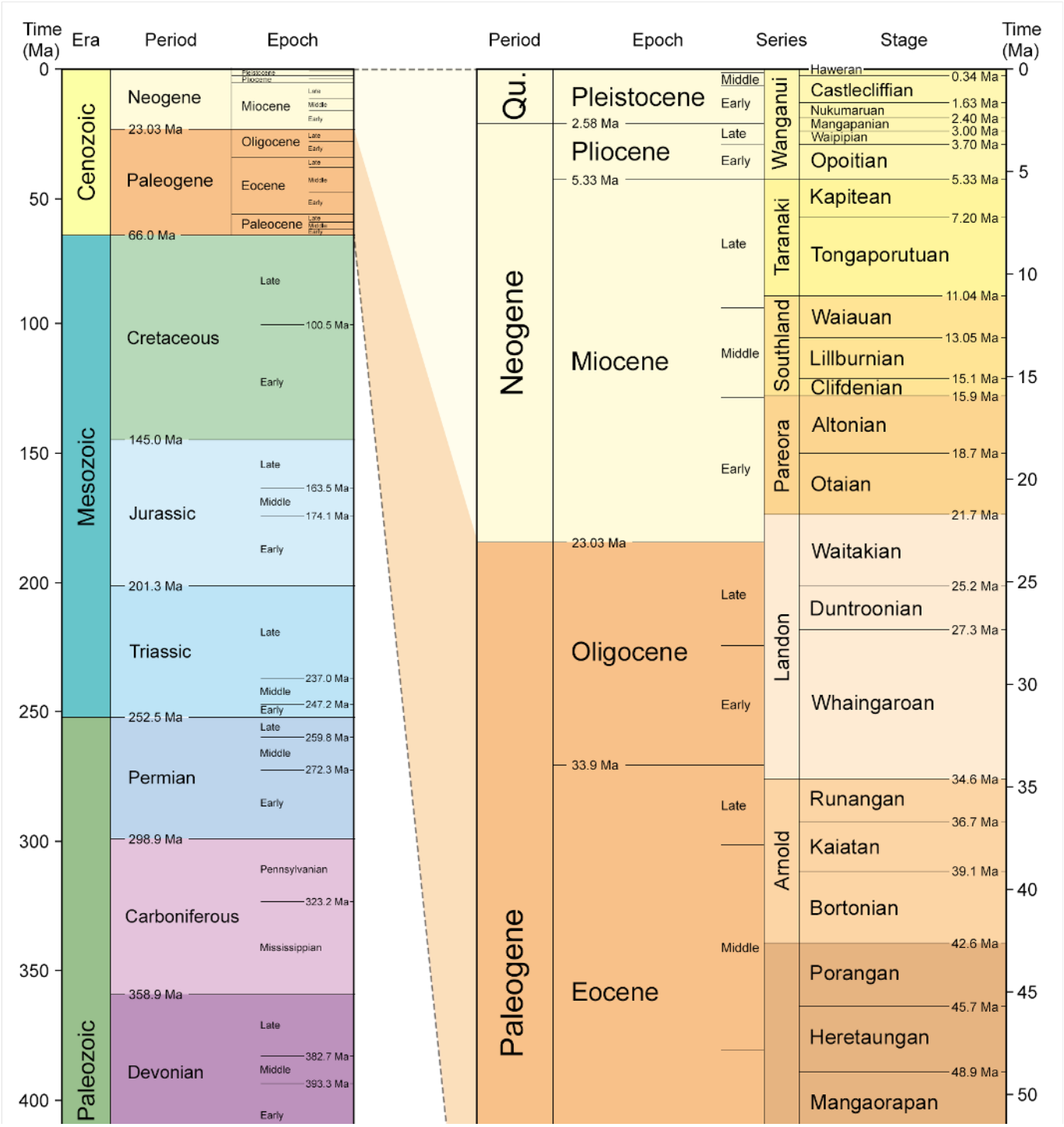
Geological Time

Geological time is vast.

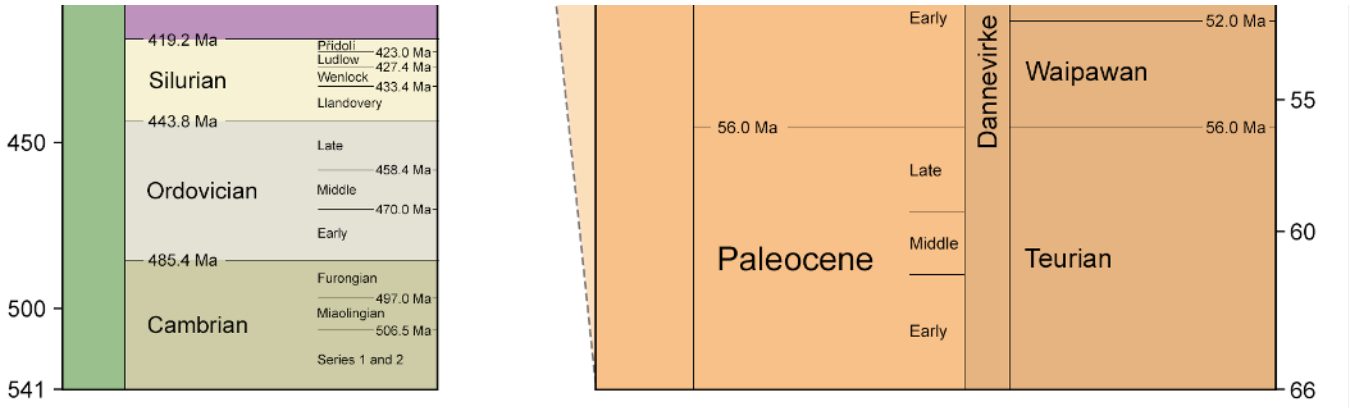
Consider that our lineage *Homo* first appeared on Earth a little over two million years ago. The history of life in Aotearoa New Zealand extends back to just over 500 million years, and the history of life on planet Earth goes back to over 3700 million years or 3.7 billion years. To help us navigate across this vastness of time the history of the Earth is conveniently divided into segments with different names that are tied to major events. Further, these segments are nested within one another to help us talk about events in Earth history at different scales.

For example, the lineages of mammals that we are familiar with today (bats, rodents, whales etc.) all have their origins within the Cenozoic, an era of geological time that spans the last 66 million years. Focussing in on whales, the origin of these marine mammals occurred during the Paleogene, a period of geological time that spanned 66.0 to 23.03 million years ago. Narrowing down further, many of the ancient whale species discovered in Aotearoa, including several that we include in this eBook (see: Archaic dolphin connects oceans of Zealandia to endangered river resident), are from rocks that were once the ancient sea floor during the Duntroonian Stage 27.3 to 25.2 million years ago. These nested divisions of geological time help to contextualise the events that have shaped the tree of life, from the grand to the fleeting.

Geological time is often represented as a time scale diagram like the one below. In our time scale diagram we show the last 541 million years out of the 4.6 billion year history of Earth. The time segments here include eras, which are divided into periods, then into epochs, then into series, and finally into stages. This geological time scale diagram is based on the New Zealand Timescale produced by GNS Science Te Pū Ao and features the local series and stages used in New Zealand.



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A diagram representing the previous 541 million years of geological time. This time scale diagram was created new for this eBook and has been adapted from the New Zealand Geological Time Scale published by GNS Science Te Pū Ao, which has the citation Raine JI, Beu AG, Boyes AF, Campbell HJ, Cooper RA, Crampton JS, Crundwell MP, Hollis CJ, Morgans HEG. 2015. Revised calibration of the New Zealand Geological Timescale: NZGT2015/1. GNS Science Report 2012/39.

Geological time scale diagrams can be challenging to read. If you would like to see the same information presented in a key word searchable table then head across to the supplementary chapter Geological Time (table).

Alt text: A diagram showing the New Zealand Geological Time Scale. Geological time is represented along the vertical axis and right. The expanded section shows finer-scale divisions of time.

Geological Time (table)

3

Geological time scale diagrams can be challenging to read. Including the diagram in our first chapter on Geological Time. Below we have provided the same information that is in the time scale diagram but this time in a table format. The table is key word searchable and also allows us to provide the epochs and stages for the Mesozoic and Paleozoic. This information is again based on the New Zealand Timescale produced by GNS Science Te Pū Ao. Note though that epochs and stages from the Cambrian through to the Carboniferous use either international epoch and stage information (Devonian and Silurian) or Australian epoch and stage information (Ordovician and Cambrian). Additional details for the Cambrian have been sourced from Wikipedia.

Stage	Time when stage began (millions of years ago)	Series	Epoch	Period	Era
Haweran	0.34	Wanganui	Holocene	Quaternary	Cenozoic
Castlecliffian	1.63		Pleistocene	Neogene	
Nukumaruan	2.40				
Mangapanian	3.00		Plio./Pleistocene		
Waipipian	3.70		Pliocene		
Opoitian	5.33				
Kapitean	7.2	Taranaki			
Tongaporutuan	11.04				
Waiauan	13.05	Southland	Miocene		
Lillburnian	15.1				
Clifdenian	15.9				
Altonian	18.7	Pareora			
Otaian	21.7				
Waitakian	25.2	Landon	Olig./Miocene	Pal./Neogene	
Duntroonian	27.3		Oligocene	Paleogene	
Whaingaroan	34.6		Eoc./Oligocene		
Runangan	36.7	Arnold	Eocene		
Kaiatan	39.1				
Bortonian	42.6				
Porangan	45.7	Dannevirke			
Heretaungan	48.9				
Mangaorapan	52.0				
Waipawan	56.0				

Teurian	66.0		Paleocene		
Haumurian	83.6	Mata	Late	Cretaceous	Mesozoic
Piripauan	86.5				
Teratan	90.5	Raukumara			
Mangaotanean	93.7				
Mangaotanean	95.2				
Ngaterian	99.5	Clarence	Early/Late		
Motuan	103.3				
Urutawan	108.4		Early		
Korangan	117.5	Taitai			
No stages recognised	145.0				
Puaroan	150.0	Oteke	Late	Jurassic	
Ohauan	154.5	Kawhia			
Heterian	164.3		Middle/Late		
Temaikan	176.0		Early/Middle		
Ururoan	188.9	Herangi	Early		
Aratauran	201.3				
Otapirian	208.5	Balfour	Late	Triassic	
Warepan	217.0				
Otamitan	221.0				
Otamitan	227.5				
Kaihikuan	238.0	Gore	Middle/Late		
Etalian	246.0		Middle		
Malakovian	249.0		Early/Middle		
Nelsonian	251.5		Early		
Makarewan	253.2	D’Urville	Late	Permian	Paleozoic
Waiitian	254.2				
Puruhauan	259.8				
Flettian	266.0	Aparima	Middle		
Barettian	276.0		Early/Middle		
Mangapirian	285.0		Early		
Telfordian	288.5				
pre-Telfordian	298.9				

No stages recognised	323.2		Pennsylvanian	Carboniferous
	358.9		Mississippian	
Famennian	372.2		Late	
Frasnian	382.7			
Givetian	387.7		Middle	Devonian
Eifelian	393.3			
Emsian	407.6		Early	
Pragian	410.8			
Lochkovian	419.2			
Přídolí	423.0		Přídolí	Silurian
Ludfordian	425.6		Ludlow	
Gorstian	427.4			
Homerian	430.5		Wenlock	
Sheinwoodian	433.4			
Telychian	438.5		Llandovery	
Aeronian	440.8			
Rhuddanian	443.8			
Bolindian	448.4		Late	
Eastonian	453.0			
Gisbornian	448.4			
Darriwilian	467.3		Middle	
Yapeenian	468.3			
Castlemainian	470.0			
Chewtonian	472.4		Early	Ordovician
Bendigonian	476			
Lancefieldian	484.3			
Warendan	485.4			
Datsonian	486.8		Furongian	Cambrian
Payntonian	489.5			
Iverian	494.0			
Idamean	497.0	Miaolingian	Epoch 3	
Mindyallan	499.0			
Boomerangian	500.5			

Undillan	503.0					
Floran	504.5					
Templetonian	508.0	Mia./Series 1-2	Ep.3/Epochs 1-2			
Ordian	511.5	Series 1-2	Epochs 1-2			
No stages recognised	541.0					

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