THE KOONWARRA FOSSIL BED

Ferns, flowers, fleas and fish…and feathers for good measure!

***On the cover**: The most recent large scale excavation at the Koonwarra Fossil Bed was undertaken in 1981. Although fossil plants were the focus of this dig, future excavations at the site might target fossil tetrapods — four-legged back-boned animals. The evidence for these is limited to a handful of feathers so far.*

Photo Andrew Drinnan

A MODERN-LOOKING FISH

Waldmanichthys koonwarri, ***the most widely represented fish from the Koonwarra dig site. In spite of its distinctly modern look, this freshwater fish is over 100 million years old.***

Photo Stephen Poropat courtesy of Museums Victoria

THE FLEA

Tarwinia australis ***is the first described Australian Mesozoic flea. At 7mm in length****, Tarwinia* ***was a giant compared with modern fleas but relatively small against some others from the same time period.***

Photo John Broomfield © Museum Victoria

Story by Dr Stephen Poropat

> "In terms of numbers of new species, excellence of preservation, and impact on palaeoecological knowledge, [Koonwarra] is one of the great fossil localities of the Mesozoic Era."

– Mary Dettmann and Jack Douglas, *Geology of Victoria (Second Edition; 1988)*.

Most people with an interest in palaeontology will eventually come across the term *Lagerstätte*. Although it sounds like a brand of Bavarian beer, you will not find *Lagerstätte* on tap at Oktoberfest. However, both the beer type called "lager" and the palaeontological term derive from the same word: *lager*, which means "storeroom" in German. Combined with *stätte*, which means "place", the translation of *Lagerstätte* is simply "storeroom place". In truth, it does not sound very exciting once you break it down. However, if you found a *Lagerstätte* and told a palaeontologist of your discovery, they would practically beg you to take them to it.

So what is a *Lagerstätte*? Put simply, it is an exceptional fossil site. The term was proposed by German palaeontologist Dolf Seilacher in 1970 to categorise fossil sites of outstanding significance. According to his criteria, in order to earn the *Lagerstätte* designation, a site had to either preserve fossils in exceptional abundance (in which case it would be a *Konzentrat-Lagerstätte* – a "concentration storeroom") or produce fossils of exceptional quality (thereby making it a *Konservat-Lagerstätte* – a "conservation storeroom").

Many sites around the world produce fossils in sufficiently high numbers to be considered *Konzentrat-Lagerstätten*, but relatively few fossil sites can be truly termed *Konservat-Lagerstätten*. Even so, there are a few in Australia! One of these is the now-famous Koonwarra Fossil Bed in South Gippsland, Victoria.

Setting things straight

Straightening roads seems to be a sure-fire way to find exceptional fossil sites in Australia. The amazing Devonian-aged fossil fish site at Canowindra in NSW – which is a *Konzentrat-Lagerstätten* – was discovered in this way (see *AAOD #4 – Buried Treasures from the Age of Fishes*). So, too, was Koonwarra.

In 1961 the Victorian Country Roads Board gave the green light on a proposal to straighten and widen a section of the South Gippsland Highway, a few kilometres east of the hamlet of Koonwarra. During this work, road gang workers discovered fossil fish. Jim Bowler, then at the Geology Department of the University of Melbourne, read about the discovery in the *Leongatha Star*. Prompted largely by his enthusiasm to follow up on this report, a team from the university visited Koonwarra in January 1962. With blasting assistance from the Country Roads Board, they were able to collect numerous fossils. Additional collections at the site were made in the early 1960s by the National Museum of Victoria and the Geological Survey of Victoria.

The discovery of the Koonwarra site, and the wide diversity, abundance and quality of preservation of its fossil content, entered the scientific literature in 1962. That year Elizabeth Carroll, a research student at the University of Melbourne, described two fossil insects from Koonwarra: one as a bee, and the other as a stonefly (the "bee" has since been reinterpreted as a leafhopper). The following year Jack Douglas from the Department of Mines published a report of a fossil fructification (from a flowering plant) from Koonwarra – a significant discovery as no fossils of flowering plants had previously been found in the Victorian Cretaceous. Then, two years later, John Talent, a palaeontologist based at the Geological Survey of Victoria, described beautifully preserved clam shrimps, further highlighting the site's potential. These initial reports were, however, merely a taste of things to come.

Crossing the road

In 1965 an Englishman named Michael Waldman successfully applied for a Monash University graduate scholarship. He and his wife Hazel boarded a ship and emigrated to Australia as assisted migrants (so-called "Ten Pound Poms"). Initially, Waldman had wanted to work on Australian dinosaurs. However, a trip to the Queensland Museum scuppered those dreams. He found that before 1965 very few dinosaurs had been found in Australia, fewer still had been described, only five had been named, and three of those had been based on isolated opalised bones. However, it is interesting to note that the specimens that ultimately became the holotypes of *Muttaburrasaurus* (see *AAOD #4 – The Muttaburra lizard*) and *Minmi* (see *AAOD #8 – Minmi: armoured car of the Cretaceous*) were collected in 1963 and 1964 respectively. In addition, a sauropod was collected from near Winton in 1964. Who knows what might have been, had Waldman arrived in Australia a few years later?

When Waldman returned to Monash his supervisor Jim Warren suggested that he take a look at the fish specimens that had been collected from Koonwarra, many of which were then housed at the University of Melbourne. Although these fish fossils were numerous and beautifully preserved, they had received no real attention since they were collected in 1962. When Waldman decided to work on them for his PhD all of the fossil fish were transferred from the University of Melbourne to the Department of Zoology and Comparative Physiology at Monash.

From 1966 to 1968 Michael Waldman, Jim Warren and a team of students from Monash University excavated the Koonwarra Fossil Bed on the southern side of the South Gippsland Highway. *Photo James Warren, 1967*

Throughout the course of his studies Waldman led several expeditions to Koonwarra, often accompanied by zoology undergraduates from Monash. Prior to 1966 all excavation efforts had been concentrated on the northern side of the South Gippsland Highway. However, access to the fossil-bearing layer on this side of the road was limited for three reasons: its proximity to the rather busy highway, its abrupt termination at an adjacent steep-sided railway cutting, and its thickness (~8 metres). Consequently, Waldman and Warren sought – and were granted – permission from the Country Roads Board to dig on the southern side of the road, above and into the road cutting. Warren also asked the property owner whose land was immediately adjacent to the cut if it would be possible to extend the site on to his turf. This request was also granted.

In early 1966 an area of 600m^2 at Koonwarra was stripped of overburden using a bulldozer. Once the fossil-bearing layer was identified the overlying rock was removed and excavation proceeded to a depth of approximately two metres. Under Waldman's supervision, this process was repeated in 1967 and 1968. In total, Warren, Waldman and students from Monash University removed 14–16m^3 of rock from the fossil-bearing layer. However, when it came to actually reducing the rock without damaging the fossils, they encountered problems. At Warren's suggestion, Waldman spread the rocks out on the flat roof of the Zoology/Comparative Physiology building at Monash and allowed them to weather before splitting them. As a result, he and his team were able to reveal beautifully preserved fossils in large numbers and with little damage. However, the idea of allowing the Koonwarra rocks to weather before splitting them was not the brainchild of Warren, Waldman or any other palaeontologist: it was thought up by a Gippsland local.

Enthusiastic amateurs

In the same way that straightening roads seems to go hand in hand with finding exceptional fossil sites in Australia, the efforts of interested amateurs seem to be a prerequisite for fully recognising how exceptional those sites are. During the early 1960s Peter Duncan, who was a senior accountant with the State Electricity Commission (SEC), a resident of Morwell (a small town about an hour's drive from Koonwarra) and a keen geological hobbyist, visited Koonwarra in the company of John Talent. Duncan became so fascinated with the Koonwarra site that his contributions to the collecting efforts there remain unparalleled.

Eodinotoperla duncanae

***This fossil stonefly nymph, now assigned to** Eodinotoperla duncanae, **was one of the first two insects described from Koonwarra by Elizabeth Carroll in 1962 — only one year after the site was discovered. More than a dozen specimens of** Eodinotoperla **are now known**.*

Photo Stephen Poropat courtesy of Museums Victoria

Cyzicus banchocarus

***Fossil clam shrimps** (conchostracans **or** spinicaudatans) **proved to be quite common at Koonwarra. This specimen is the holotype of** Cyzicus banchocarus, **described by John Talent in 1965**.*

Photo Stephen Poropat courtesy of Museums Victoria

Koonwarra feather

This beautifully-preserved feather, found by Peter Duncan, was the first of ten to be discovered at Koonwarra. Although thought to pertain to a bird when it was described in 1966, it is possible that it was once part of the plumage of a non-avian dinosaur rather than a true bird.

Photo Stephen Poropat courtesy of Museums Victoria

Unweathered fossil-bearing rocks from the Koonwarra site tend to break irregularly across bedding planes. Unfortunately, this often results in fossils being incompletely exposed or, worse, fractured or shattered. Duncan stumbled upon the solution to this problem when he decided to split some rocks that had been exposed to weathering. When he did so he found that they split regularly along the bedding planes – where the fossils occurred! Armed with this knowledge, Duncan took to this task with relish. As his fascination grew, he filled his backyard with empty cable spools from the SEC and spread rocks from Koonwarra out on the flat sides. He believed that one shower of rain was all that was required to facilitate the splitting.

As John Talent recalls: *[Peter Duncan] would regularly take his car and trailer to Koonwarra, fill it with blocks from the productive interval [of the Koonwarra Fossil Bed] and split them during his lunch hours, after work and on weekends. He would leave all 'unproductive' claystones from his splitting to weather in his backyard. The weathering took place very quickly. He would then further reduce the material until the fragments were the size of a fingernail. Most of Peter Duncan's backyard eventually became covered with a substantial layer of the comminuted material. This process went on for years, even after he retired to live at Whittlesea.*

By employing this method, Duncan found thousands of invertebrate fossils. Sometime later Peter Handby, another SEC employee, followed Peter Duncan's lead. In next to no time the efforts of both Peters reaped rewards – although their most exciting discoveries were not invertebrates!

Feathers and fleas

In 1966 some of the most significant fossils found in the Koonwarra Fossil Bed were announced in the Journal of the Royal Australasian Ornithologists Union – simply known as *The Emu*. Although some might wonder why a paper on fossils from Koonwarra would be published in an ornithological journal, the answer is simple: the fossils in question were two feathers. One had been found by Peter Duncan and the other by Peter Handby, and John Talent (who lead-authored the paper) included his two friends as co-authors in recognition of their discoveries.

When the Koonwarra feathers were described the only older feathers in the fossil record belonged to the famous *Archaeopteryx* ("ancient wing") from the Late Jurassic of Germany. Amazingly, at the time only three other bird fossils were known from the entire Early Cretaceous worldwide! It is hard to imagine how other palaeontologists received the news back then, since we are now so spoilt by the relative richness of the fossil record of Cretaceous birds.

It should also be borne in mind that, in the mid-1960s, no non-avian dinosaurs had ever been found with feathers preserved – indeed, this would not transpire until 1996. Consequently, it was assumed that birds were the only animals to have ever had feathers and, understandably, the Koonwarra feathers were taken as unequivocal evidence of Victorian Early Cretaceous birds. However, it is now widely acknowledged that some of the Koonwarra feathers might pertain to non-avian theropod dinosaurs rather than true birds.

In the same year that Talent and the two Peters announced their feathers, a third feather was found at Koonwarra by one of the Monash students in Mike Waldman's field crew. Waldman described this feather in 1970 in *The Condor*, the American Ornithological Society's journal.

All of the known feathers from Koonwarra are tucked away in the collections of Melbourne Museum, in a small section of a single drawer. However, they now have more company since an additional seven feathers have been found in rocks from Koonwarra since 1970 – still nowhere near enough to fill a doona, but impressive nonetheless. All of these remain undescribed, although photographs of several have been published in various places (even on a Melbourne Museum postcard!). Despite the fact that the majority are thumbnail-sized or smaller, their preservation is absolutely exquisite: in the best feathers, the vanes either side of the rachis still show their individual barbs, and on each barb can be seen the tiny barbules that connected the adjacent barbs to one another and enabled the surface of the vane to remain smooth. They are beautiful fossils, and if more complete fossils of the animals to which these feathers attached were found, there is no doubt they would be beautiful too.

Other significant fossils from Koonwarra were announced in 1970 in the prestigious journal *Nature*. The man responsible for this paper was Edgar Riek, an entomologist working for CSIRO in the ACT. The fossils Riek studied were insects – amazingly enough, fossil fleas! Although their precise position on the flea family tree remains unclear to this day, there is no doubt that these insects were blood-sucking parasites: they lacked wings, they had long legs and (as noted specifically by later workers) they had piercing and sucking mouthparts.

One particularly surprising thing about one of these fleas – later named *Tarwinia australis* – was its size. At 7mm long, it was a giant compared with most modern fleas, even though it was only half the size of the largest living species. However, Riek determined that this flea was a male, which was noteworthy because, in modern flea species, males are distinctly smaller than the females. One can only wonder how big *Tarwinia* females must have been!

An important question that Riek tried to answer was this: what sort of animal's blood was *Tarwinia* consuming? Based on its anatomy, and on comparisons with modern fleas, Riek suggested that the Koonwarra flea's host must have been warm blooded and sparsely haired. Consequently, Riek suggested that mammals, probably marsupials, were the most likely hosts. This was a bold hypothesis, since no Cretaceous mammal fossils had been found anywhere in Australia at that time: the first reported from Australia, *Steropodon* from Lightning Ridge in NSW, was only announced in 1985, whereas the first from Victoria – *Ausktribosphenos* – was only discovered and described in 1997. All of the Victorian Cretaceous mammals found to date are tiny, and none are marsupials. Was this giant flea sucking on something else? Perhaps. Some palaeontologists have suggested that *Tarwinia* parasitised pterosaurs. Given that these flying reptiles were almost certainly warm blooded, covered in relatively sparse fuzz and definitely present in Victoria during the Cretaceous (based on bones and teeth found at fossil sites along the coast), this idea is plausible – albeit hard to prove.

Horseshoe crabs and fishes

In 1971 another noteworthy fossil was reported from Koonwarra. This was a horseshoe crab, found on 21 March 1962 by Korumburra high school student James McQueen. McQueen's science teacher heard about the fossil discoveries at Koonwarra and encouraged him to develop an interest in the geology of his local area. McQueen did so, and even wrote a school project on the subject. At the time, for various reasons, quite a few excavations were underway in the Korumburra district; consequently, McQueen had

access to several fresh rock exposures, including Koonwarra. McQueen collected some rocks at Koonwarra, took them home and broke them up. In so doing, he found an unusual fossil, which to his eyes looked like a trilobite. McQueen showed his find to his teacher, who in turn showed it to botanist Leon Costermans (who knew McQueen from his time as a teacher in Korumburra). Crucially, Costermans immediately recognised the significance of McQueen's "trilobite" and showed it Edmund Gill, then deputy director at the National Museum of Victoria. Gill excitedly, and correctly, identified McQueen's find as a horseshoe crab and asked McQueen (via Costermans) if he could hold on to the specimen for study. He also noticed that the tail piece was missing, and wondered if it could be found. Unfortunately, by this time, the Country Roads Board had become fed up with prospectors at Koonwarra filling their drains with debris and were doing their level best to deny access. Nevertheless, McQueen convinced his father to take a trailer to Koonwarra in the dead of night to collect rocks from the spot where he'd made his find! Unfortunately, their search proved fruitless, but the specimen was worthy of study regardless. McQueen donated the specimen to the museum, and Edmund Gill teamed up with Edgar Riek to describe it. As a show of gratitude for McQueen's generosity, Riek and Gill named the horseshoe crab *Victalimulus mcqueeni*. Later in life McQueen joined the Royal Australian Navy, but evidently maintained an interest in ancient relics. In the 1970s he discovered two mortars and pestles in sand dunes on the Wessel Islands, Northern Territory – now thought to be Macassan (native Indonesian) artefacts that pre-date European settlement. Tragically, McQueen was lost at sea in 1986; his body was never recovered.

James McQueen's discovery of a horseshoe crab at Koonwarra was significant for several reasons. First of all, the fossil record of horseshoe crabs is quite poor worldwide, so any discoveries are noteworthy. Furthermore, horseshoe crabs no longer live in Australia, despite surviving elsewhere in the world. *Victalimulus* was – and is – the youngest horseshoe crab ever found in Australia, demonstrating that this group lived here as recently as the Early Cretaceous (and perhaps persisted for some time after). Finally, all modern-day horseshoe crabs are marine, yet *Victalimulus* was found in a freshwater setting. Riek and Gill suggested that it was a mature adult that had migrated upstream to breed, as some modern horseshoe crabs are known to do, but never made it back to the sea. However, in 1984 John Pickett suggested that the inverse might in fact be true – that *Victalimulus* lived in freshwater but bred in the sea – based on the discovery of a Triassic-aged horseshoe crab (*Dubbolimulus*) near Dubbo, NSW, which clearly lived some distance from the sea.

1971 was not just the year of the horseshoe crab for Koonwarra. It was also the year of the fish.

After completing his PhD in 1968 Mike Waldman moved to Canada where he took up a National Research Council of Canada Post-Doctoral Fellowship at the National Museum of Natural Sciences in Ottawa. He largely worked on Canadian dinosaurs for the following two years before moving back to England, and in 1971 he discovered the first Jurassic mammal ever found in Scotland. Throughout, however, he was also readying his PhD thesis for publication. In 1971 Waldman's research on the fossil fish from Koonwarra was published in *Special Papers in Palaeontology* – an apt avenue for a paper on such a special site. Waldman reported five different types of fish in the fauna, and also discussed other aspects of the site.

The most abundant fish at Koonwarra was also the most "modern-looking" – it would not seem out of place in a modern aquarium. Waldman originally described this fish as *Leptolepis koonwarri*, but it was later transferred by Argentine palaeontologists Emilia Sferco, Adriana López-Arbarello and Ana María Báez into its own genus, *Waldmanichthys* – Waldman most definitely did not name it after himself! Based on the sheer number of specimens preserved at Koonwarra, these fish were evidently very successful, or at least more prone to being fossilised than the other species. The largest *Waldmanichthys* at Koonwarra reached a mere 15cm in length – if they were still around today, any self-respecting fisherman would throw them back.

The next most abundant fish at Koonwarra was *Wadeichthys oxyops*. It was named after prominent Australian palaeontologist Reverend Robert Thompson Wade who worked extensively on fossil fish from NSW, including those from the famous Talbragar site (see *AAOD #5 – The Talbragar Fish Beds Uncovered*). *Wadeichthys* was even smaller than *Waldmanichthys*, with the largest specimens only around 12cm long, and was completely covered in diamond-shaped scales.

An uncommon fish at Koonwarra was *'Coccolepis' woodwardi*, named after British palaeontologist Arthur Smith Woodward. However, although it was rare, *'Coccolepis'* evidently made up for its scarcity with its ferocity. This 22cm long, sleek-bodied fish was a large-eyed, wide-mouthed, sharp-toothed nightmare. It was clearly a predator, and no doubt would have been a threat to the *Waldmanichthys* and *Wadeichthys* with which it shared its habitat. If you caught a *'Coccolepis'* today you'd probably want to keep it at arm's length in order to stay away from its gnashing maw.

The second-rarest fish in the Koonwarra fauna – represented by only four specimens in 1971 – is one of the most enigmatic, and also the largest (of the bony fish, at least). *Koonwarria manifrons* (no prizes for guessing the inspiration for the genus name) was up to 30cm long, with a deep body and relatively small fins. The relationships of this fish with others from around the world remain unclear to this day, although Waldman thought it was probably most closely related to *Leptolepis* (=*Waldmanichthys*) among the Koonwarra fishes. Waldman also suspected that *Koonwarria*, *Wadeichthys* and *Waldmanichthys* all fed on plankton and/or invertebrates.

The rarest fish at Koonwarra, known only from a single incomplete specimen found high in the sequence, was a lungfish. Tooth plates and scales of lungfish had been found in Victorian Cretaceous rocks as early as 1903; however, they could not be compared against Waldman's fragmentary specimen, since its tooth plates were not preserved, and its scales, though present, were very poorly preserved. This was not, however, the fault of the lungfish! When Waldman collected the lungfish in the field he noticed that it had been smashed by either illegal fossil hunters or curious tourists who were presumably seeking perfect little fish specimens and evidently didn't realise its significance. Waldman and Warren placed the fragments of the lungfish into a sand tray and left it on a table in a heavily-used corridor of the Zoology department at Monash. Next to the tray they left a note, inviting people to try to fit a piece or two of the puzzle as they passed. Surprisingly, this was a huge success! Despite its imperfect and incomplete preservation, this fossil at least demonstrated that lungfish lived at Koonwarra, and implied that they achieved larger sizes than even the largest bony fish in the fauna.

Victalimulus mcqueeni

Victalimulus mcqueeni — ***named after its discoverer, James McQueen, a Korumburra high school student — is the only known horseshoe crab from Koonwarra, and the youngest known from Australia. Although these arthropods are still with us today, they no longer inhabit Australian waters.***

Photo Frank Holmes © Melbourne Museum

Wadeichthys oxyops

Wadeichthys oxyops, ***the type specimen of which is shown here, is the second most abundant fish — and the smallest of the five named taxa — found at Koonwarra. Its body is covered in diamond-shaped scales.***

Photo Stephen Poropat courtesy of Museums Victoria

'Coccolepis' woodwardi

'Coccolepis' woodwardi, ***named after famous British palaeontologist Arthur Smith Woodward, was clearly a predator. Its jaws were lined with sharp teeth, and its body shape shows that it was built for speed.***

Photo Stephen Poropat courtesy of Museums Victoria

Koonwarria manifrons

The largest and least common of the ray-finned fish in the Koonwarria Fossil Bed is *Koonwarria manifrons*, ***the type specimen of which is shown here.***

Photo Stephen Poropat courtesy of Museums Victoria

Ceratodus sp. ***axial skeleton***

The only evidence of a lungfish from Koonwarra comes in the form of this fragmentary tail. This specimen, discovered by Mike Waldman, was presumably more complete before being disturbed by amateur fossil hunters.

Photo Stephen Poropat courtesy of Museums Victoria

Duncanovelia extensa

The true bug *Duncanovelia extensa* ***was named after Peter Duncan's son, also named Peter. Fossil insects from Koonwarra were also named for Duncan's wife Ilma, and their other two children, Robyn and Suzi. The whole Duncan family supported their father's collecting efforts over several years.***

Photo © Melbourne Museum

Before saying "so long, and thanks for all the fish" Waldman made a concerted effort to work out how and why the fish at Koonwarra came to be fossilised in the first place. Based on Edgar Riek's unpublished assessments of the invertebrate fauna, Waldman noticed that some of the insect groups represented at Koonwarra are today found in calm waterbodies in cool climate regions. He also noted that many of the invertebrate specimens were aquatic larval forms. These two observations suggested that the Koonwarra sediments were laid down in a low energy environment – maybe a pond or a lake – in a cool-climate setting.

Waldman noted that the plants, as studied by Jack Douglas, were consistent with this sort of palaeo-environmental setting. Consequently, he envisaged that the Koonwarra rocks had been deposited in a shallow lake, adjacent to and periodically separated from a larger lake by an oft-submerged sandbar. This lake was surrounded by ferns, ginkgoes and conifers, portions of which would have periodically fallen into the lake and been buried, ultimately becoming fossilised.

Waldman also noticed that the rocks at the Koonwarra site were variable, but seemingly rhythmically so. They alternated between slightly coarser sediments and slightly finer ones, and Waldman inferred that each coarse-fine couplet represented a year, implying distinct seasonality at Koonwarra. This seasonality would have resulted in fluctuations in water flow. When the water flow rate was high, more sediment was brought in; when the water flow rate was low, the sediment in the water column would have settled out of suspension.

The excellent preservation of the fish and invertebrates, the small size of the fish and their lack of gut contents, the near absence of predation or advanced decomposition among the fish, and the lack of trace fossils from burrowing organisms or root casts from plants in the surrounding sediments, implied that the Koonwarra lake setting was still, shallow and lacked oxygen in its lower level. Furthermore, the distribution of the fish within the sequence implied that the events that killed them *en masse* occurred regularly and frequently.

After considering and rejecting multiple different scenarios Waldman suggested that the little lake preserved at Koonwarra periodically became shallow and isolated from the main part of the lake, and that this allowed it to freeze over in winter, resulting in fish dying in huge numbers. Although this idea of "winterkills" has met with some criticism since its proposal, it remains one possible explanation for the repeated mass-mortality of fish at Koonwarra.

Waldman's interpretation of the environmental setting of the Koonwarra site was presented to the public in a 1970 ABC documentary entitled *Digging up Ancestors*. With Waldman having already left Australia for Canada it was up to Jim Warren to showcase the most significant finds from the Koonwarra site, and to present the hypothesis of fish "winterkills".

Renewed interest

After an almost-decade-long lull during which very little on Koonwarra was published, interest in the site was renewed in 1981. In February that year the first excavation at Koonwarra since the 1960s was spearheaded by a University of Melbourne team. Its express purpose was to amass a collection of fossil plants for a master's student, Andrew Drinnan, working under the supervision of the renowned botanist Carrick Chambers. Permission to dig was sought and obtained from the Country Roads Board, and a contractor with a bulldozer was hired to expose the fossil bed. Jack Douglas, Tom Rich, Tim Flannery, Alex Ritchie and dozens of others took part on this trip as well, which led to the recovery of thousands of fossils. This collection provided more than enough material for Drinnan's thesis, which he submitted in September 1982, and also led to the discovery of fish types never seen at the site before; these remain undescribed.

At some point during 1982 or early 1983 interest in the Koonwarra invertebrates was also renewed. However, the circumstances surrounding this were somewhat unusual.

Peter Jell had been appointed Curator of Invertebrate Palaeontology at the National Museum of Victoria in 1978. Within the first few years of his tenure one part of his job had been to accession specimens from Koonwarra that had been held at Monash University into the museum collections. This was because Jim Warren had been given orders by Monash to remove all of Mike Waldman's specimens from the basement tunnels, and the best place for them was the museum. Apart from a day trip to Koonwarra in February 1981, while the University of Melbourne's dig was in progress, the registration of former Monash specimens into the museum collections had been the extent of Jell's involvement with the site. However, that changed in 1982 or early 1983 and it all started with a letter from John Talent.

Talent informed Jell that while he had been in London he had visited the Natural History Museum. There he had found out that Peter Duncan, who had retired in 1982, had embarked on a three-month-long round-the-world trip with his wife Ilma. On his travels Duncan had met with numerous leading palaeo-entomologists (palaeontologists specialising in insects) and had shown them specimens from his collections at Koonwarra. He was hoping to entice one of them to conduct research on the Koonwarra insects, since Edgar Riek's work on the insects – which had started back in the 1960s – had stalled. Riek had made allusions to various specimens from Koonwarra in a 1970 book, and made notes and sketches on many others. However, in 1971 he and his wife had purchased a patch of land on the edge of Lake George and he had started planting grape vines with such success that he became one of the pioneers of the Canberra wine industry. Thereafter, Riek's viticultural ventures and his study of Permian and Triassic insects from South Africa took up much of his time, and he published no further papers on Koonwarra.

John Talent had learned that one of the palaeo-entomologists whom Peter Duncan had met was Paul Whalley from the Natural History Museum. Whalley had agreed to formally describe the Koonwarra insects in a scientific publication, but only on one condition: Duncan would have to deposit his entire Koonwarra fossil collection in the Natural History Museum in London! Understandably, this proposition appalled John Talent – and it was this that prompted him to write that letter to Peter Jell, beseeching him to do whatever it took to get Peter Duncan to donate his collection of Koonwarra fossils to the National Museum of Victoria.

Jell agreed that the notion of having Duncan's collection half a world away was unacceptable. Consequently, he visited Duncan on his farm, north of Whittlesea, and discussed the situation with him. Duncan confirmed that it was a combination of his frustration with Riek's lack of progress on the Koonwarra insects, and his fervent desire to see the Koonwarra insects published, regardless of where the specimens ended up, that had prompted him to seek the assistance

of foreign palaeo-entomologists. Jell and Talent's top priority was keeping the specimens in Australia so, on that first visit, Jell proposed to conduct the research on Duncan's insects. Jell was not an insect specialist – he had undertaken studies in entomology at university, and worked on fossil arthropods (trilobites) – and he knew that he would need assistance from entomologists if he was to undertake such a mammoth project. He also stressed that the whole project would have to be done with the co-operation of Edgar Riek. Thankfully, Duncan agreed to Jell's proposition. He decided to donate his entire collection of Koonwarra insects and other invertebrates to the National Museum of Victoria. We should all be relieved that this transpired – had these fossils been shipped overseas, Australia would have lost a wondrous and irreplaceable palaeontological resource.

Duncan contacted Riek and invited him to his farm for a weekend so that they could work out how the project would proceed. Jell joined them on the Saturday afternoon, and as he recalls: *Edgar had with him all his notes, some greatly enlarged photographs and a range of pertinent literature (mainly photocopies). He was very humbly apologetic to Peter and conceded that he had spent most of the 1970s working on Permian and Triassic insects from South Africa…and he also acknowledged that he had devoted a lot of time to his vineyard, which had cut his productivity considerably. He made it clear he had baulked at the Cretaceous fauna because of his unfamiliarity with insects of that age and, as he saw it, their similarity with Recent faunas. So, he was happy that I was going to take up the task... Before we parted that day he passed over all his notes…and the specimens from Peter's collection upon which he had been working. Peter also passed to me several large cartons full of small boxes with fossils in cotton wool – several thousand specimens, though largely duplicates of larval forms.*

In order to undertake this work, Jell visited CSIRO in Canberra several times to discuss the Koonwarra insects with the entomologists based there. He also sought advice and information from entomology staff at the National Museum of Victoria, particularly Arturs Neboiss. When the paper describing Duncan's Koonwarra insects was finally nearing completion Jell sent it to Riek for comment. Riek's suggestions for changes were few, and he informed Jell that, in his mind, the paper *"…was ready for publication and should be published to let the world know what was there."*

Jell knew Carrick Chambers through the Royal Society of Victoria, and was also aware of Andrew Drinnan's as-yet-unpublished study on the Koonwarra plant fossils. Jell suggested to Chambers that they try to get Drinnan's plant paper, and his own invertebrate paper, published together. Chambers was delighted with the suggestion. He encouraged Mary Dettmann (via Jack Douglas) to write a paper on the spores and pollen from a core drilled near the site in order to round out the coverage of Koonwarra's fossil content, and even obtained financial support for the publication through the University of Melbourne.

The end result of this arrangement was a 1986 volume of the *Memoirs of the Association of Australasian Palaeontologists*, entirely focused on fossils from Koonwarra. With this publication, the palaeontological world had to sit up and take notice: Koonwarra was an exceptional site, easily worthy of *Konservat-Lagerstätte* status.

The most abundant fossils preserved at Koonwarra were plants. Drinnan and Chambers' report detailed a diverse flora, with liverworts, mosses, clubmosses and horsetails all present, and ferns, cycads and ginkgoes all common. Conifers were well represented, with araucarians, podocarps and cheirolepidaceans all recorded. Although Drinnan and Chambers didn't identify any angiosperm macrofossils (and questioned the 1963 interpretation by Douglas of angiosperm "nuts"), Dettmann did identify pollen possibly from flowering plants, indicating that they might have been there.

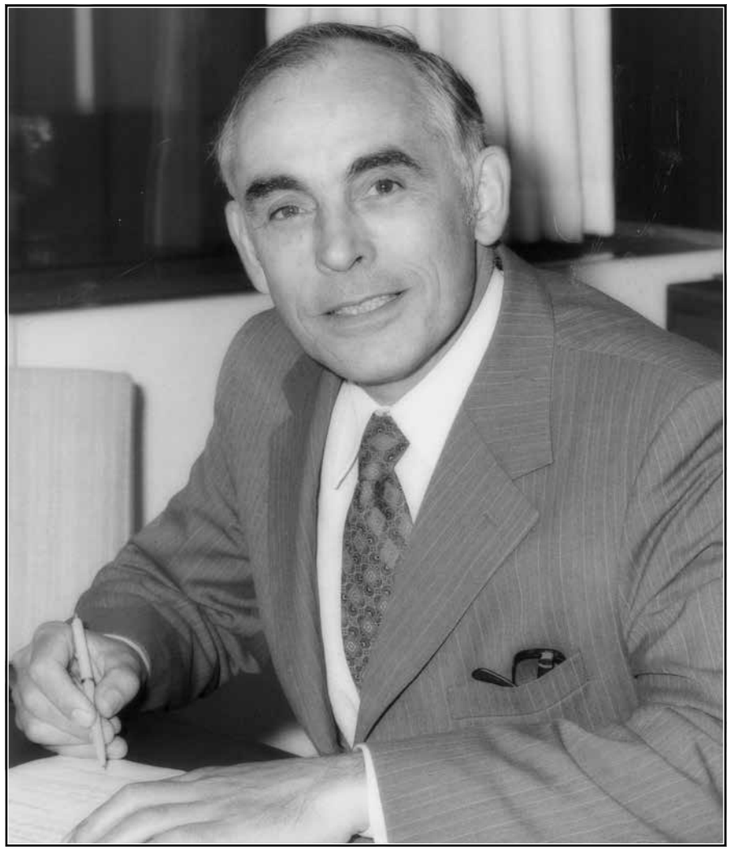
In fact, not long after Drinnan and Chambers' paper was published, a flowering plant was identified from Koonwarra! In 1990 David Taylor and Leo Hickey, both based at Yale University, worked out that one plant, described as a fern by Drinnan and Chambers, was in fact a flower attached to a stem. At the time of the announcement of their discovery this was the oldest flower in the world. Although older fossil flowers have since been found elsewhere, this beautiful fossil still emphatically demonstrates that the flora at Koonwarra was beginning to take on a somewhat modern look, despite the fact that it was living ~120 million years ago.

It would be hard to question the notion that Koonwarra's diverse fossil invertebrate fauna is what has truly earned it the title of *Konservat-Lagerstätte*. The palaeontological community as a whole owes Peter Duncan a debt of gratitude for that – he was responsible for discovering the overwhelming majority of the invertebrate specimens that he and Peter Jell described (with several other important specimens discovered by graptolite specialist Fons VandenBerg). More than 70 different species of insect were identified in the Koonwarra fauna, pertaining to thirteen separate orders. Jell and Duncan also reported fossil spiders, crustaceans (water fleas, fairy shrimp, a syncaridan and an ostracod) and a bivalve. Koonwarra was notable among Australian fossil insect faunas as the oldest to be dominated by aquatic and immature forms – most others were dominated by terrestrial forms represented by isolated adult wings or parts thereof. It was also notable because, like the Koonwarra flora, the invertebrate fauna had a decidedly "modern" look – many species living in southeast Victoria approximately 120 million years ago were virtually indistinguishable from living forms.

One particularly noteworthy fossil described by Jell and Duncan was the syncaridan crustacean *Koonaspides indistinctus*. Although syncaridans still live in Tasmania today, the modern forms were separated from the youngest Australian fossil forms (from the Triassic of NSW) by more than 200 million years – until the discovery of *Koonaspides*, that is! Its discovery in ~120-million-year-old rocks effectively halved the gap in the Australian syncaridan fossil record, and implied that they had continuously inhabited southeast Australia from the Triassic right up until the present.

The arachnids from Koonwarra described by Jell and Duncan were also noteworthy, since the fossil record of spiders in Australia otherwise constitutes just three specimens: one from the Triassic of Queensland (*Edwa maryae*), one from the Jurassic of NSW (*Talbragaraneus jurassicus*) and one from the Neogene of Victoria (*Ariadna resinae*). In addition, one of the Koonwarra arachnids is the only known fossil harvestman of any age from the whole Australian continent.

Another important aspect of Jell and Duncan's work was the reassessment of the palaeo-environment of the Koonwarra site. As mentioned above, Waldman had interpreted the site as a small portion of a larger lake, in a cool climate setting, which periodically froze over resulting in "winterkills" of fish and invertebrates alike. Strong opposition to this interpretation had been voiced in 1982 by Jack Douglas and George Williams. These



Following a visit to Koonwarra in the early 1960s, accountant and amateur geologist, Peter Duncan discovered a lifelong interest in fossils.

Loading blocks of material into the back of his car, Duncan became proficient at splitting rocks after a period of weathering. Over time, this technique enabled him to amass a collection of thousands of fossils, later donated to the National Museum of Victoria.

Photo courtesy of Suzi Duncan

men suggested that the presence of a lungfish at Koonwarra was evidence against freezing temperatures, given that modern forms tend to live in waters with temperatures of 10°–30°C, and that they are partially reliant on air-breathing, which would be impossible in a frozen-over lake. They scrutinised the coarse-fine couplets of sandstone and siltstone and suggested that they did not represent periodic over-freezing events, instead citing the abundance of transported plant debris and the fact that the rocks became more clay rich towards the top of the sequence as evidence for a flood-prone lake or pond setting. Contraction of this waterbody during dry seasons or instant burial by floodwaters could just as easily be invoked to explain the repeated mass fish kills.

Jell and Duncan built on the arguments put forward by Douglas and Williams with observations derived from the invertebrate fauna. They agreed with Waldman that the Koonwarra lake had only been a small part of a much larger lake, the two were not always interconnected, the water was generally still, and that the mass-mortality events affecting the fish fauna occurred periodically. However, they contended that the preservation of clearly terrestrial insects in the sediments was hard to explain if freezing over of the lake was invoked. Insects such as adult fleas, dragonflies, cockroaches, wasps and large beetles would need to have been buoyed up in the water column somehow to escape being incorporated into the ice and then somehow reach the bottom of the lake without disturbance. Jell and Duncan (and Drinnan and Chambers) noted that the insects and plants tended to predominate in the lower, finer beds near the base of the fossil layer, whereas the fish tended to be more common in the coarser beds higher up in the sequence. This suggested that the events that killed the fish were not necessarily the same as those that devastated the invertebrates, and vice versa.

Finally, Jell and Duncan noted that ostracods were extremely rare at Koonwarra – only a single valve of one of these tiny crustaceans had been found. This is unusual: in both modern and ancient lake settings, ostracods are abundant and, given that the valves of their shells sink, their scarcity was not easy to explain. Jell and Duncan suggested that this reflected near-permanent separation of the Koonwarra pond from the main lake, with only infrequent strong winds periodically carrying floating debris (ie future fossils, including the odd ostracod valve) from the main lake into the shallow backwater that ultimately formed the Koonwarra Fossil Bed.

Needless to say, Peter Duncan was delighted with the outcome of the whole project. He was particularly chuffed to be included by Jell as joint author on the invertebrate paper, a deserved hat tip to his collecting efforts. Jell and his family became good friends with Duncan and his wife Ilma, and he and his wife regularly visited the Duncans when they went on weekend fossil echinoderm collecting trips near Whittlesea. Although Jell moved to Queensland in 1985, and was only irregularly in touch with Duncan thereafter, Duncan continued to weather and split material that he had collected from Koonwarra. On a trip to Victoria in the 1990s Jell visited Duncan and was shown all of his new finds. They agreed that another paper would have to be written once all of the material

in the shed had been split, but this never eventuated.

Peter Duncan passed away on 19 February 2014. At Duncan's daughter Suzi's request, Jell provided recognition of Duncan's contribution to the Koonwarra collection effort for her father's eulogy. Prior to his passing Suzi Duncan had suggested to her father that they donate the remaining Koonwarra rock to the National Museum of Victoria and he agreed that this was the best course of action. Although Suzi Duncan had put the idea to Peter Jell before her father's passing, it was not until after the funeral that Jell was able to assist in clearing out the remainder of the Koonwarra material that filled Peter Duncan's study. Jell travelled to Whittlesea, packed up the remnants of Duncan's collection and took it to the museum. Of particular note was that Duncan had kept half of the first fossil feather that he had found; on his return to the museum Jell was able to reunite it with its counterpart! The entirety of Peter Duncan's Koonwarra collection is now deposited in Melbourne Museum, and we should all be grateful to Peter Duncan and Peter Jell – and John Talent's catalytic letter – that these wondrous fossils never left Australia.

Since the publication of Jell and Duncan's report some elements of the Koonwarra invertebrate fauna have been revised. This is not surprising, especially given that Jell and Duncan openly stated that their *"…intention in this paper [was] to illustrate the Koonwarra fossil insects accompanied by such taxonomy and other pertinent intelligence as our meagre ability in palaeo-entomology would allow…"*

The fact that this work was accomplished at all, drawing on the expertise of so many entomologists and palaeo-entomologists, is remarkable.

Some of the more noteworthy revisions to Jell and Duncan's work have been the questioning of their tentative interpretation of *Cretacoformica explicata* as an ant, the reassessment of the water fleas by two groups of researchers and the revisions of the fleas, scorpion flies and bugs. Regardless, Jell and Duncan's work remains the first port of call for anyone wanting to know about the Koonwarra invertebrate fauna.

Work on the Koonwarra invertebrates has continued in recent years. For example, in 2016 Sarah Martin (Geological Survey of Western Australia) and colleagues described the first aphid from Koonwarra as *Koonwarraphis rotundafrons*. The giant flea *Tarwinia* has been reassessed numerous times, most recently by Chinese palaeontologist Huang Diying. He considered *Tarwinia* to be a true flea (in the new family Tarwiniidae) and raised the possibility that it parasitised feathered dinosaurs or even true birds.

There is no doubt that future collections at Koonwarra will turn up more and better specimens of some or all of the groups we know so far. We can only hope that representatives of previously unrecognised groups of plants, invertebrates and vertebrates will also be discovered.

Unrecognised potential?

Between 1981 and 2013 no further excavating was done at Koonwarra. The discovery of dinosaur bones near Eagles Nest by Tim Flannery, John Long and Rob Glenie caused Tom Rich and his team to turn their attention towards the Victorian coast. This was in large part because Rich was looking for Cretaceous mammals, his wife Patricia was looking for Cretaceous birds, and Koonwarra – sadly – was not producing them.

Although Rich's team eventually found fossil mammals at three separate localities along the Victorian coast, most of the specimens were lower jaws with teeth. From these bones alone, Rich could only work out so much about Victoria's Cretaceous mammals – more complete specimens were desirable. Unsurprisingly, Rich never forgot about Koonwarra, and he visited the site several times to consider how to proceed there in order to have a chance of finding skeletons of vertebrates other than fish. However, it was not until Rich travelled to China that an idea of how to tap into Koonwarra's potential started to form in the back of his mind.

In June 2009 Rich visited the Sihetun region in Liaoning Province – an area now famous among palaeontologists. The reason for this fame is that the rocks there have produced thousands of fossils, most notably feathered dinosaurs. Of course, Sihetun was not always famous. Fossils were reported from the region as long ago as in the 1920s, but these were bivalves and little attention was paid to them. Between the 1920s and 1990s the only additional fossils reported from Sihetun were fish, plants and invertebrates. This sounds somewhat familiar, doesn't it? Throw in a few feathers, and you have a site that sounds just like Koonwarra.

Sihetun went one better than a few feathers. The 1992 announcement of a tiny bird fossil from the region, dubbed *Sinornis* ("China bird"), triggered a "fossil rush" in the region. From the mid-1990s onwards fossils of breathtaking quality were exhumed in staggering numbers. Among their ranks were feathered dinosaurs (including birds), furred mammals and fuzzy pterosaurs.

While visiting Sihetun Rich pondered why it had taken so long for the region to produce its first fossil bird, and why the rate of discovery had risen asymptotically since. The answer he settled on was simple, and was inspired by his visit to the fossil pits dotted around the region. It was manpower, and nothing more.

In the 1990s farmers in the Sihetun region realised the significance – and value – of the fossils on their land. Consequently, several started to dig for fossils and sell them to palaeontologists and fossil dealers. This enabled them to make more money than they could from farming. As more and more farmers downed one set of tools in favour of another, vast quantities of rocks were extracted and examined, and myriad fossils other than plants, fish and invertebrates were found. Rich wondered: what would happen if Koonwarra was subjected to a similarly intense collection effort?

Rich's notion that a more extensive excavation at Koonwarra might be a game changer was galvanised by his visit to the Sihetun Landscape Fossil Bird National Geopark. As is the case at Lark Quarry *(see AAOD #2 – The Ghosts of Lark Quarry)*, the Sihetun museum building was constructed directly above the fossil-bearing rocks. All of the dinosaur fossils under the roof had been left in place where they were discovered, and display cases had been built around each one. Virtually all other fossils found at the site had been removed, although some fish remained. Rich noticed that all of the dinosaurs preserved on site were complete skeletons – there were no isolated bones. This implied that the carcasses were buried quickly, or decayed very little before burial as a result of a lack of oxygen in the water. Additionally, he noted that these dinosaur fossils – all of which were from rather small forms – were sparsely distributed, with only 31 specimens in an area of 400 square metres.

Knowing this, Rich wondered if the only reason that Koonwarra had not produced any mammal, dinosaur or bird skeletons, despite producing everything else that Sihetun had, was because too little rock had been excavated. The most extensive digs at

Koonwarra flower

This fossil flower from Koonwarra, originally identified as a fern, was described in 1990. At the time, it was the oldest fossil flower known anywhere in the world.

Photo Stephen Poropat courtesy of Museums Victoria

Peraphlebia tetrastichia

This beautifully preserved dragonfly wing, the type specimen of** Peraphlebia tetrastichia, **is one of thousands of spectacular insect fossils found at Koonwarra. However, wings like this are rare; fossil nymphs are much more common.

Photo Stephen Poropat courtesy of Museums Victoria

Koonaspides indistinctus

The only known specimen of** Koonaspides indistinctus **is the sole representative of a group of crustaceans called syncaridans from the Cretaceous of Australia. This fossil effectively halved the gap in time between the modern syncaridans which live in Tasmania, and the only other Australian fossil forms from the Triassic of New South Wales.

Photo Shane Ahyong courtesy of Museums Victoria

A small scale test excavation at Koonwarra was carried out in 2013 to determine whether the site might produce mammal, dinosaur or bird remains if more rock was removed. Although this exercise did not produce any significant discoveries, many plant, insect and fish fossils were recovered. *Photo courtesy of Tom Rich*

Koonwarra had only shifted 14–16m^3 of rock. What if that figure were doubled? Or tripled? Or quintupled?

In April 2013 Tom Rich and Tim Flannery led a small-scale dig at Koonwarra, effectively as a proof of concept – a demonstration that even if dinosaur or mammal skeletons were not found, at least many other amazing fossils would be. Koonwarra did not disappoint, again yielding exquisite fish and plant fossils. Unfortunately, neither mammal nor dinosaur skeletons turned up. This was not surprising: compared with the scale of the excavation that Rich wanted to conduct, this dig was tiny.

Until a large-scale dig is held at Koonwarra this is where the story of this amazing site must end. Despite the fact that the only traces of vertebrates other than fish at Koonwarra are ten tiny feathers, it should now be clear just how phenomenal this site is, and the potential it has to produce amazing fossils long into the future.

The discovery of a single dinosaur, bird, mammal or pterosaur at the Koonwarra *Lagerstätte* would be a palaeontological game changer – just as it proved to be for Sihetun. However, as Tom Rich often says, *"The hardest fossil to find is the first one."* Were he, or someone else, to raise sufficient funds to excavate properly at Koonwarra, then there might just be a chance of finding something spectacular. There is no doubt that future excavations at Koonwarra, just like virtually every dig that has taken place at the site since its discovery in 1961, will benefit greatly from the participation of enthusiastic volunteers like Peter Duncan. At Koonwarra, those volunteers just might find something that will rewrite Australian palaeontology – or at least one aspect thereof!

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The Author

Dr Stephen Poropat is a postdoctoral researcher in palaeontology at Swinburne University of Technology, Melbourne. He has been a research associate at the Australian Age of Dinosaurs Museum since 2011 and has worked extensively on Cretaceous sauropods from the Eromanga Basin. He is passionate about promoting palaeontology to the public.