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The art of finding and discovering fossils: a personal perspective

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Abstract

Palaeontology, the study of fossils, is an enjoyable activity: one that many from the public rarely see in action. For palaeontologists, *finding* a fossil is not the same as *discovering* a fossil. Anyone can find a fossil by being simply the first person to unearth, pick up and recognizing something of interest. A discovery, however, comes when that fossil is compared to other known specimens, described, identified as an existing species, or named as a new one. Only palaeontologists compare, describe and name fossils something they spend a great deal of time doing. Surprisingly, finding fossils is only a small part of palaeontology and is something palaeontologists rarely do. Discovery is the true joy of palaeontology. The authors share their own personal experiences of how they have found and discovered fossils, as well as unveiling how that process works. Readers will be surprised how exhilarating taxonomy really is once you gain a glimpse into the mind of the palaeontologist.

Finding Fossils

Here's a surprise: palaeontologists rarely find fossils. We do try. The palaeontologist has a hawkeye for detail, yet lacks the natural instinct to look down and randomly pick up natural curios. That task is often left to the millions, no, billions of people across the globe who have started their own collections, be it a pile of rocks on the verandah or something found or bought while on holiday and displayed proudly in the trophy cabinet. Sometimes collectors get curious and want a name and story to these natural curios. That's where we the palaeontologists come in. Often a member of the public walks into a university department or natural history museum (or more recently, sends a carefully worded email with photos) and asks for an expert opinion. It is people like us that identify and describe these fossils for them. Without these citizen scientists, many famous fossils and fossils sites would be unknown, and without palaeontologists ground-breaking discoveries would simply sit on someone's shelf collecting dust.

Collecting fossils at new sites is a palaeontologist's dream, and we do plan meticulous expeditions to areas where (according to the geology and palaeoenvironments) fossils *should* occur. Normally, a short reconnaissance trip is necessary, just to make sure that the site will yield new discoveries. Such trips are taken with caution, as expeditions are costly and funders want written guarantees that the sites are fossil-laden with new finds before any funds are transferred. Even the best guesses may lead nowhere: a fossil in the hand is worth more than any palaeontologist's prediction. Finding fossils is simply the first stage of discovering new species. The trilobite or ammonite you've found may actually be a well-known species from which specimens have been collected many times before, or it might be something never professionally described before. In order for it to be *discovered*, you need a palaeontologist who will examine the characteristics, compare the specimen to existing fossils, and, having determined the differences, give it a new name. There is an art to finding and discovering fossils, something that we wish to share with you through our own experiences. Between us, Malte and Patrick, we have discovered and named 6 new genera and 35 new species, but we've only collected a few of them ourselves. How, then, are fossils found?

Fossils are found in many different ways. For instance, Malte worked at a site in western New South Wales containing Devonian (395-million-years-old) shallow marine fauna. The locality was known to a station owner who had found it during the construction of a tank for his livestock. The tank sat directly over the fossil fauna in the Biddaburra Formation, a hodgepodge of rocks, mostly lithic-quartz sandstone interbedded with siltstone, mudstone and fine sandstone. The fossil fauna contains corals, brachiopods (they have hard shells on the upper and lower surfaces), some molluscs and, most excitingly of all, trilobites. Thankfully, the landowner was a former teacher at the local high school and had shown the fossils to a friend of Malte's. That newly found fauna became a Masters project, and later a publication, which included several discoveries of new species of trilobite (Ebach and Edgecombe 1999; Ebach 2002). In fact, there are still more discoveries to be made, as Malte only surveyed part of the site, much of which is buried under metres of alluvial clay. During his research Malte discovered that in the 1960s the New South Wales Geological Survey had visited the very same site and had recorded the same fossils from this formation. These fossils were held in the Survey's collections in Orange, which were later transferred to the Australian Museum, and a typed report with a list of the found fossils was forgotten in a filing cabinet. If the landowner had not rediscovered these fossils, they would have remained unknown to science.

Other discoveries come as the result of dedicated groups of amateur fossil hunters and enthusiasts, for example, "The Fossil Club of Australia." On one of their more recent trips, approximately two years ago, Patrick had the good fortune to be involved in uncovering a plethora of new species of Late Ordovician (450-million-year-old) trilobites. This happened at a highly unlikely place: a garbage tip near the town of Gunningbland (close to Parkes and Forbes) in western New South Wales. The site itself could be described as an eyesore: piles of dull grey-green to yellow boulders skirting an 80-metre-long trench, full of the obligatory old wedding dresses and discarded food scraps. Yet, the innocuous-looking rocks at the site belonged to the extremely old geological unit known as the Gunningbland Formation. This is a series of limestones and shales laid down as deep marine deposits at the foot of a now-extinct underwater volcano. The entire area had been mapped by government geologists in 2001, but they had missed this particular fossil site as it was buried under soil at the time. The site was only discovered later by the Fossil Club members (and other enthusiasts) after the local council excavated a trench. The site contains a diverse list of trilobite species which were already well described from other areas nearby, including *Amphilichas shergoldi*, *Cromus* cf. *optimus*, *Eastonillaenus goonumblaensis*, *Eokosovopeltis currajongensis*, *Erratencrinurus* (*Prophysemataspis*) sp., *Parkesolithus* sp., *Remopleurides* cf. *exallos*, *Sinocybele thomasi* and *Sphaerexochus* sp. However, two of the Fossil Club members recognized several undescribed forms, which they couldn't place taxonomically. On inspection, Patrick and other colleagues recognized that one needed to be placed in a new genus, and another into a new species, both then recorded in Holloway *et al.* (2020). The first, *Prophalaron jonsei*, is a highly unusual trilobite resembling members of a subfamily called the reedocalymeninae. However, it lacked several key characteristics of the group, and instead is likely an excellent example of the phenomenon called "convergent evolution." The second, *Dicranurus webbyi*, was a totally unexpected find as the family (the odontopleurids) to which it belongs was previously unknown from rocks this of this age in Australia. Hence, it was only through careful fieldwork, observations, and comparisons of their fossils that these enthusiasts were able to bring these specimens to specialist attention. Without their assistance, it is highly likely these specimens would have never been found.

Sometimes, palaeontologists also discover fossils themselves, but not necessarily while they are at work. Whilst on a driving holiday in Gunns Plains in northern Tasmania, Malte answered the call of nature only to discover trilobites embedded in a fine muddy layer at the side of the road within the Ordovician Gordon Group. Usually trilobites are preserved in limestones during secondary mineralisation of the rock. Silica solution that moves through the limestone during rock formation binds to the trilobite carapaces, meaning that they become harder than the surrounding limestone. Once immersed in 20% acetic acid, the limestone dissolves, allowing the carapaces to fall out. These siliceous trilobites are beautifully preserved in three dimensions and display characteristics that may not necessarily be found in trilobites encased in mudstone and other clastic rock. However, here in Gunn's Plains the limestone had a muddy layer through it, possibly due to deep underwater landslides known as slumps. No palaeontologist would think of looking in this mudstone layer, simply because it contains no silicious material, and the chances that the rock would contain a rich fossil assemblage are thought to be low. It just so happened at the time that Malte's Masters supervisor Greg Edgecombe was working on similar fossils preserved in mudstone from a location 80 km away in Moles Creek. Regardless, the species were discovered by Edgecombe et al. (1999) and only a specimen was found by Malte. It wasn't until many years later that Patrick looked through the Australian Museum's collection and found the specimen Malte had donated from the site. It appeared to be missing from Edgecombe et al. (1999), as there were no mentions of this species despite it being relatively large and obvious. That single trilobite was the only one Malte ever found, and, thanks to Patrick's examination of the Museum's collection, was then discovered by Malte and Patrick). We named it *Gravicalymene bakeri*, after Tom

Figure 1. *Gravicalymene bakeri*, named after Tom Baker, the fourth Doctor Who (Photo credit: Patrick Smith).

Baker who played the fourth Doctor Who (Smith and Ebach 2020; Figure 1).

Occasionally palaeontologists do find new species lurking in existing collections, often mislabelled or misidentified. The eminent crustacean systematist Shane Ahyong once asked Malte how many mantis shrimp (stomatopod) fossils there were in Australia. There were none known. After some persuasion Malte patiently showed Shane the fossil crustacean collection at the Australian Museum, sifting carefully through each drawer. The last drawer produced a misidentified and mislabeled fossil mantis shrimp collected in 1916 from Brisbane River in Queensland. Yes, indeed, there were mantis shrimp sub-fossils in Australia. It was a subfossil of an already known and living species named *Harpiosquilla harpax*, possibly only 10,000 years old. Australia's first known mantis shrimp sub-fossil, it was reported as a Palaeontological Note in Ahyong and Ebach (1999).

Of course, not all geoscientists are palaeontologists and frequently people working in a different discipline will find fossils without realising their true significance. This is particularly the case for geoscientist looking at geological cores (Figure 2). Since the coring process often takes such a small sample of material from a single bedding plain (generally a resulting in a long cylinder less than the width of a single beer coaster), it's often assumed there won't be any useful fossils found. However, during his PhD studies Patrick found this assumption does not always hold true. Combing through 30-year-old records for the Hermannsburg 41 core, Patrick found a page reporting a layer from the Tempe Formation

Figure 2. Tempe Vale 1 drill core from the Northern Territory containing hundreds of Ordovician trilobites (Photo credit: Patrick Smith).

containing "fine fossil fragments." Piquing his curiosity, as the rocks in this units were relatively unstudied, Patrick visited Geoscience Australia where the core is now stored. Splitting some of these layers revealed over 20 near-complete head and tail shields of a new species of trilobite, named *Gunnia fava*, described in Smith *et al.* (2015, Figure 3). Alongside this trilobite were also brachiopods. These turned out to be species known only from the latest part of the Early Cambrian Period (510-million-year-old), thus enabling a precise date to be given to this geological unit. A precise age for a geological unit is important, as it allows for detailed correlated to be made with other nearby geological formations. Hence, despite these fossil having been "found" 30 years prior, it was only when they were "discovered" that this useful geoscientific information be ascertained. How, then, do palaeontologists "discover" fossils?

Discovering fossils

Once found and collected, fossils are brought back to the Museum or University for preparation. Silicified or phosphatic specimens are steeped in acetic acid for a month or two and monitored weekly. Specimens in clastic rock (composed of fragments of pre-existing minerals and rocks) are prepared by literately cutting them down to a particular size and shape. Often, larger pieces are broken up in the hope that the rock may produce more finds. A diamond-bladed circular saw is used to cut the rocks into the right size and shape in order for it to be stored within a collection. Vibro-tools and Dremel drills are used to clear any rock obscuring the fossil specimen and to remove any protruding rock that might get in the way of photography.

Photographing specimens is important, as it is a visual record of the specimen and its characteristics, namely the parts

Figure 3. An Ordovician aged trilobite pygidium from the Tempe Vale 1 drill core from the Northern Territory (Photo credit: Patrick Smith).

that we use to describe the fossil. In order to get the best contrast, most specimens and the surrounding rock are painted black. These specimens are then coated in either magnesium oxide or ammonium chloride via a process known as sublimation, therefore accentuating the highlights and down-playing the low points (Figures 4 and 5). Some characters that are barely visible under the microscope visually leap out at you once dusted. Siliceous fossils, on the other hand, are perfect in every sense and are sometimes photographed as they are on a black background. Once prepared, the fossils are photographed in black and white to avoid colour giving the false impression of depth. The photographs are assembled into plates and captioned. Photographing and creating plates is a process that has improved greatly since Malte started fossilising. Now the photography and plate assembly are done digitally. No more mucking about with glue, transferable text and darkrooms.

The final plate is the start of the discovery process (Figure 6). Yes, we have *found* fossils that we *suspect* are new. But the real fun, namely the science of discovery, begins once we closely observe and compare the specimens in a process that is off limits to the public and to historians and philosophers of science. Sure, you can sit next to a palaeontologist, or any comparative biologist, and watch them go about their business of observing and comparing, but much of what goes on occurs in the mind's eye of the taxonomist. In other words, what may look to the casual observer of someone sitting there looking down a microscope, is in fact someone having an exhilarating experience, one that is impossible to share with a passive observer.

Figure 4. An example of a fossil specimen that has not been altered in any way. *Prophalaron jonsei* cranidium (head shield) from the Gunningbland Formation. A newly discovered genus initially found by members of the Fossil Club of Australia (Photo credit: Patrick Smith).

Figure 5. An example of a prepared fossil specimen that has been painted black and dusted with magnesium oxide. Near complete *Prophalaron jonsei* from the Gunningbland Formation. A newly discovered genus initially found by members of the Fossil Club of Australia (Photo credit: Patrick Smith).

It would be difficult to describe exactly what goes on when we observe and compare. You too, dear reader, do the same when you observe and compare the natural world or even the world of man-made artefacts. The taxonomist is simply trained to do this at a higher level, to see characteristics that many people have pondered over for centuries. One or two significant characteristics are enough to justify a new species. In other cases, one characteristic is quite sufficient to justify a genus or a family. Let us consider, for a moment, a collector of man-made objects, such as Faberge eggs or watches. In fact look no further than an episode of *Antiques Roadshow* and the sheer excitement that many of the experts exhibit when they are confronted with a rare watch or silver creamer. The expert seems to have all the fun as they carefully point out hallmarks in silver or missing bezels in Rolex watches. Most impressive is when people show up with plain-looking cups and saucers only to be told that these are Meissen porcelain and made in a factory near Dresden hundreds of years ago. What these experts look for are characteristics that are unique to the object and other characteristics that they share with other objects. Simply put, *Antiques Roadshow* is more about classification (discovery) than it is about estimating the value of man-made objects.

Now imagine that same enthusiasm for natural objects, namely for organisms and their parts that many people rarely see. This is the world of taxonomy and comparative biology. In this world we need to make sense of what is out there in the same way that astronomers make sense of the different types of stars and galaxies, or the way quantum physicists make sense of new quantum particles. All accept that there is a natural order and that discovering that order is essential to being able to propose new theories about the universe. For taxonomists, a major goal is to discover whether their taxonomic groups are part of that natural order.

Consider mammals: they are described as vertebrates that have hair and mammary glands. These characteristics are enough to

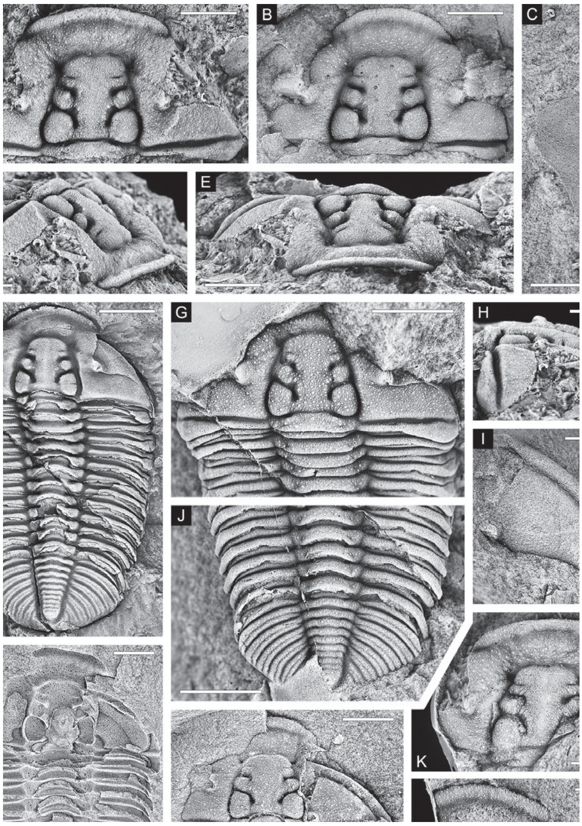

Figure 6. A photographic plate of *Prophalaron jonsei* from the Gunningbland Formation (Photo credit: David Holloway).

classify a mammal. Yet mammals are an easy group to identify. Other groups are harder to identify based on characteristics because they were insufficiently described and named. Consider the fishes. No one characteristic defines the fishes. Reptiles and birds have scales and lay eggs. So do fish. There are many such groups and they exist because someone grouped them based on a name and a written description. These groups are what revisionary taxonomists work on, because they need to be revised (including reptiles and dinosaurs). Describing, identifying and naming new species is only one aspect of taxonomy. Revisionary taxonomy is unfortunately almost entirely left out of many commentaries of taxonomy.

Regardless, let's get back to the matter in hand: discovering new characteristics. Once found, the taxonomist needs to compare a find to other specimens, that is the defining characteristics of other species, and ask "Is this specimen something new or is it part of something known?" Do we have enough evidence to propose that it is a new species? If we do, we create a *Diagnosis*, a concise description of the characteristics that make it new. This is then followed by a *Description* or commentary, which discusses how it differs from other named species from the same genus.

Other data will also need to be recorded, such as the name, the etymology of the name, the age, the geological formation it occurs in, and which specimens are the types and paratypes. Types are essential, as they represent physical manifestations for a given species name. Also important are the specimen numbers, equally essential as they identify the specimens assigned as types and paratypes. If another taxonomist wishes to see the type of any new species, they need to go into the designated museum collection and find the specimen with that number. This all sounds like a lot of work. But believe us when we tell you this is the most fun part of palaeontology. The sheer excitement of finding a new characteristic may seem trivial to a many, but it heralds a landmark in a taxonomist's career — you have discovered something that no one has ever seen or noticed, something that has been hidden away by nature for millions of years — a true scientific discovery! However, many outside the field find the discovery of species not very ground-breaking. Let us compare that to astronomy. There are a finite number of trilobites, many still waiting to be found, either in a rocky outcrop or in a museum collection. Yet, there are seemingly an infinite number or stars and planets, billion upon billions of them, and every time one is discovered it makes it into the news. The odd trilobite makes it into the news, but not fossils such as brachiopods or corals. The reason is quite simple: in order to understand what these fossils are and what characteristics make them unique rarely captures the public's imagination. In stark contrast, in astronomy the discovery of a habitable Earth-like planet 200 light years away would prick up the ears of many a reader.

Naming fossils

Another similarity between astronomy and taxonomy is nomenclature, that is, the rules governing the naming of names. Each group of organisms (plants, animals, bacteria etc.) has its own nomenclatural code. The nomenclatural codes specify that each named organism has a binomial name and is linked to one or more specimens (such as the type and paratype we mentioned above). Nomenclature gets tricky once we discover that two names, proposed by different people at different times, represent the same fossil. This is called a synonymy, and a revision is necessary with the more recent proposed name becoming junior and being replaced by the oldest name. Nomenclature is quite technical, but naming species can be fun.

Astronomers recently named a whole star system, TRAPPIST-1, after Trappist beers (Gillion et al. 2017). Palaentologists have also named species and genera after people both famous and infamous. The trilobite genus *Arcticalymene* contains *A. rotteni*, named after Johnny Rotten, lead singer of the Sex Pistols (Edgecombe and Adrian 1997). The same palaeontologists (Adrain and Edgecombe 1995) named another genus *Aegrotocatellus*, Latin for "sick puppy" (for added effect they included the species *A. jaggeri*, named after Mick Jagger of Rolling Stones fame). The fun taxonomists have discovering and naming species is evidently not the rather dry and verbose technical language of taxonomic treatments. Every now and then you can see the enjoyment in the names, not unlike the medieval scribes who drew scandalous figures in the borders of religious parchments.

Conclusion

Taxonomy is fun, but it is also a lot of work and commitment. What we have described above can take weeks, months and even years to do. Taxonomic revisions take even longer. Learning and understanding species characteristics takes years to learn. An average postgraduate student would need a minimum of four years, that is, the span of their entire PhD, to familiarise themselves with a subgroup of organisms. Four years does not maketh an expert, and it certainly does not mean you have seen all the characteristics known or to be discovered: that would take several lifetimes. There are people out there who have spent a lifetime working on their organisms, and others, such as us, who have recently begun (Patrick) and who continue to do so (Malte).

The art of finding fossils starts with you, and the discovery of new characters with the taxonomist. Without the public finding fossils and making palaeontologists aware of them, there would be a dearth of scientific discovery. What perhaps is less well understood and less talked about is the excitement and joy comparative biology brings to the taxonomist. The thrill of wandering through a collection or the delight of seeing new a structure in a well-known fossil. This is only possible with years of dedication and a passion for discovery. These are just a few of the experiences we have had. There are many more to come.

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