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Author(s): Russell Garwood [*1]
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Life as a palaeontologist: Palaeontology for dummies, Part 1

by Russell Garwood[*1]

pa·lae·on·tol·o·gy / pa·le·on·tol·o·gy noun /ˌpælɪɒnˈtɒlədʒi/ or /ˌpeɪlɪɒnˈtɒlədʒi/ — The scientific study of prehistoric life.

Introduction

Palaeontology. If you're reading this, it is likely that you've already encountered this particular corner of the scientific world, and know what it involves. If not, welcome: I think palaeontology is awesome and I hope that by the end of this article, you will too. Either way, it never hurts to define terms. As the above definition says, palaeontology is the study of prehistoric life. The discipline is actually rather wide ranging, with many sub-disciplines, but it is fair to say that most forms encompass the study of fossils or their traces. This study allows us to better understand extinct organisms' biology, evolutionary relationships and interactions with each other and their environment. So far, so good. The primary reason for writing this article, however, is that misconceptions abound regarding palaeontology and the people in it. One of the most common is that palaeontology and archaeology are the same thing. This usually comes to light in conversations like this

"I'm a palaeontologist.":
"Oh cool, I love Time Team/Indiana Jones/history*." / "You're not dashing enough to do what Indiana Jones does." / "Nice, National Treasure was awesome and I love Nicolas Cage." / "You're like Lara Croft?"
*Delete as appropriate

Figure 1 —An archaeologist sieving soil to look for artefacts (left) and a palaeontologist splitting rocks to look for fossils (right). If the artefacts being studied relate to modern humans, their study is known as archaeology, whereas if they are any other form of ancient life, it is palaeontology

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These responses, although always good fun, demonstrate a fundamental misunderstanding. It is one that is easy to make — both disciplines involve digging stuff up, right? Well, to an extent, yes (Fig. 1). But archaeology is about anatomically modern humans, their activity and their culture. Anything else is palaeontology (or, if the remains are recent enough, zoology). And by anything else, I do not just mean dinosaurs. A number of my esteemed colleagues do work on these wonderful creatures, but a casual inspection of the articles at Palaeontology [online] shows that our field is more diverse than that. Someone, somewhere has worked on every fossilized creature we know from the 3.8-billion-year history of life, from the earliest single-celled organisms to the rise of humans and their ancestors in the recent geological past.

Another misconception is that all palaeontologists conduct fieldwork to find and dig up new fossils. For some researchers there is indeed a field season to spend looking for new fossils. But there are more than enough woefully understudied fossils in museum collections around the world to keep palaeontologists busy without having to head out into the wilderness to find more. And not all palaeontological disciplines deal directly with fossils. In recent decades, with increased computing power, a number of fields of study have developed that use databases of fossils or already-published studies to look at general patterns and processes in the fossil record.

Another common conversation runs:
“I’m a palaeontologist.”
“Oh cool, just like Ross from friends.”

Although this is getting mercifully less common as *Friends* fades in the memory of the 20-to-30-somethings whose formative years were spent watching the 1990s–2000s sitcom (myself included), it is still the calling point for a large number of people. Ross remains many people’s greatest point of familiarity with palaeontology. Which is unfortunate, because his career is the butt of many a *Friends* joke — and by all accounts he is a pretty poor palaeontologist. At one point, by his own admission, the last two papers he had written had been widely discredited (he mentions this in the episode The One With The Soap Opera Party, if you’re wondering). Unsurprisingly, his character is not an accurate portrayal of a palaeontologist. Despite the fact that none of the *Friends* ever seem to actually do any work, Ross’s seems to specialize in many more subjects than is possible over the course of several careers. He works on everything from punctuated equilibrium in the Devonian era (*The One With The Soap Opera Party*) and sediment flow rates (*The One Where Joey Loses His Insurance*) to magnetic resonance imaging, DNA work, carbon dating, herbivores, carnivores, species related to humans and Mesozoic fossils (*The One in Barbados*). This diversity of subjects is unheard of even in the most versatile of modern scientists, palaeontologists or otherwise — especially for someone so young.

If Ross isn’t a great role model, or representative of palaeontologists in general, the obvious question would seem to be — who is? Well, beyond the well-known palaeontologists whom you can read about in lots of other places, a number of unexpected names have trained as, or dabbled with, palaeontology (Fig. 2). For example, Marie Stopes (1880–1958), now better known for her pioneering role in family planning, was once a central figure in the world of palaeobotany (the study of fossil plants). Her scheme for describing the properties of coal is still used today. Similarly, Charles Darwin (1809–1882) spent much of his formative sea voyage on the *HMS Beagle* pondering geological questions, and he described a number of fossils — although, as we shall see in part two of this article, he did not use these when he developed the theory of evolution by natural selection. More recent figures have brought palaeontology to a wider audience; they include broadcaster David Attenborough, whose love of fossil collecting was the inspiration for his 1989 series *Lost Worlds and Vanished Lives* — which was, in turn, probably the reason a number of younger palaeontologists (the current author included) followed this career path.

Figure 2 —Famous faces who have either worked as — or had brushes with — palaeontology. Left: Marie Stopes, before rising to fame for her family-planning activities, was (and remains) a well-regarded palaeobotanist. Middle: Some of Charles Darwin's earliest academic work was as a geologist, and he collected fossils on the voyage of the HMS Beagle. Right: David Attenborough collected fossils as a boy (Image source: BBC).

The misconceptions mentioned above are among the inspirations for this article. I hope to counter them by providing, in part one, an overview of modern palaeontology. Rather than looking at methods or what palaeontologists spend their time doing (for that, see this, or indeed this, Palaeontology [online] article) I will look at the different subdisciplines in the field. Modern palaeontology is a diverse and complex landscape; navigating it can be tricky, and this guide aims to help with that quandary. In part two — coming in a month or two — I will provide a quick history of human interactions with fossils, from prehistory to the start and then establishment of palaeontology. But first I want to finish this introduction by providing a brief idea of why palaeontology is actually worth doing. Beyond the practical applications in the search for oil and dating rocks (see below), it can provide evidence to answer many of the major questions in the history of life. Nearly all species to have ever lived — far more than 99% — are now extinct. The fossil record is our only direct insight into these, and hence into how we ended up with the bewildering variety of species we have today. It can tell us about evolution on a big scale; aid conservation efforts by comparing past extinctions to those occurring now; help us to understand how the species alive today may be related to each other; and yield unique insights into the origin and early evolution of life. It is thus a vital part of efforts to answer these interesting questions and many more in the history of life and Earth. So, next we will look at the subdisciplines that tackle such questions.

Elements of Palaeontology

Palaeontology: Within palaeontology, a range of subdisciplines have developed over the past 50 years or so. These are loose groupings rather than rigid boundaries, and there are overlaps between many of them. Researchers working mainly on the description and interpretation of fossils usually describe themselves as palaeontologists. However, if the research focuses on an organism's biology, they may prefer the label palaeobiology or, less frequently, palaeozoology (only if the fossils in question are animals). Traditionally, the broad field of palaeontology has been split on the basis of whether the animals being studied are vertebrates (have a backbone) or invertebrates (Fig. 3); some researchers' interests straddle both groups, but this division still proves useful. As touched on in the introduction, researchers working on fossil plants are termed palaeobotanists. And if the study of the living members of a group has its own name, the same can be true of the study of their fossils — for example, the study of living insects is called entomology, so work on fossil insects is palaeoentomology.

FIGURE 3 — PALAEONTOLOGY IS OFTEN BROADLY SPLIT BY THE ORGANISMS INVOLVED. THREE COMMON SUBDIVISIONS ARE VERTEBRATE PALAEONTOLOGY (FOR RESEARCHERS WORKING ON ANIMALS WITH BACKBONES, SUCH AS THE THIS FOSSIL FISH, LEFT), INVERTEBRATE PALAEONTOLOGY (WORK ON ANIMALS WITHOUT BACKBONES, REPRESENTED HERE BY A TRILOBITE, MIDDLE) AND PALAEOBOTANY (THE STUDY OF FOSSIL PLANTS, SUCH AS THE PETRIFIED TREE-TRUNK RIGHT).

Increasing computing power and the development of non-destructive scanning techniques such as computed tomography (CT) in the 1970s has opened up new avenues of research for three-dimensionally preserved fossils. Using these approaches to build up digital visualizations of a fossil's anatomy, it is possible to gain a better understanding of the palaeobiology of a wide range of organisms. This is called virtual palaeontology. Such techniques also make studies through techniques such as geometric morphometrics easier (see below), and open a range of other computer-based options for assessing the fossil. These include finite element analysis — which allows researchers to map the stresses and strains of actions such as chewing or running onto an organism's shape — and approaches such as computational fluid dynamics, which models fluid flow around marine organisms.

Evolutionary biology: The study of fossils can provide key insights into evolution, and many fossil workers consider themselves first and foremost evolutionary biologists. Through the study of extinct organisms and using a method called cladistics to build evolutionary trees, fossils can be instrumental to researchers' understanding of the shape of the tree of life. Associated with this approach is a raft of techniques that have surfaced in the past 15 years. The Palaeobiology Database — an online catalogue of the ages of fossil species and where they were found — has made large-scale quantitative studies possible. These allow researchers to record changes in the distribution of species (their biogeography) and link them to evolution; such studies have also allowed greater insight into mass extinctions. A related development is the use of techniques such as geomorphometrics to understand the evolution and palaeobiology of extinct organisms (Fig. 4), which has become relatively common in recent years with the advent of suitably powerful computers.

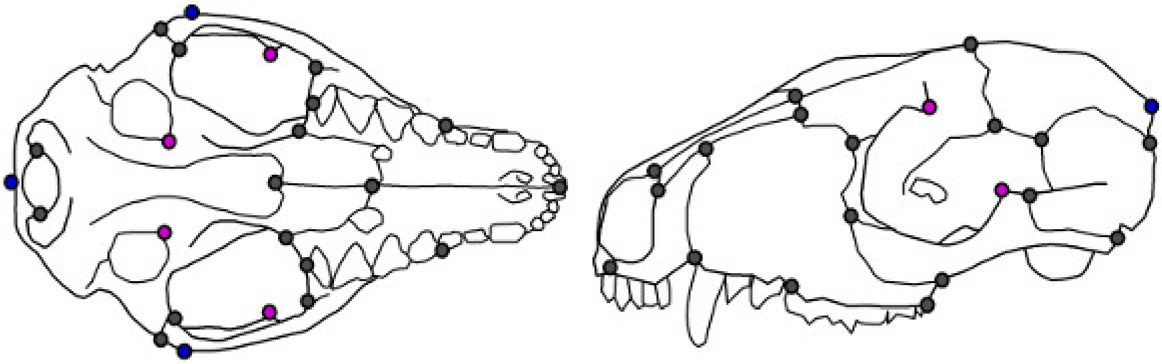

FIGURE 4 — AN EXAMPLE OF THE LANDMARKS USED FOR GEOMETRIC MORPHOMETRICS. MORE DETAILS CAN BE FOUND IN THE PALAEONTOLOGY [ONLINE] ARTICLE PATTERNS IN PALAEONTOLOGY: OLD SHAPES, NEW TRICKS — THE STUDY OF FOSSIL MORPHOLOGY, WHICH IS ALSO THE IMAGE SOURCE.

Palaeoecology: Rather than studying a fossil of a single individual, studying fossil assemblages — groups of fossils found in the same place and time — can allow us to reconstruct past ecosystems. By combining details of fossils' distributions, life cycles, possible interactions, habitats, and death and burial, palaeoecology can study patterns of biodiversity through geological time. Many such studies can be heavily statistical, providing overlap with other areas of quantitative palaeobiology. They need to consider the impact of taphonomy, or the process of fossil preservation, which we shall get to later (Fig. 5). A strength of palaeoecology is its potential for improving our knowledge of modern biodiversity and how it may respond to the ecological strain caused by humans, in addition to identifying other long-term trends involving both life and climate. Another avenue of quantitative research — more palaeontological in nature — is the statistical analysis of fossil databases to assess how geology affects the fossil record. For example, researchers can use databases and specialized software to work out how strongly the amount of sedimentary rock laid down in any given age affects the number and type of fossils preserved from that time period, and so how it affects the apparent diversity of species.

Palaeoclimate: Loosely related to this is the analysis of the remains of organisms from the geological past to find out about the climate of the time. Fossil assemblages will give an idea of climatic factors such as the salinity of seawater and the temperature for the period in which they were deposited. Interpretations of these factors are usually based on our knowledge of the current habitats of related organisms. The anatomy of some fossils can be used to assess past climate directly: for example, the shapes of both bryozoans and leaves can be used as indications of temperature in the past (Fig. 6). Geochemical analyses — which often look at stable isotopes of elements such as oxygen — can provide estimates of ocean temperature from organisms' remains. In any group of organisms there is usually a relationship between the balance of isotopes in their hard parts, and the temperature of the ocean in which they lived. Comprehensive studies can help us to build a much clearer picture of how climate varied in the past, and what impact future climate change caused by humans may have.

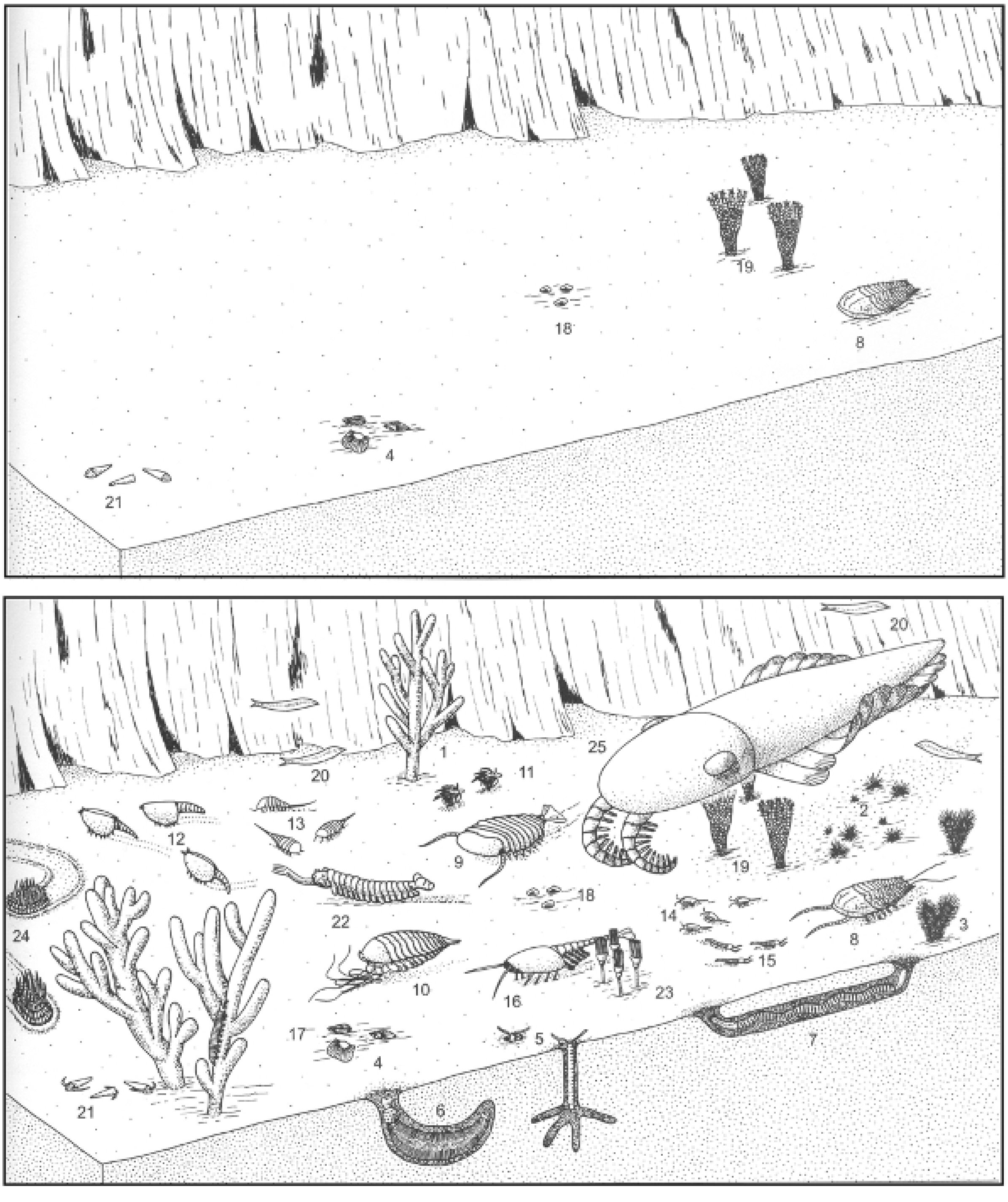

Figure 5 — An example of the possible bias that taphonomy causes in our picture of a Cambrian ecosystem. Top: What we see from the fossil record, animals with soft-bodied organisms not preserved. Bottom: A possible reconstruction of the true diversity, including soft-bodied organisms. More details can be found in the *Palaeontology [online] article Patterns in Palaeontology: Who's there and who's missing?* Images from Fossils of the Burgess Shale, edited by Derek E. G. Briggs, Douglas H. Erwin, Frederick J. Collier and Chip Clark (1995).

Figure 6 — Fossils that can be used as palaeoclimatic indicators. Left: Examples of Bryozoa as illustrated by Ernst Haeckel in 1904. Right: Fossil leaves. More information on how these are used to tell us about past climates can be found in the Palaeontology [online] article Fossil Focus: Using Plant Fossils to Understand Past Climates and Environments. Source for leaf photos: L. Seyfullah.

Micropalaeontology: Studying microscopic fossils (those smaller than 4 millimetres across, and usually smaller than 1 millimetre) is known as micropalaeontology. Microfossils include small organisms from across the tree of life, from single-celled organisms (Fig. 7) such as diatoms and foraminifera to bits of larger, multicellular life such as ostracods (small crustaceans) and the mouthparts of some worm and vertebrate species. The researcher must isolate the microfossils from the host rock in a lab, using either physical techniques — for example, sieving or separation by centrifuge — or chemical approaches such as dissolving the rock with a strong acid. Once isolated, the fossils can be studied with a light microscope or, for higher magnification, electron microscopy, and species can be identified and counted. The techniques recover lots of fossils at a time, so researchers can perform statistical analyses on the collection, gleaning information about past environments, very robust biostratigraphy (see below) and accurate dating of rocks. For this reason, micropalaeontology is used a lot in the oil industry to help to locate rock formations that are likely to hold oil. If the remains are primarily organic, such as spores and pollen (as opposed to the biomineralized bits mentioned above), the study of microfossils is termed palynology.

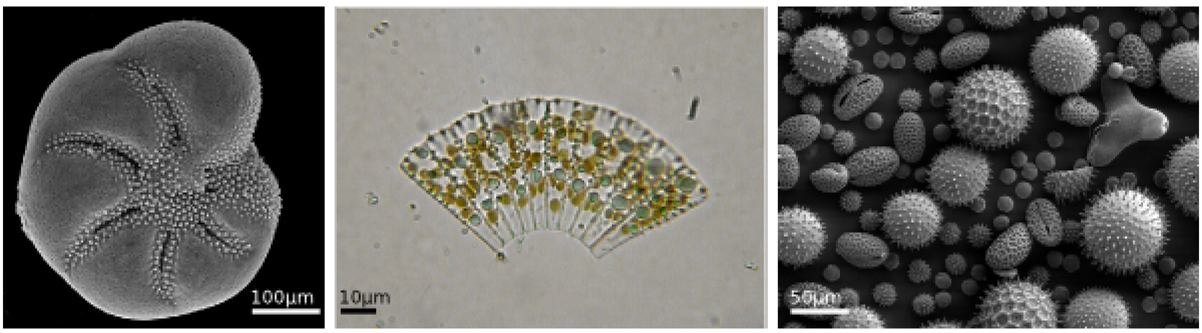

Figure 7 — Examples of different microfossils. Left: A foram of the genus Elphidium. Middle: An example of a freshwater diatom. Right: A mixture of different kinds of pollen.

Biostratigraphy: As touched on just above, working out how rocks are related to each other in time by looking at the fossils found in them is known as biostratigraphy. Global comparison of different fossil assemblages has allowed researchers to assign relative dates to any sedimentary rock with enough specimens in it. Through radiometric dating, the fossil sequences can be calibrated, converting relative dates to absolute dates. In addition to microfossils, a range of fossils of multicellular organisms lend themselves well to correlation, because the species evolved rapidly and tended to be well preserved. These organisms include graptolites, ammonites and trilobites. As mentioned above, biostratigraphy using microfossils is particularly valuable in the oil industry. In research, biostratigraphy can help us to understand the geological structures of an area, and the processes that have affected it. The field can also inform studies in biogeography and sedimentology (the study of the deposition of sediments such as mud and sand).

Taphonomy: The study of the processes of fossilization — from the decay of dead organisms to their burial and transformation into fossils — is known as taphonomy. This area of study started with researchers looking at fossils directly to see how they are preserved, sometimes using the techniques of geochemistry to investigate how minerals replaced an organism's tissues. In recent decades it has moved beyond just observing fossils to conducting decay experiments on modern organisms. In particular, researchers are now starting to try to quantify how the processes involved in fossilization might affect what we can say about the palaeobiology of an animal, and how they might affect the evolutionary trees we recover from fossils.

Figure 8 — Examples of trace fossils (All scale bars 1 cm). Left: A Cambrian arthropod trackway from the United States. Left middle: A lower Jurassic dinosaur footprint. Right middle: Cambrian trackways from the United States, possibly made by a large slug-like mollusc. Right: Coprolites — such as this dinosaur poo — are also examples of trace fossils.

Ichnology: Ichnology is the study of traces that record the behaviour of an organism (Fig. 8). These can include footprints and burrows. Researchers often compare the traces left by extant organisms to those found in rocks. Knowing about the behaviour of living organisms that left tracks similar to fossil ones can provide direct insight into the behaviour of the organisms that left the fossil tracks. It can provide information on the species present when the tracks were laid down even if there are no body fossils (although associating traces with their makers is often very challenging) and can thus help us to understand past ecosystems as a whole. In recent years, the growth of computing power and advanced techniques has even allowed researchers to simulate traces digitally, to better understand the impact of properties of the sediments in which the traces are made.

New frontiers: Thanks for making it this far! I am sorry to say that this is actually a fairly incomplete overview of current trends and subdisciplines in palaeontology. I have missed out a few fields, and new ones are constantly becoming possible thanks to advances in technology and collaborations between disciplines. In the past decade, obvious trends have included the use of next-generation sequencing to study ancient DNA, the use of geochemical techniques to assess the probable colours of fossil organisms (Fig. 9), and paleo-evo-devo, the study of the evolution of development in the fossil record. Indeed, in many cases the study of fossils drives advances in the techniques forwards, rather than researchers merely looking at fossils to make the most of technological advances.

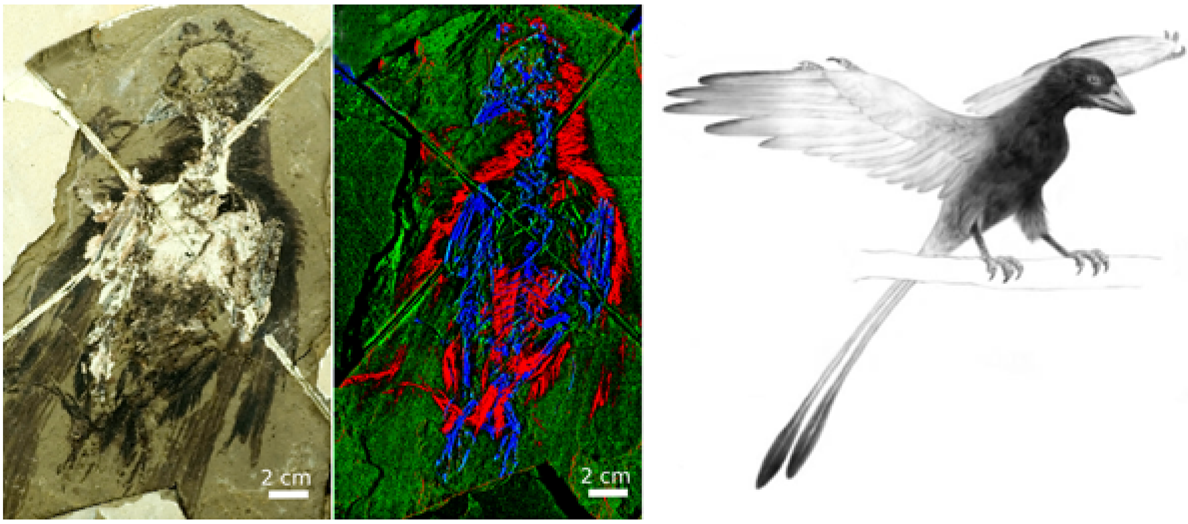

FIGURE 9 — AN EXAMPLE USING THE EARLY CRETACEOUS BIRD CONFUCIUSORNIS SANCTUS (LEFT) OF USING GEOCHEMISTRY AND TRACE METAL CONCENTRATIONS (MIDDLE) TO RECONSTRUCT COLOUR IN LIFE (RIGHT). MORE DETAILS CAN BE FOUND IN THE PALAEONTOLOGY [ONLINE] ARTICLE FOSSIL FOCUS: THE PRESERVATION OF COLOUR. IMAGES FROM WOGELIUS, R. A., ET AL. 2011. TRACE METALS AS BIOMARKERS FOR EUMELANIN PIGMENT IN THE FOSSIL RECORD. SCIENCE 333, 1622–1626. (DOI:10.1126/SCIENCE.1205748)

Conclusion

Palaeontology is not an old-fashioned or anachronistic discipline. It is studied by a wide range of people, and over the course of the twentieth century it has expanded to become a diverse discipline, taking advantage of, and often helping to drive, technological advances. Palaeontology is increasingly wide in its scope, and the questions it can address are fundamental to the study of life. Finally — and possibly most importantly — Ross from friends is an *awful* palaeontologist.

Further Reading

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[1] 1851 Royal Commission Research Fellow | School Of Materials / School of Earth, Atmospheric and Environmental Sciences, The University of Manchester, Oxford Rd., Manchester M13 9PL.