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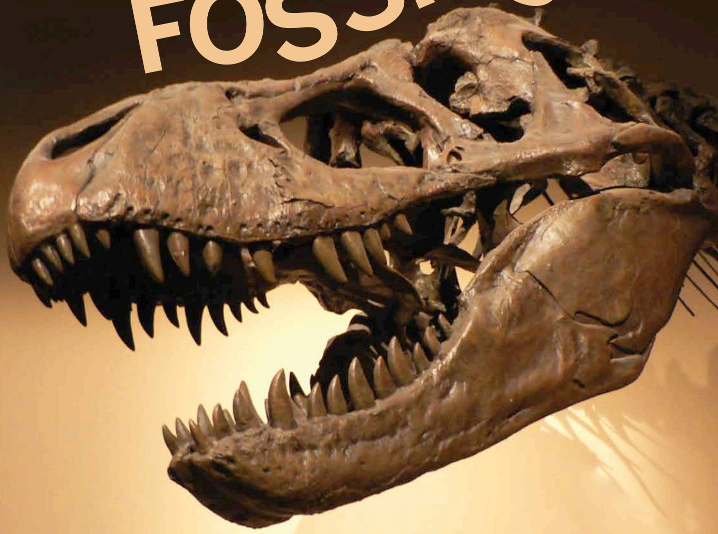
The Small Book of Big Thoughts

FOSSILS



Reminders of a forgotten past

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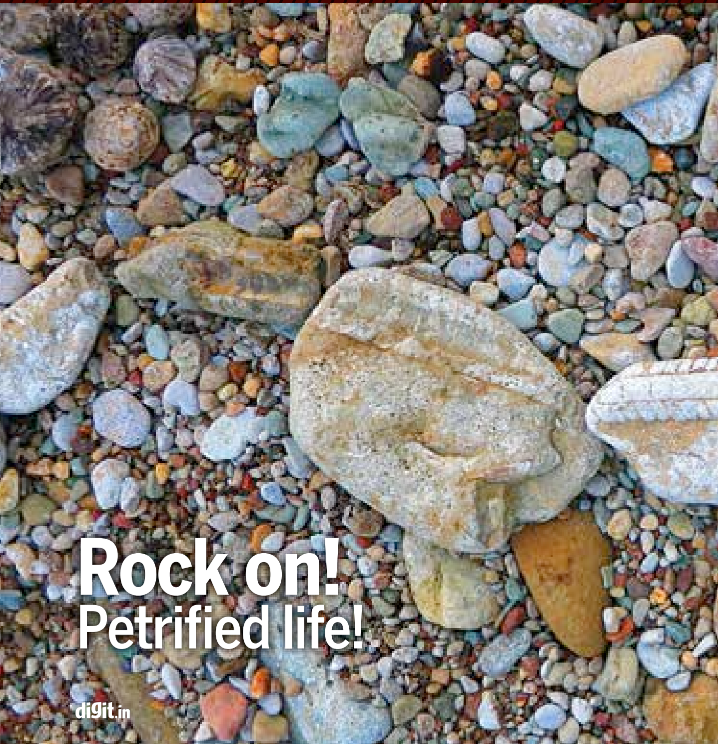

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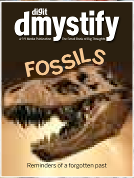

Cover Design
ANIL VK

Credits

The people behind this book:

Executive Editor & Writer:
Robert Sovereign-Smith
Managing Editor:
Siddharth Parwatay
Assistant Technical Editor:
Mithun Mohandas

DESIGN
Sr. Art Director: Anil VK
Visualiser: Baiju NV

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Not bones

Well, to be more precise, almost always not bones. Let us explain. When you hear the term fossil, you're likely thinking dinosaurs. We're assuming you've been to some museum and seen at least one fossil... if not, you have to once you've finished reading this book. In fact, the aim of this book is to get you all to choose just one day to not waste money on a movie, or some other regular outing, and to give your local natural history museum some business instead.

Coming back to the point we were making: with very few exceptions, almost all fossils are not "bones". When the living thing died, thousands, millions or even billions of years ago, it was engulfed in some material (more on this later in the book), and the hard surfaces (bones, shells, etc) would be preserved. However, everything breaks down with time and eventually the bones would dissolve – slowly. With layers forming over the buried bones, they would soon be encased in rock. As they decayed, tiny amounts of water with dissolved minerals would seep into the gaps left by the decayed part of the bones, and slowly but surely be entirely replaced with minerals. Thus, most fossils are just one kind of rock inside another kind, and are actually the exact shapes of the bones or shells, but not the bones themselves ■

Paleontology

A quick look at the history and science of fossil studies

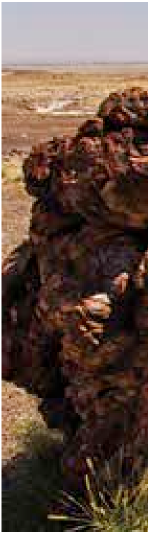
Paleontology is a cross between the sciences of biology and geology, because it involves biological creatures (living things), but is a field that relies heavily on geological knowledge of rocks – their formation, how to date them, etc.

Although not as well documented as other science disciplines, there is evidence that the ancients had indeed come across fossils. The Greeks (as usual) were writing about fossils of animals with shells, which were likened to shellfish as early as 600 BCE. In fact, fossils of sea creatures found on land was one of the reasons why the ancient Greeks were convinced that the land was at one time submerged in water.

In Greek mythology, Medusa – a woman-like creature with wings, snakes for hair and a very ugly face – was a monster that would cause anyone who looked at her face to turn to stone. Although there is no evidence to suggest this, we do wonder if fossils had just a little

Medusa gave whole new meaning to a stony stare!

something to do with the creation of this myth. Of course, statues were probably the main inspiration... There have been many other myths across cultures that essentially describe the same story,



because human imagination is limited to our experiences and knowledge, and back then it was all very limited.

What did come of these myths was the idea of petrification – turning to stone. Turns out nature easily lives up to our wildest imaginations, because it actually does happen to fossils. Called "petrifaction" in paleontology, it is the process by which animal parts gradually decay and are replaced by minerals, and eventually, turned to stone.

It was between 600 and 500 BCE that Greek philosopher Anaximander and his student Xenophanes started thinking about early life on earth. Anaximander was one of the first people in known history to state the theory that we now know as abiogenesis (life arising from non-living things), and his student Xenophanes would then take his work further by observing the fossil record and arriving at the conclusion that the earth was covered in water. Thus, obviously, life began in water and moved to the land – and even today this is what science teaches.

Next, we jump forward to the Islamic scholar Ibn Sina (known in the western world as Avicenna), who was the first to propose the theory of *succus lapidificatus* (petrifying fluids), which would eventually be accepted by everyone between the 16th and 17th century CE.

That's not wood, it's stone, but it was wood once

It wasn't until the 16th century when fossil collection took off, and classification of fossils started in earnest. However, the scholars digging them up weren't doing so because they realised that fossils were long extinct living organisms, but more because they were a curiosity. In fact, the word "fossils" itself comes from the Latin word "fossilis" which means "obtained by digging".

It was in the 17th century that Robert Hooke (1635 to 1703), an English philosopher started working on petrified wood, and proposed that the difference between wood and petrified wood was that the latter was just wood that had been soaked in water that had "stony and earthy particles". What was true for wood, could also be true for other living things, and thus began the "Aha!" moment of paleontology.

Age of Rationalism

It was in the 17th century that "Modern Philosophy" is thought to have taken root in western society. That bit is in quotes because we don't mean "modern" as current philosophy, we mean it is literally what the school of philosophical thought was called. Modern Philosophy is what came after Renaissance Philosophy, and has since been replaced with Contemporary Philosophy. Modern Philosophy was popular between the 17th and early 20th century (early 1900s).

It is in the age of Modern Philosophy (also called the Age of Rationalism), that paleontology took off as a proper discipline with more indepth analysis of fossils.

It was in 1667 when Danish scientist Nicolas Steno published a paper about the similarities between the teeth of a shark that he had

Nicolas Steno – pictured here as a bishop

dissected and that of a common fossil finding at the time, known as tongue stones. Because of the similarities between the two, Steno arrived at the conclusion that the "tongue stones" must be fossilised teeth instead. Of course, since most scientists at the time in Europe were Christian, it was obviously believed that the Earth was only a few thousand years old.

Steno got very interested in geology and started studying rock layers, and differentiating between natural rock formations and fossils. He learnt that certain rock formations were formed in layers (sedimentary rock) and realised that fossils were usually found within these layers, which meant that fossils were obviously what remained of skeletons of living things after they were covered by layers of sediment. Like any good Christian, he believed that the great biblical flood had caused this, and assumed that fossils were merely the remains of drowned animals. It should have occurred to him that marine life would not have drowned, and finding shark teeth didn't explain the flood, but then again maybe it did and was pushed to the back of his head because that would be akin to questioning the authenticity of the Bible, which was unthinkable at the time.

Steno did, however, kickstart the scientific field of discovery that we call paleontology today. In 1669 he published his book *Forerunner to a Dissertation on a solid naturally enclosed in a solid*. Despite the phenomenal success and influence of Steno's book, there were many who doubted his findings, again, because of religious reasons. Because many of the fossils found were of animals or creatures that were unrecognisable as life that still existed, it suggested that there were many extinctions, and many species were wiped out. The biblical

The woolly mammoth may make a comeback soon!

flood might have explained the formation of the fossils, but it didn't explain why God would wipe out several species of animals, insects, birds, etc, when he specifically commanded Noah to build the ark to save them from extinction.

Thankfully, the field of paleontology eventually overcame such superstitions and continued hunting for fossils.

The woolly mammoth is back in the news recently as scientists want to resurrect it using DNA, and we very well might see something like *Jurassic Park* become a reality. However, it is thanks to French Zoologist, Georges Cuvier, that we first came to know about the origins of the woolly Mammoth. He published a paper in 1796 that compared the anatomy of Indian and African elephants, as well as that of the Mammoth and the Mastodon, and was the first to come to the conclusion that the Indian and African elephants were a different species. He also showed how the Mammoth and the Mastodon were different from each other, and also from the existing Indian and African elephants, and surmised that the Mammoth and Mastodon were an extinct species of animal that were distant cousins (in species terms) of the elephants that live today. This was not only proof of ancient life existing on the planet, it was also proof of evolution.

Cuvier would then continue his work, and start identifying dinosaurs, and discovered the age of the reptiles (what we call the Jurassic period). He speculated that there was an age of reptiles that predated the age of mammals that we live in now. This was because the large reptile fossils were always found in lower layers of the rock formations, and thus, obviously, are considerably older.

Georges Cuvier proposed extinction level events

Cuvier also arrived at the conclusion that there was an extinction event (based on the fossil record), which he called a catastrophe. Obviously, once he started digging (pun intended) deeper, he noticed that there were what appeared to be several of these catastrophes. The most obvious evidence was that there were no mammal fossils in the same rock layers as the dinosaurs. This obviously meant that if there was an extinction event, and many dinosaurs died and were fossilised, and no mammals, it stands to reason that there were no mammals back then, because the dinosaurs died much earlier.

He was obviously correct, and we know that now, but it took decades of fossil hunting and data gathering before he was proven correct. A lot of fossil hunting was done in England, and the British would eventually gather enough data to prove Cuvier correct.

It was a student of Cuvier, Henri Blainville, the Editor of the famous French scientific publication *Journal de Physique*, who would eventually coin the term "palaeontologie" in 1822. This has since been Anglicised to "paleontology".

Here come the British!

It goes without saying that the British at the time were extremely religious. It made perfect sense to many to link the last extinction event with the biblical flood. However, as we mentioned before, the Bible speaks of animals we know exist today being saved from the

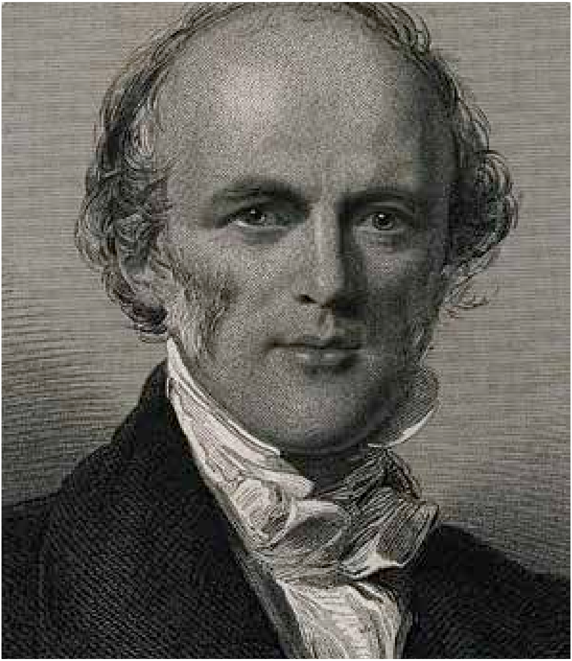
William Buckland insisted that dinosaurs were killed by the biblical flood

flood, but that meant that there should be many fossils of the ones that weren't saved right there in the fossil record. So why were there only Mammoths and creatures that are unrecognisable as living things today that were fossilised?

Although he was very, very influential and did a lot of very important paleontological work, William Buckland (and team) was a theologian before he was a paleontologist. He was insistent that the flood was indeed the last extinction event, and that fossils were the result of flood waters settling mud into layers upon the dead bodies of drowned animals. He was convinced that there had been extinction events before as well, but that was not something that he felt went against biblical teachings.

It was a British geologist, Charles Lyell, who disagreed with the idea that only extinction events could form fossils, or rather, what was more interesting to him, was the formation of rock. He was a proponent of the geological theory of uniformitarianism – which basically means that there was no reason to believe that the processes and forces that shape the earth today did so at a different pace or in a different manner in the past. If layers upon layers of sediment eventually compress one another and form rock today at a certain rate, there is no reason to believe that the process was any faster or slower in the past.

This led to the idea that fossils need not only be formed by extinction events, but could also form naturally when one or a few

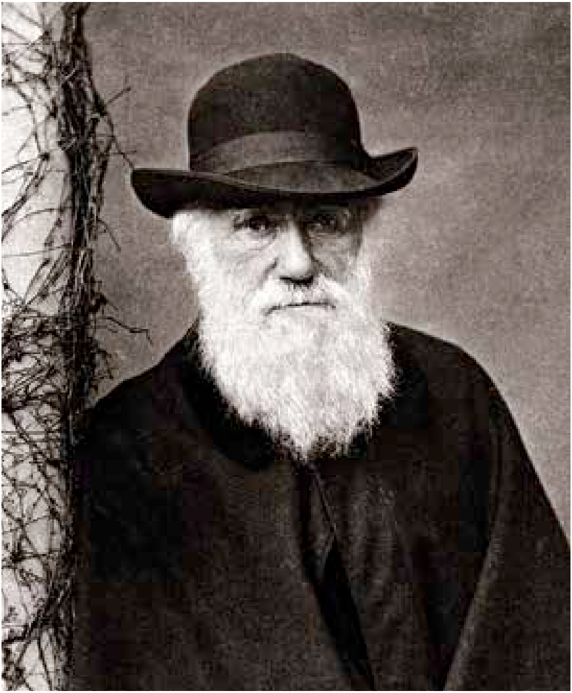


Charles Lyell believed that you didn't need a flood to make fossils animals die and the conditions are right for preservation of the carcass to occur.

He also proposed the idea that although it was rare for birds or mammals to be fossilised, it was more because of their environment and habitat than because of anything else. A marine animal just has much more chances of being fossilised at the bottom of the ocean, whereas a bird will usually die on land, and will rarely ever be covered by sediment. Most likely the carcass of birds and animals are scavenged or lie on the surface and rot, and thus are not prominent in the fossil record. As a geologist, his views about the uniformitarianism of geology were well received, but his views about the imperfections in the fossil record were never accepted.

Darwin

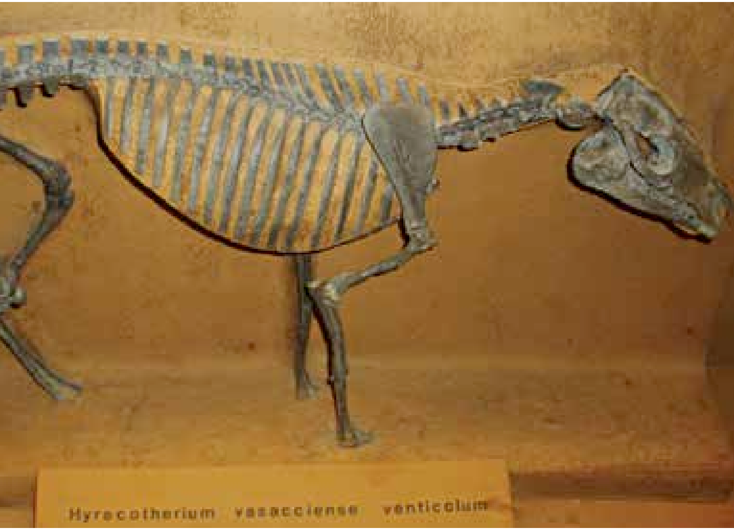
Of course he was British, but lumping Darwin in with all the others doesn't seem right somehow. He deserves his own headline, surely. In 1859, he published *"On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life."* We know it now as just "Darwin's On the Origin of Species". Although Darwin had studied finches and the flora and fauna of the Galapagos, he also researched fossils and the evidence they provided, because his theory had to hold true when going back in time as well over longer periods. In fact, fossils probably played a



Darwin in 1881

large role in helping Darwin arrive at the correct answer about evolutions and natural selection. He had also collected fossils himself in South America while on his voyage on the HMS Beagle.

What Darwin kickstarted, however, was the idea that there should be transitional fossils between species that were thought to be related but separated by large gaps of time. Almost immediately, as soon as people started hunting for aforementioned transitional fossils, links were quickly found and formed between flying dinosaurs and birds, and between five-toed mammals and the modern horse. First, it was fossils of early birds appearing everywhere. Reptiles with feathers in various transitional forms were found all over the world. Then of course, there was the search for the transitional fossils between the Hyracotherium and the modern horse. Hyracotherium was a dog-sized animal that lived between 55 to 34 million years ago, and was thought to be related to horses. Eventually, of course, we found that they were on a different evolutionary path and were an unrelated species, but this wasn't known in the late 1800s when the evolution of the horse was being pieced together.



Ancestor of the horse, the hyracotherium

Finding transitional fossils was not just exciting because those transitional species were being discovered, it was also important that they were being found in the right rock layers and were thus being found in the correct ages as expected. Paleontology, along with help from Darwin, was finally able to make predictions based on theories, and then geologists and paleontologists could go out and prove theories right or wrong. Darwin gave paleontology a shot in the arm, and most of what we now know about our past, and about evolution, is all thanks to very hard working paleontologists from across the globe who brave terrible weather conditions to dig and find fossils.

Eventually in the 20th century, the discovery of radioactivity and the subsequent development of science and measuring equipment meant that radioactive dating was able to put absolute numbers to what was merely a series of befores and afters. Before radiometric dating, a geologist could guess at how fast certain rock layers formed, and how old they were, but it was in no way an accurate science. Since rock layers were hard to date, so were the fossils embedded in them, and this meant that we only knew that large reptiles ruled the biology of earth before the mammals came on the scene, but it was almost impossible to tell *how much* before. Thanks to radiometric dating, we were quickly able to measure and then date rocks and fossils, and put together the fascinating history of life on our planet. ■

Formation and types

So how are fossils formed anyway, and how many types of fossils are there?

We've given you the short version of the formation story before this, but it should be obvious that the short versions are usually not the most accurate. This chapter will highlight the ways in which fossils form – that we know of!

Permineralization

This is the term that describes the process by which fossils are formed, and is often used interchangeably with petrifaction. As we have described before, if a creature dies and is quickly buried (before it can rot, or be scavenged), under layers of sand or sediment, it stands a good chance of being fossilised. Water is always involved in permineralization, first to cover the body and form the rock, and then to slowly fill in minerals into the cells of the organism being fossilised. Cell walls are porous to minerals, and crystals begin to form as water deposits the minerals inside the very cells

Ammonites that have been fossilised

of the creature. In a gradual process, a mineral cast is made of the creature, but instead of being an external cast as we are used to, it is a cast that is made from the inside out, and slowly replaces the entire cell structure of the creature.

Permineralization is an especially useful process for us humans to study, because it preserves the internal cell structure of the creature, which means we can almost perform an autopsy by cutting open the fossil itself to get a look at its innards (inside the hard cells such as bone or teeth). In many cases, even soft tissue can be preserved, and this is a bonus for paleontologists, as it enables us to look much further back into the Earth's past than we ever could otherwise.

There are a few different nomenclatures of the permineralization process, based on the minerals that seep into the fossil. Silicification, for example, is a permineralization that occurs with silicate materials. The silica (SiO_2) finds its way into most still water bodies, and then seeps into the body of the dead creature, where it thickens into a gel, and is eventually dehydrated to form a crystalline structure. Silicification is a very common type of permineralization, and is the reason we can find fossils of bacteria, plants and algae.

Another form of permineralization is the formation of coal balls. These are literally nearly spherical balls of stone (sometimes also found as slabs) that form when plant masses are fossilised. These are usually also plant masses from the carboniferous period (which is when most of the coal that we have on earth was formed). While most of the dead plants became the coal that we depend on still, in some cases there was just too much calcite ($CaCO_3$) present, and this resulted in a stone, rather than a nice chunk of coal. They are very important to paleobotanists, because often they preserve the cellular structure of the plants that made up that ball (at the microscopic level), and thus, scientists are able to "peel" off layers from the coal ball and analyse it. This gives paleobotanists an insight into the plant life that existed in the carboniferous period – about 350 million years ago!

Some marine plants and small creatures are also fossilised by being pyritized, which is basically being fossilised using iron sulfide (pyrite). This usually happens when the organism died in a clay rich terrain if it was a land animal, or if it is a sea creature this happens when the iron sulfide content in the seabed is high.

Body or trace?

It's important to understand that most fossils aren't entire animals. In fact, for larger animals, often only a few bits and parts might be fossilised, or even if the whole animal was fossilised, because of how volatile the earth's crust is over the course of millions of years, only bits and pieces remain of the original fossil.

A body fossil is a fossil of an actual part of an animal or organism. It may or may not be the whole body of the animal, and this usually depends on how big the original animal was and how much of it's body was made up of hard material. For example, animal with shells are much more likely to get fossilised, as are other hard parts of a body such as teeth. Most of the important fossil discoveries are part body fossils.

Body fossil of the famous T-rex

Then there are trace fossils, which aren't fossils at all, actually, but are signs left behind by a once living creature. So, for example, animal tracks left in a rock layer when it was still just mud might become fossilised and then be found later. It's a complex field of study, and that's perhaps the simplest of all trace fossils (footprints). Everything from burrows that an animal dug, or footprints, or bite marks on wood that become fossilised, or even the chemicals left behind when an organism decays, or even dinosaur poo! Yes, even

Fossilised poo!

droppings of animals (not just dinosaurs) can become fossilised, and they are called coprolites. Want to study hard and become an ancient poo expert? You can!

Because of the inability (usually) to tie trace fossils to actual fossilised animals, it makes no sense to have the same biological classification that regular fossils have for the animal kingdom. This is also because all things that burrow could have made a trace fossilised burrow, and it's hard to find out which specific species did the burrowing. However, it's important to scientific discovery to know where there are ancient burrows, and how old they are, because it tells us about the area at the time, and the condition of the earth, and what kind of life inhabited it, etc. Trace fossils are almost as important as fossils are to us, as they help us recreate the visions of what life would have been like back when the fossils of that area were alive.

Trace fossils can be classified into five major categories based on the activities they describe:

- **Cubichnia:** These are traces of living things that sat on top of sedimentary layers and left a mark. An outline of a starfish in a sedimentary layer would be an example.
- **Domichnia:** When living spaces or "houses" of organisms are found, such as little burrows made by sea animals.
- **Fodinichnia:** This is a trace fossil formed by deposit feeders, such as earthworms. Deposit feeders feed on "waste products", which could be anything from decaying plant matter to decomposing animals and also faeces (poo). The fossil is formed in the sedimentary layer as the deposit feeder eats it way through it, and because it doesn't cover the same area twice, a network of burrows occurs which forms a complex pattern.
- **Pascichnia:** These are fossil traces of surface grazers such as shrimp, which leave a distinct mark on the surface of the sea bed.
- **Repichnia**: When animals move, they sometimes leave tracks, and if those tracks are fossilised and then found by humans, we call them repichnia. Note that there are several marks left by shells of dead animals as they move across the sea bed due

Fossilised tracks in stone

to water currents, these are not considered repichnia, as they are caused by natural forces, and not by the organism moving itself when alive.

These five categories were first suggested by the German paleontologist Adolf Seilacher in the mid 1950s. Since then many more categories have been added to explain other traces of life.

Modern examples of other categories that might not fall into the five above would be termite mounds, structures built for reproduction such as the cells built by bees, or even bite marks of a predator on another fossilised bone – the fossil may belong to an animal, but the bite mark itself is an indication of a predator, and is thus a trace fossil.

Other fossilisation categories

Whilst petrifaction, or permineralization is the main way in which fossils are formed, sometimes the conditions are different, and this results in different types of fossils.

Freezing is a typical example of an animal being preserved better than is possible with petrifaction. However, because of the permanent temperature needed to keep an animal frozen can only exist for relatively short bursts of time on the planet, animals which are preserved in ice blocks are normally never more than a few thousand years old. Examples of between 10,000 to 40,000 year old frozen woolly mammoth carcasses have been found, and is the reason why we might be able to bring them back to life.

It's no secret that fossils of sea creatures easily outnumber those that live on land. This is because sea creatures live closer to the seabed than land dwellers, and since it's a lot easier to create fossils in the sea than it is on land, it's been thought that perhaps the fossil

Blue Babe is 36,000 year old male steppe bison that was preserved in ice in Alaska

record is a little too one sided. In many cases, the fossil is not really a fossil at all, because the sedimentary layer formed, the remains of the organism got dissolved, and water couldn't enter the space left behind. What this results in is what's called an external mold fossil.

Sometimes water enters and fills up the insides of the animal (usually the bits where there is soft tissue) with minerals, and then the shell or bone dissolves and you end up with an internal mold fossil. Sometimes the gaps just get filled in later with other minerals, and this results in a "cast fossil" – which is exactly as it sounds... think of filling a mold with plaster to create a cast... this is just like that.

Imprints are another interesting type of fossil. These are basically external molds of thin or flattened life forms. Usually plants, leaves, shoots, etc can be fossilised like this. Trilobites are also often found as mere imprints instead of actual fossils. A billion years from now, cockroaches could be found as imprint fossils by some alien paleontologist after we've wiped ourselves out.

Apart from freezing, another way to preserve a carcass is to dry it out. There are some places in South America and Australia that are so dry that remains of dead animals are preserved for thousands of years because there is no moisture, and as a result no bacteria to decompose the bodies.

Another way to make a mummified fossil is inside tar pits across the world. The tar insulates and protects the creature for thousands of years.

Pyritisation, as we mentioned earlier, also undergoes the permineralization process, but it results in some very impressive soft tissue fossilisation. This is thought to occur because high concentrations of iron are thought to limit bacterial decay, much in the way formaldehyde (CH_2O) does.

This woolly rhino fell into a tar pit and was almost totally preserved!

Types of fossils

Thus far we've only talked about fossilisation techniques, and mentioned two types of fossils – body and trace. However there are a few more than we should explain, before we move on to the next chapter.

- **Index:** Also known as guide fossils, these are fossils that give a guideline or a timeline to other fossils found in the same layer. For example, ammonites (extinct molluscs) are the most common fossils found, and based on radiometric dating, they thrived from 420

Paradoxides are large trilobites from 509 to 500 years ago and are index fossils

million years ago until 66 million years ago. Although extinct now, they did thrive for a whopping 350 million year period, and thus are very common fossils. They are called index fossils because all the hard work has already been done dating them. If you found the fossil of a creature in a layer of rock, and saw that there were ammonite fossils in the same layer, you could safely assume that the fossil in question belongs to an animal that thrived in the same 350 million year period as the ammonites. If, however, you found a lot of ammonites in lower layers, but none in the layer in which your fossil is, then it would suggest that your fossil is younger than 66 million years old. Paleontologists use the many already discovered index fossils to identify and date layers, and thus, can tell you how old each layer of rock is based on the fossils it contains.

- **Resin:** Also known as amber fossils, resin, as we all know, is a plant excretion that helps cover damaged parts of the plant, and also protects the plant against insects. Fossilised resin is often a cause for delight to paleontologists, because resin traps a lot of life inside it. Most commonly resin contains bacteria (dead, of course), but nevertheless invaluable for scientists to find the DNA of bacteria from millions of years ago and compare that to current day bacteria. If the finder is lucky, he may find amber with a small insect trapped inside, and if he or she is luckier than most lottery winners, he/she could find amber with a small lizard, or some other small creature trapped in it.
- **Microfossils:** The name pretty much sums it up... microfossils are fossils that are too small for us to see with the human eye. This is obviously because the organism that's been fossilised itself is smaller than what we can pick out with our naked eyes. They are super important though, because they are the most used fossils when it comes to matching ages of rock strata across large areas of land. So, for example, you have a rock layer you

are examining and 20 km away there is another rock layer, and radiometric dating is painstaking and expensive, how do you correlate the layers? By using a microscope to examine the microfossils, of course!

- **Zombie fossil:** Also called a "reworked fossil", these are fossils that are "walking dead". Sometimes a fossil will be exposed to the elements, and might be washed out of its layer, and then fossilised in a layer that is much younger. This causes the fossil and the layer it is in to have wildly varying dates, because the fossil literally moved from one layer to another, or "walked", despite the organism being dead for millions of years!
- **Transitional fossils:** The missing links we mentioned earlier, transitional fossils are those that fill in a gap between known species of extinct or living creatures. Transitional fossils usually fit right in between an ancestor and a dependant, and exhibit traits of both species. Although the humanoid transitional finds are what you will have heard about the most, there are also thousands of other transitional fossils that show the links between say, invertebrates and fish, or lizards to snakes, dinosaurs to birds, and of course the evolution of the horse.

Apart from these, there are also wood fossils, which as the name suggests are fossilised wood. Then there're chemical fossils, which we have mentioned earlier in this book as well. Chemical fossils are the signatures left behind by organic life. Chemical fossils are the only way to go back to the beginning of life itself, because the earth was still a very violent and volatile place, and rocks were forming and then being melted again. All that remains of the earliest years of our planet are chemical signatures, and chemical fossils of bacterial colonies, for example.

- **Sub-fossils:** These are partially fossilised remains, and can be part bone part fossil, because the fossilisation process has not had time to complete before we extracted the fossil from its layer. It's common to find, say, dodo fossils, which have only been dead a few thousand years. Even trace fossils can be sub-fossils, because things such as bird's nests, or faecal matter can also be partially fossilised. Obviously sub-fossils are rarely ever older than a few thousand years old, but the upside is that because they contain so much organic matter, they're perfect for extracting DNA from.
- **Pseudofossils:** These aren't fossils at all, and are actually naturally caused shapes and patterns that can often be mistaken for fossils. Dendrites for example, are often mistaken for plant or tree fossils, because they form in a very plant-like shape. If you have ever lived in a country where it snows, you will have noticed the patterns of ice and frost that form on a window, which appear to be intricate designs, but are actually totally naturally caused. ■

Fossil dating

Geochronology and how we date fossils, and a look at some famous fossils

It's one thing to find fossils, but they also need to be dated. We've mentioned a technique or two in passing in the earlier chapters, but now it's time to look at the many methods of dating that are used to identify and categorise fossils.

Dating methods

Most paleontologists cannot get a break, and they usually have to date other paleontologists. A few will hit it big and date and marry a hot friend, but this is a rarity. Oh wait... that's the story of the fictional character Ross Geller from friends... err... nevermind...

Dating of fossils is a very important aspect of tabulating the history of our planet. We're literally painting a picture of our past by digging up the remains of long dead creatures, and often trying to use one tooth or a jaw bone to piece together a picture. Think of it like doing a million piece jigsaw puzzle, with 999,000 missing pieces, no guide picture to follow, and still trying to find exactly where each of the faded and crumpled up 1,000 pieces should fit in... Accurate dating of fossils is like being given a hint for the jigsaw puzzle, and a general area where the jigsaw piece fits in...

Radiometric dating: Radioactive elements have known half-lives. Radioactive decay occurs at a fixed rate, which means the mass of a radioactive element should halve in a given time frame, known as the half-life of the element. Knowing the half-lives of radioactive elements is merely one parameter. If we know how much of the element there was to begin with, we can measure how much is left, and then use that to calculate how old the rock is. Easy, right? Not one bit, and it is a very painstaking and tedious affair. As far as possible, radiometric dating is kept as a last resort, to resolve disputed ages of fossils. Radiometric dating is not exactly the most accurate of dating methods. The longer the half life of an element, and the less accurate the dating method that can be obtained from it. If you want to know the age of something from about a billion years ago, be prepared to get numbers that are have an error factor of several dozens of millions of years. Carbon dating is a radiometric dating technique, and although it is more accurate, it cannot be used to date anything older than, say, 60,000 years.

Incremental dating: This is a much simpler method of dating that is used to date relatively newer remains. It involves using cyclic patterns, which are usually annual, to associate and date remains of a creature. For example, dendrochronology is a way to count tree rings and find out the age of a tree. However, because we have analysed and counted the width of individual rings and formed a pattern for the past 9,000 years of earth's climate history, we know which years were good years for trees and which were bad. When a tree had a good year it adds on a wide ring, and when it's a bad year the ring is narrow. Based on this we can date tree remains from the recent past, and also tell the approximate climate of the area, say, 7,000 years ago. Another method used in incremental dating is using ice cores, and studying the layers of ice that are formed when the surface of an ice sheet melts in the summer and then when more is added on in the subsequent winter, etc. Obviously, creatures extracted from an ice layer would correspond to the age of the layer they were in, for example. Although very accurate, this method is very limited by how far back in the past we can go.

Paleomagnetism: When rocks are formed, many minerals (many iron based ones) in the rocks are left with a "memory" of the earth's magnetic field at the time they were locked into the rock. By analysing the magnetic direction of the rock, and equating that to various factors such as continental drift and the earth's magnetic field flipping in the past, and you can also get an age of the rock. Paleontologists have come up with a chart called the apparent polar wander path

(APWP), which tracks the polar direction of the continental landmass and that of the earth, and plots it over time. When they come across a rock formation of unknown age, they measure the magnetic directions in the minerals, then plot it to the APWP graph, and where it co-incides with the data, is how old the rock is. The problem with this method, and another method called magnetostratigraphy, is that they rely on already knowing an approximate age of the rock in question. This is usually found either by equating layers that have already been radiometrically dated close by, or else by radiometrically dating and finding a rough age for the rock. Once you have an approximate age for a rock formation, APWP can be used to narrow down that age range considerably.

Fission track dating: This is a radiometric dating technique that uses optical technology as well to arrive at an age of a fossil. Other radiometric dating techniques measure the amount of radioactive elements and also the amount of "daughter" elements (these are the product of the decay of a radioactive isotope). Uranium-238 has a known rate of spontaneous fission, and the fragments emitted in the fission leave a tell-tale sign in the crystal structure of the rock (or minerals) that contain the ^{238}U isotope. These tracks are large in comparison, and can be anywhere from 1 to 15 microns, which is long enough to be visible with a microscope. So the more fission tracks there are the older the sample. We need to find out how much

^{238}U there was to begin with, and this is done by using neutron radiation to fission ^{235}U, and finding out how much of that there is and then using the standard ratio of ^{235}U to ^{238}U to arrive at how much Uranium-238 is in the sample. Of course, the mineral can always be vaporised using a laser and then analysed in a mass spectrometer to find the amount of Uranium-238 as well.

Stratigraphy: The most common way to date fossils is the same way in which layers of rock are dated. Layers of rocks generally get older, the lower down in the rock formations you go. Of course there are problems with layers, which are caused by fissures in rock layers, volcanic eruptions, etc. To know more about geology and the dating techniques used to date rocks and rock layers you should read our dmystify Geology and Dating book, published in October 2016. Fossils are almost always dated by dating the rock layers they are in, though sometimes the rock layers are dated by looking at the fossils in them. So if a particular species is known to be short lived (existing for a few hundred thousand to a million years), and if fossils of that species are found in a rock layer, then you know how old the rock layer is. Although this may sound like it's circular reasoning when you don't know your science – "rocks date fossils, and fossils date rocks" – it's not, because most of the hard work dating fossils and rocks have been done painstakingly using complex machines that measure radiometric ages to very high precision. In order to avoid such complex systems being used for every little find, we use the data we have already proven to date subsequent finds. It's a bit like how all math problems can seek to prove that 1 + 1 = 2, or 2 x 2 = 4, etc., but once it's been proved, why bother to do it again and again? We all accept that our multiplication rules hold good for even large numbers even if we haven't verified them. You can verify that 2 x 3 = 6 by doing 2 + 2 + 2, but you don't do that for, say, 67523 x 87234 = 5,890,301,382 – no one wants to do 67523 + 67523 + 67523… and so on… 87234 times, do they?

Famous fossils

Now it's time to move on to some famous fossil discoveries and to take a quick look at why they were important.

Dakota: This fossil of a Edmontosaurus annectens, a species that lived in the cretaceous period (145 to 66 million years ago), is a very important find, and very, very rare. The E. annectens is a duck-billed dinosaur that grew to about 40 foot lengths and weighed about 6.5 tonnes. What's special about Dakota is the fact that this particular specimen is one of the rarest of the rare finds – even the soft tissue and skin were fossilised. For this to happen, the animal has to die, not be subjected to predators, be naturally mummified, have the soft tissue survive long enough for fossilisation to occur, survive all sorts of geological events such as fissures and earthquakes and the like,

Dakota the duck-billed, fast running dinosaur

survive the process that raises it upwards, and then also be found by humans! It's like winning the lottery everyday for a month! Dakota was discovered by a high-school student, Tyler Lyson, on his family's farm in 1999. It was only when Lyson later became a paleontology student (thankfully), that he realised that the fossil in his backyard was special as it had soft tissue fossilisation as well. He then teamed up with British paleontologist Phillip Manning to excavate the fossil in 2006. It is being studied in detail, and is revealing a lot of its secrets

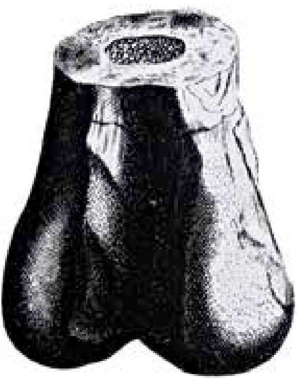
– for example, studying its muscle structure has revealed that the Edmontosaurus annectens was capable of running at a top speed of 45 kmph, much faster than T-Rex's 32 kmph!

Big Mama: This is a tale of false accusations and tragedy, but eventually ends up proving the link between dinosaurs and birds – has all the makings of a best seller! In 1993, a team of paleontologists digging in Mongolia came across a fossil of a dinosaur with its arms spread out. While extracting the fossil they realised that the dinosaur was sitting on a nest of eggs and in a brooding position that we now

No Big Mama isn't an Age of Empires cheat code, it's a dinosaur

associate with birds. Fossils of the same species had earlier been found near eggs, and were thought to be predators who were stealing eggs, and died while caught in the act. They were termed oviraptors, or "egg thief", which was later discovered to be a misnomer. Big Mama was a Citipati (a type of oviraptor) who died protecting her eggs. By studying her in detail (along with other Citipati fossils) we have discovered that they were theropod dinosaurs, probably had feathers which would explain the brooding position that Big Mama and a few others were found in, and were definitely a lot like birds are today – establishing another link between dinosaurs and birds.

Megalosaurus: Literally meaning "giant lizard" this was one of the first giant fossils discovered in modern history. The first part of this species was a fossil of a lower thighbone discovered in 1676. It was first thought to be from an ancient roman war elephant, and then was mistakenly assumed to be from a giant human, as described in the bible. Because of the shape of the fossil, which resembled a pair of human testicles, it was named Scrotum Humanum, the Latin origins of which are self explanatory. Although a petition was made in 1993 to rename that particular fossil and suppress the silly name, it was denied. Of course, after that first find, over the hundreds of years, many Megalosaurus fossils have been found. They were a meat-eating theropod that lived between 200 and 145 million years ago. Theropods are bipedal dinosaurs who mainly walked or ran on

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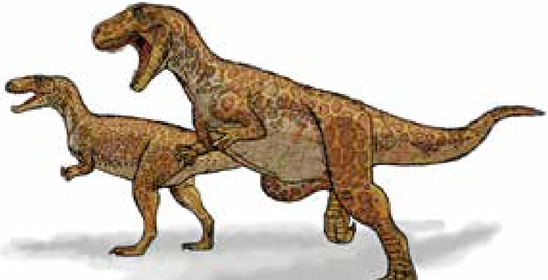

A giant lizard associated with large testicles!

their hind legs. Megalosaurus usually grew to about 23 feet long, and weighed just over a tonne. It's still a very elusive fossil though, and no complete skeleton has ever been found fossilised. It did, however, kickstart the fascination of all of us with the big lizards that eventually get us all interested in the history of earth.

Archaeopteryx: Darwin's On the Origin of Species was released in 1859, and whilst the scientific world was still either trying to wrap their brains around the concept, or hotly arguing for and against it, a mere year later a fossil imprint of a single feather seemed to prove him right. Of course, this dinosaur feather was not immediately taken seriously, but Darwin must have been smiling from ear to ear just another year later when a full skeleton fossil of a dinosaur with feathers was found. The fossil, which would later be called Archaeopteryx, looked almost exactly like a bird, except it had teeth (and as we all know, no birds have teeth), claws at the end of a hand-like skeleton, and a string of tailbones from which feathers grew (again, like no bird today). One of the first questions that arose after reading Darwin's Origins book was "where are the transitional species?", and as if on cue, scientists were delivering just that. The species is thought to have lived about 150 million years ago, could grow as large as 0.5 metres long, and weighed about 1 kg or slightly less. The Archaeopteryx was a perfect transitional fossil specimen that got people thinking along the lines that birds had evolved from dinosaurs, which today we just take for granted based on the sheer amount of evidence. However, evidence doesn't stop some people, and famous astronomer Fred Hoyle was one of them. Hoyle was also famous for some wild conspiracy theories and also went against accepted scientific conclusions – most notably the Big Bang theory, which is funny because Hoyle came up with the term when he was criticising it. Hoyle was a steady state theory proponent. Hoyle claimed that the feathers found in the first few fossils in London and Berlin

The missing link between dinosaurs and birds?

were forgeries. He claimed that the forgeries were done to support Darwin's theory of evolution, and this, obviously, got a lot of backing from religious people, and still does even today. Hoyle was wrong, of course, because some physicists think they know everything about other fields, when it is painstakingly obvious that they do not. Many geologists have published papers and explanations about why Hoyle was totally wrong on every single count, merely because he just had no clue about the intricacies of fossil formation, and didn't have anything more than a basic understanding of geology. Although many more fossils have been found to link dinosaurs to birds, Archaeopteryx is special for being the first, and being so controversial.

Diplodocus: One of the largest dinosaurs that roamed the earth, diplodocus is what usually greets you at a lot of the natural history museums across the world. Andrew Carnegie, one of America's richest men in the 1800s in the US funded a fossil hunt in order to get fossils for a museum he was planning to build. The expedition ended up finding one of the most complete fossilised skeletons of a large dinosaur ever discovered. Although Diplodocus Carnegiei is not considered to be the largest or longest dinosaurs ever to walk the earth, the fossil that Carnegie got for his museum was so complete and impressive that casts of it were made and sent all over the world. This writer was awed by the cast of Carnegie's Diplodocus that is displayed at the entrance of the Natural History

Diplodocus Carnegiei is one of the most complete large fossils ever found

Museum in London – you really have to see it to believe it. Sadly, Dippy the diplodocus (as it was called) is no longer in the museum, and is in the process of being replaced by a real skeleton of a 25 metre long blue whale.

Human evolution

Fossils that show us our history, and evolution from earlier species are always going to hold a special place in our hearts. It's nice to know about crustaceans and dinosaurs, but it's much better when things get personal, and we learn something about ourselves!

Lucy: In 1974, near a village we have never heard of, somewhere in Ethiopia, a paleoanthropologist (studying humanoid fossils) from the Cleveland Museum of Natural History, Donald Johanson, decided to skip his routine of updating his notes, and accompanied his student Tom Gray to search a new area for bone fossils. For the past 3 years they had been searching, and had found a few bone fossils here and there, which were dated to 3 million years old (older than the oldest Hominid known at the time), but they were just fragments and not enough to be definitive as a new species. He decided to look in a gully that had been searched before, and just about spotted a piece of an arm bone when he was leaving. They got down into the gully and immediately uncovered a small skull bone right next to the arm. In no time flat they realised that this was a good find, as they kept uncovering and finding more bones from various parts of the body, which suggested that they were all bones of a single individual. They marked it and went to get the rest of the team. It took three weeks, but eventually they ended up with about 40% of a complete skeleton, which is a pretty good find. However, the completeness of the skeleton was just the beginning... The fossil was named after the Beatles song Lucy in the Sky with Diamonds, which was played very often during

This is what Lucy could have looked like the course of the dig. What really set Lucy apart, however, was the fact that she was old (as a fossil), but still displayed a lot of similarities with hominids. For example, she walked upright, had a brain that was between 375 to 500 cc in volume (humans have about 1450 cc, and modern gorillas have 350 to 450 cc), and had a rib cage like apes, which suggests a mainly vegetarian diet. Lucy has been classified as one of the early australopithecine fossils, and they are somewhere in between current gorillas and humans. For example, Lucy's species exhibit greater sexual dimorphism (bigger differences in body structure between male and female) than humans, but less than gorillas. They are thought to be between 4 to 5 feet tall, and weighed between 30 and 55 kg. Later australopithecine members could have had brain sizes are large as 600 cc! She has since been surpassed as the oldest known fossil in the human evolutionary lineage, but she is still considered special because of the completeness of her skeleton.

Piltdown man: In 1912, an amateur archaeologist called Charles Dawson claimed to have found a human-like skeleton, which was the missing link between humans and apes. He called on experts in the field to come and examine his find, and Arthur Smith Woodward, head of geology at the National History Museum answered the call. The dig site was located near Piltdown, East Sussex, and thus the name. After digging together, and unearthing many more bones, they put together a skeleton that indeed looked like the missing link

Gentlemen, you've been hoodwinked!

between humans and apes. The discovery was officially announced to the world, and it sparked a great debate about the evolution of man. Originally thought to be 500,000 years old, Piltdown man was the subject of much controversy, with not everyone believing it to be an actual fossil. Eventually, in 1953, Time magazine published an article conclusively proving it to be a forgery. It was shown by scientists that the bones had been stained with chemicals to appear older than they were, teeth had been filed to complete the bite so that the upper and lower jaw would match, and the fossil was proven to be a mix and match of three species – a medieval human skull, a 500 year old lower jaw from a orangutang, and teeth from a long dead chimpanzee. So sophisticated was the forgery that it was suspected that more people were involved. One amongst a list of suspects was Sir Arthur Conan Doyle, of Sherlock Holmes fame, but as recently as 2016 a case study into the forgery acquitted him of suspected guilt.

The Hobbit: Actually called Homo floresiensis, and nicknamed the Hobbit because Lord of the Rings was popular at the time of its discovery, this is a fossil discovered in 2003 in Indonesia. It's called the hobbit because it stood only 3.5 feet tall. They are thought to have descended from Homo Erectus, who arrived on the island a million years ago. However, something must have caused them to shrink to their smaller sizes, and we don't know what that factor is. Many theories exist, but every theory has dissenters so we might never know. The theories range wildly from one that suggests that a diet in the area could cause dwarfism, based on evidence of another species of animal that's a distant cousin of elephants which was also found to be dwarfed on the islands. Another theory is that the more

Indonesia had Hobbits before we had heard of them!

complete fossils found happened to be individuals suffering from Down Syndrome, and the other fragments from other individuals could be from normal sized adults. This is suggested because of the strange jaw shape of the fossils found. It's not a widely supported theory though. Another theory is that a congenital disease called cretinism (hypothyroidism) could affect populations and cause the smaller stature. This is by far the most plausible theory as evidence of the condition still exists in Indonesia, even today in rare cases.

Peking man: This was a sub-species of Homo Erectus called Homo Erectus Pekinesis that lived in China about 750,000 years ago. The fossils were discovered over a period of years (1923 to 1937). Sadly, the excavations ended when Japan invaded China in 1937, in what would eventually turn out to be the second world war. Peking man fossils were not studied in detail though, and have not been looked at by modern paleontologists and paleoanthropologists because of a very strange reason. While Peking was under Japanese control, all of the discovered fossils from the site were packed up and shipped off to a US naval base where they were eventually supposed to go to the US. They never made it though, and disappeared without a trace. With the chaos of the wars and the later bombing of Pearl Harbour by the Japanese, all traces of the shipment were lost. The fossil remains of over 200 individual Peking men, women and children just vanished, and years of painstaking work to extract them

Peking man – gone without a trace!

was lost. Only in 2009 did digging work start again on the same site after 72 years. Picking are slim, however, as the bulk of the fossils were already unearthed. We may never know the proper history of

Peking man, and where he fit into the puzzle that is the tree of life, and that's a pity. There are theories about what happened to the shipment – some say it was probably lost at sea when the vessel was sunk or capsized, whilst others say criminals stole it and ground up the fossils to make Chinese medicine. Whatever the truth is, it's a huge loss to paleoanthropology.

We hope you've enjoyed this little run through the rather vast subject that is paleontology, and will be interested enough to read more about it. If you happen to live close to rock formations, we urge you to grab a geology book and some fossil hunting equipment and get out there and start digging for fossils. With so many gaps that still exist in the map of the history of life on this planet, there are a million discoveries just waiting to be made, and you could be the one to make them. You never know. Paleontology is all about being in the right place at the right time, and keeping alert to possible fossils hiding in plain sight. The experts will come in later, but you could still have a fossil named after you if you make a big discovery... Happy fossil hunting! ■

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Stromatolites are cyanobacterial colonies
that existed billions of years ago!
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