CAN MODERN TECHNOLOGY UNCOVER THE SECRETS OF EVOLUTION?

A mysterious group of fossils called the Elgin Reptiles has been puzzling scientists for centuries. Existing only as cavities hidden within rocks, these fossils could help scientists unravel the mysteries of evolution. Thanks to modern technologies, **Dr Davide Foffa**, a research associate at **National Museums Scotland**, and his colleagues have examined these fossils using digital technologies for the first time, resulting in some exciting new discoveries.

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PROFILE

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Vertebrate Palaeontology, Palaeobiology, Palaeoecology

Research project
Using micro-computed tomography to uncover the secrets of the Elgin Reptiles

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TALK LIKE A …

PALAEONTOLOGIST

Anatomy — the science that studies the structures of living (extinct or still living) organisms

Evolution — the process of gradual change over many generations through which species slowly develop into new species

Fauna — the animal life of a particular region or time period

Fossil — the remains (e.g., bones) or impressions (e.g., footprints) of prehistoric life-forms that have been preserved in rocks

Mass extinction — a widespread (global) and rapid decline in biodiversity in which many species die out

Micro-computed tomography (µCT) — a 3D imaging technique that uses X-rays to see inside objects

Permian — a period of geological time, from 299 to 252 million years ago

Triassic — a period of geological time, from 252 to 201 million years ago

Over the past few billion years, life on Earth has evolved into the incredible diversity of organisms we see today. All species that exist today have evolved from earlier ancestors, while many others have long since died out. In fact, more than 99% of all species that have ever lived on Earth are no longer around. The family tree that links these species together is therefore incredibly complex.

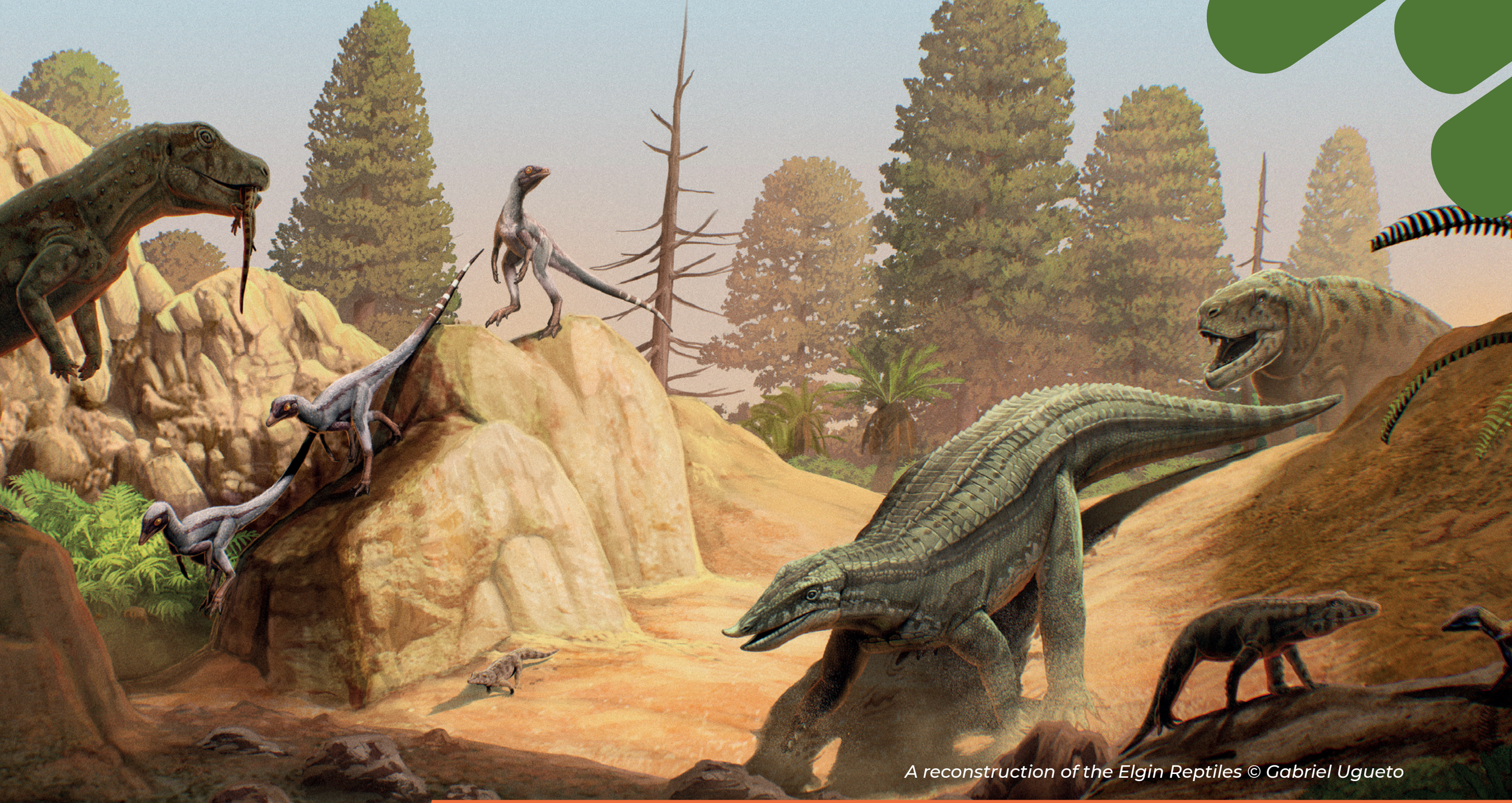
This 'tree of life' describes the pathways of evolution and shows us how organisms are related to each other. Since Charles Darwin first proposed the theory of evolution in 1859, scientists have been trying to solve this giant jigsaw puzzle. Dr Davide Foffa, a researcher at National Museums Scotland, is one such scientist who has been studying a key piece of this puzzle – the Elgin Reptiles.

What are the Elgin Reptiles?

In the late 1800s, workers were extracting rock from a sandstone quarry near the town of Elgin on the north coast of Scotland when they made an interesting discovery: these rocks contained fossils of ancient animals. Named the 'Elgin Reptiles', the fossils from this region can be split into two groups, one from the later part of the Permian period (more than 252 million years old) and one from the Late Triassic period (around 235 million years old). "At these times, Scotland was much closer to the equator than it is today, and the climate was considerably warmer," says Davide. The sandstone rocks in which the Elgin Reptiles are preserved were once desert sand dunes, indicating these animals lived in a significantly hotter and drier environment than is found in Scotland today.

Why are the Elgin Reptiles important?

The Elgin Reptiles give us a glimpse of life on Earth both before and after the most severe mass extinction event that has ever occurred. Known as the Permian-Triassic Mass Extinction, this took place 252 million years ago. During the extinction, over 70% of all species that lived on land and over 90% of all species in the oceans were wiped out. With fossils of creatures that lived at the end of the Permian and the beginning of the Triassic, the Elgin Reptiles can tell us how life on Earth is affected by catastrophic events such as mass extinctions, and how it recovers from them. These fossils can also teach us about the anatomy and behaviour of extinct animals, as well as the origins of evolutionary lineages and ecosystems. In his research, Davide has been focusing on the Triassic fossils of the Elgin Reptiles, which include groups of animals that survived or evolved just after



A reconstruction of the Elgin Reptiles © Gabriel Ugueto

the extinction, many of which still have descendants living today. The Triassic Elgin fauna include some of the oldest ancestors and cousins of crocodiles, lizards, dinosaurs (and therefore birds) and pterosaurs. "The Elgin Reptiles are important windows into the past, which tell us about the very origin of modern faunas," says Davide.

Why are the Elgin Reptiles so hard to study?

"Most of the Elgin Reptiles are not preserved as traditional fossils, where the bones turned into rock over millions of years," explains Davide. "Instead, there are no bones left in many specimens, particularly in the smaller animals." After fossilisation, the bones of these animals dissolved, leaving cavities in the rock that perfectly preserve the shape of their skeletons. Since their discovery in the late 1800s, the best way to study the Elgin Reptiles has been to crack the rocks open and pour rubber into the holes to create casts of the bones.

Unfortunately, this technique has several disadvantages. Firstly, it is destructive. The rock must be broken to examine the fossil so the specimen is damaged in the process. Secondly, the casting process often misses important details as it is hard for the rubber to reach all cavities. Large parts of many specimens remained unknown and small details such as hand and foot bones were often missing.

How is Davide studying the Elgin Reptiles?

Davide has been making use of modern technology to uncover the secrets of these ancient fossils. After re-assembling the broken rocks containing Elgin Reptile specimens, he scans them using micro-computed tomography (μCT). "A μCT scanner is essentially a fancy 3D X-ray machine," he explains. "When you get an X-ray at the hospital, the machine produces a 2D image showing the inside of your body. A μCT scanner takes thousands of 2D X-ray pictures showing the inside of an object, all from different angles. Using special computer software, we can stitch these 2D images together and use them to create a 3D model of the inside of the object." These 3D models show the shape of the fossil skeletons, preserved as cavities within the rock, in incredible detail, revealing parts of the specimen that were not known from the original rubber casts.

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What has Davide discovered?

"The amount of information we can get from the rocks with μCT data is outstanding," says Davide. His scans of fossils have helped him determine the anatomy of some of the Elgin Reptiles, including *Erpetosuchus*, a cat-sized animal from the crocodile-line of reptiles, and *Scleromochlus*, a tiny creature that has been puzzling researchers for over a century. Understanding an animal's anatomy is essential for palaeontologists to place it in the evolutionary family tree and develop hypotheses about aspects of its behaviour, such as what it ate and how it moved.

From his 3D models, Davide discovered new details across all parts of *Scleromochlus's* skeleton, from its skull and spine down to its feet and tail. "The new information has transformed our idea of what *Scleromochlus* looked like," he says. Some palaeontologists, for example, had previously assumed that *Scleromochlus* moved by hopping like a frog, due to its apparently short tail and shallow body. However, Davide has revealed that it had a deep ribcage and a long tail, as well as small, weak hips that would not have been suited to hopping.

With this new information, Davide deduced that *Scleromochlus* belongs to an evolutionary group known as the lagerpetids. These are the closest relatives to pterosaurs, the first boned animals to start flying. "*Scleromochlus* is not a direct ancestor of pterosaurs," emphasises Davide. "However, *Scleromochlus* tells us that pterosaur's ancestors would have been small, agile and light-built land-dwelling animals."

What next?

"This research demonstrates that there is a lot to be gained from μCT scanning these fossils," says Davide, "and there is a lot we still do not know about other animals preserved from this exceptional assemblage." Therefore, he hopes to perform the same process with other specimens of the Elgin Reptiles.

Davide will use the new information he uncovers to reconstruct past ecosystems and investigate what happened to them before, during and after the Permian-Triassic Mass Extinction. "The fossil record is the only source of information we have to understand what happens to life on Earth during biodiversity crises, such as the one that we are currently facing due to climate change," explains Davide. His research is therefore vital to help us prepare for our current ecological challenges.

ABOUT *PALAEONTOLOGY*

There is far more to palaeontology than dinosaurs! Dinosaur discoveries may make the headlines and dinosaur films may fuel our imagination, but palaeontologists investigate all types of prehistoric life. While Davide currently studies the creatures that came before the dinosaurs, and has previously studied those that lived in the sea while dinosaurs roamed the land, other vertebrate palaeontologists investigate the ancestors of mammals, the evolution of amphibians and how fish first came ashore to start animal life on land. Invertebrate palaeontologists study prehistoric animals without a backbone, addressing topics such as how the earliest life began and how the first shelled sea creatures became fossilised. Palaeobotanists study fossilised plants.

Fossils give us a window into the past and show us what ancient plants and animals looked like. By studying them, palaeontologists can learn what life on Earth looked like many millions of years ago. Palaeontologists may be involved in finding and excavating fossils from the ground as well as re-examining fossils that have spent years in museum archives.

What does fieldwork involve?

"Fieldwork is usually very hard work!" says Davide. "Days in the field are long, we sometimes walk a long way, and we are out in all weathers. But fieldwork is also a lot of fun." Before they start fossil hunting, palaeontologists must ensure the area has the right type and age of rocks for the fossils they hope to find. For example, sedimentary rocks deposited in low energy environments (e.g., in calm lakes not fast-flowing rivers) are more likely to contain fossils than lavas erupted from volcanoes.

"Patience is key for palaeontologists," says Davide, as excavation is delicate work and there are then many more steps to complete before a fossil is ready to be studied. "Overall, it is very exciting and the thrill of finding a fossil for the first time is one of my favourite parts of the job!"

What does museum work involve?

Museums play a fundamental role in curating fossil specimens and making sure they can be studied by researchers. Most specimens held in museum archives are not displayed in exhibits that are open to the public. "Browsing among collection drawers is very exciting and even old collections are constant sources of new discoveries," says Davide. When he visits museum collections, Davide will examine, photograph and describe fossils to add to his knowledge of past species.

What are the joys of palaeontology?

"Being the first person to see an animal that has been buried for millions of years is breath-taking," says Davide. "I enjoy learning new techniques from other fields of research and adapting them to answer questions about the fossil record. Overall, I see palaeontology as a team effort. We keep building on new discoveries to push the field forward."

Pathway from school to *palaeontology*

- As palaeontology draws on skills and knowledge from geology and biology, you can enter the field from either of these directions. University degrees in geosciences, evolutionary biology, zoology and natural sciences can all lead to a career in palaeontology.

- "Palaeontologists often need to know anatomy very well, as we use the features of individual bones to identify fossil species," says Davide. Therefore, whatever route to palaeontology you follow, ensure you take anatomy classes.

- "Palaeontology is evolving fast and now requires more skills not traditionally associated with the field," says Davide. Computer coding is essential for complex data analyses, and knowledge of maths and statistics is also important. Some palaeontologists are using techniques from engineering to study how extinct animals moved.

- As most scientific literature is in English, Davide advises that a good grasp of the English language is important, and that reading and writing are fundamental skills.

Explore careers in *palaeontology*

- Many palaeontologists work in research institutions, such as universities or museums, where they study specimens found in the field or contained in collections.

- One of the best ways to gain palaeontology experience is by getting involved with a museum. Many museums have volunteer programmes or even paid internships.

- The Palaeontological Association creates a Careering off Course newsletter that features tips from palaeontologists that have been successful in their chosen career paths: **www.palass.org/careers/series-careering-course**.

- In this interview, Dr Susie Maidment, a palaeontologist at the Natural History Museum in London, shares how she got into this career: **www.nhm.ac.uk/discover/how-to-become-a-palaeontologist.html**


A reconstruction of *Scleromochlus* © Gabriel Ugueto

Q&A

Meet Davide

What were your interests when you were younger?

When I was very young, I loved collecting dinosaur figurines and cards. I then 'forgot' about that early interest, and I didn't pick up palaeontology again until I was in university. In my teenage years, I spent a lot of time hiking outside and playing computer games.

What pathway has led you to become a palaeontologist?

I went to the University of Pisa in Italy to study maths, but quickly realised that although I had loved maths at school, it was not a suitable career for me. I switched to studying geoscience, thinking I could apply my maths skills in the field of geophysics. But when I took a geology course in vertebrate palaeontology, I became convinced that this was the branch of geoscience that was most interesting for me.

After I graduated, I moved to the UK to complete a master's in palaeobiology at the University of Bristol. This taught me that palaeontology is much more than studying dinosaurs – there are so many interesting groups and time periods to be studied! For my master's research I used 3D models to understand the feeding behaviour of a large Jurassic marine reptile, called *Pliosaurus*.

My time in Bristol opened the doors for the many opportunities that have followed. I completed a PhD at the University of Edinburgh, where I described some odd ancient relatives of crocodiles that lived in the sea, and I looked at the ecology of Jurassic marine reptile faunas and their evolution through time. I studied the Elgin Reptiles during my postdoctoral research with the National Museums Scotland and I have now moved to the US to expand on this research by investigating the evolution of ecosystems across the Permian-Triassic Mass Extinction, working with colleagues at Virginia Tech (USA) and the University of Birmingham (UK).

What have been your favourite fieldwork experiences?

I will always remember the first plaster jacket I made. To extract a fossil from the ground, you must first cover it with plaster to protect it. My first plaster jacket was for the bone of a turtle from the Cretaceous period. Although it was nothing special from a scientific point of view, it was a great moment for me.

I did quite a bit of fieldwork on Scottish islands. A highlight was finding a new site of Jurassic dinosaur footprints and a large tooth from a carnivorous dinosaur on the same day. Since moving to the US, I have been involved with fieldwork in the deserts of Texas, Arizona and New Mexico where we have discovered lots of fossils.

What do you enjoy doing in your free time?

I love many activities that go well together with my interest in geology and palaeontology, such as visiting museums, hiking, outdoor activities and travelling.