THE OCEANS BEFORE FISH

Despite their huge abundance and diversity in the oceans today, modern bony fishes (ostéichthyens) were not among the first animals to evolve. Before bony fish, the oceans teemed with invertebrate life, those animals that have shells or carapaces instead of bones, such as oysters or crabs, or that lack any hard parts whatsoever, such as worms.

In a rapid burst of evolution known as the Cambrian Explosion, the oldest known animals originated in the oceans more than 500 million years ago during the Cambrian geological time period – making them twice as old as the oldest known dinosaurs and at least 50 million years older than the oldest bony fishes. These first animals were often bizarre in appearance and difficult to interpret, but they actually represent the ancesters of many modern animal groups still alive today. The Cambrian Explosion was followed by a second burst of evolution during the Ordovician geological time period, called the Great Ordovician Biodiversification, when animals started looking more similar to what we see in the oceans today as the weird wonders from the Cambrian started going extinct.

The fossils of the Fezouata Biota in this exhibit represent a brief glimpse into life in the oceans at a moment exactly between these two evolutionary bursts, capturing the last gasp of the strange ancient ancestors of the Cambrian Explosion together with the rise of more typical invertebrate animals at the dawn of the Great Ordovician Biodiversification.

FEZOUATA FOSSILS

In the Anti-Atlas region of Morocco, some 300 kilometers southeast of Marrakech, a series of high cliffs and beautifully exposed stratified rocks give a striking landscape, but the magnificent fossils shown in this exhibit actually come from the low gentle hills of the desert in the foreground of these cliffs. The rocks belong to the Fezouata Shale formation, and were deposited during the Early Ordovician geological time period, 480 million years ago. They are made from fine particles of mud that settled out of ocean waters around 100 metres deep, off shore of an ancient continent located near the south pole. Trapped in these muds are fossils of bright yellow, orange and red colours that show exceptional completeness, and sometimes preserve non-shelly parts of their bodies that don't normally make it into the fossil record.

The shelly fossils from these rocks have been known since the 1950's, but the exceptionally preserved fossils from Fezouata were discovered nearly 50 years later, in the early 2000's, by Mohamed 'Ou Said' Ben Moula, a local collector from Taichoute, near Alnif. The fossils of this exhibit were selected from a collection of over 3'000 specimens excavated by Ben Moula and his sons during 2015 to 2016, and brought to the University of Lausanne in 2017, where they have since the subject of major paleontological investigation. We invite you to explore these beautiful fossil and the remarkable insights they bring to understanding life in the oceans of the south pole half a billion years ago.

A COLOURFUL TREASURE TROVE OF ANCIENT POLAR FOSSILS

Deep in Ordovician time, the continents were gathered in the southern hemisphere and the seafloor of Fezouata was located close to the south pole. The temperatures of the ocean water were not glacial like today, but were more temperate, in a globally hotter context where ocean waters could reach up to 40°C in tropical zones. At Fezouata the water was 50 to 150 metres deep, and the seafloor was periodically smothered by influxes of mud and fine sands kicked up by storms in the shallows.

Each fossil bed represents a snapshot of the animals that lived or had recently died at that place on the seafloor. As these carcasses were buried, their bodies flattened and shells, carapaces and some internal organs were replaced by iron-rich minerals during the rock-forming process.

Hundreds of millions of years later, the formation of the Atlas Mountains and erosion brought the rocks close to the surface and the circulation of rainwater caused the iron-rich minerals to rust, giving the fossils their bright red, orange and yellow colours.

CRAWLERS OF THE SEAFLOOR

Currently the most numerous and diverse group of animals, arthropods—today including insects, spiders, millipedes, lobsters, and crabs—have always been important components of ecosystems in the past. The Ordovician Fezouata was no exception, with many arthropods walking or crawling on the seafloor.

Trilobites are abundant and diverse, showing different life stages, both babies and adults, and many different ecologies. Some individuals preserve soft antennae or walking limbs, in additional to their thick, hard exoskeleton. Fezouata has also yielded the oldest known horseshoe crabs.

They were extremely numerous, sometimes found with dozens in close proximity on the same surface of rock. Juvenile and adult life stages are recognized at Fezouata overall, with juveniles typically found in rock layers deposited at shallower water depths, while adults predominate at rock intervals deposited at deeper water depths. Individuals migrated from shallow to deep waters as they grew, similar to what modern horseshoe crabs do today – a migratory behaviour that has been conserved for 480 million years.

A STRANGE ARTHROPOD WITH SO MUCH TO TELL US

One of the most remarkable Fezouata fossils is this marrellid arthropod, which was distantly related to trilobites and crustaceans. The marrellid's most distinctive feature is a large head carapace bearing three pairs of long spines.

What would have been the purpose of this big head shield? Protection from predators, or maybe to achieve stability when crawling on the soft sediment? What we do know is that the fossils of this head carapace provide us with information about moulting – the shedding of the exoskeleton that all arthropods must do in order to grow.

At Fezouata we find the discarded moults of the marrellid with distinctive breakage lines through the head shield, separating the two anterior pairs of spines from the third posterior pair of spines. Fezouata also preserves both juvenile and adult specimens, meaning we can track the growth of this arthropod from tiny baby size of just a few millimeters in length, up to the adult size ~8 cm in length.

To study the smallest specimen, researchers at UNIL employed CT-scanning, similar to a medical 3D x-ray scanner, to reveal tiny appendages and spines still embedded in the rock.

GENTLE "GIANTS" OF THE ORDOVICIAN

In the oceans before there were fish, whales and sharks, what were the largest swimming animals? At Fezouata, a group of bizarre arthropods called radiodonts occupied a similar ecological role to whales and whale sharks – giant planktivores, meaning that they filtered plankton made up of microscopic algae, plants and animals.

The broad, rounded bodies of these radiodonts were equipped with a series of lateral swimming flaps that enabled them to swim like manta rays. Their heads were covered by a carapace, and two frontal appendages possessed very fine spine-like structures to trap small plankton, like whale baleen. At Fezouata, these animals could reach an estimated size of two meters and are known from hundreds of fossils.

These gentle giants evolved from Cambrian superpredators, which possessed two large compound eyes, frontal appendages adapted to grasping and slicing up large prey, and a circular jaw. These last two structures are found as rare fossils at Fezouata, showing that some predatory radiodonts were still lurking in the shadows during the Ordovician.

THE IMPORTANCE OF BEING BIG

As the largest animal in the Fezouata ecosystem, fossils of the giant radiodont *Aegirocassis* reveal important ecological interactions in unexpected ways. Their large head carapaces are sometimes found covered in small round shells of brachiopods, and a study at the University of Lausanne suggested that these were attached to the radiodont during life. These normally sedentary animals are filter feeders, just like *Aegirocassis*, and were hitching a ride on the giant swimmer to ensure they always have access to the richest plankton sources.

After death, *Aegirocassis* was a hugely important food source for scavengers living on the seafloor, similar to whale falls in the modern oceans. Their carapaces are sometimes covered in tracks, trails and burrows of animals that likely ingested the organic component of their carapaces.

As can be seen here, numerous large *Aegirocassis* carapaces are sometimes found piled up together covering a large surface area. Exactly how these accumulations of large carapaces formed is a mystery that is still being investigated by researchers.

ONE OF THE EARLIEST ANCESTORS OF SCORPIONS, SPIDERS AND HORSESHOE CRABS

Modern scorpions, spiders, and horseshoe crabs belong to a group of arthropods known as chelicerates, equipped with pincers used for biting, grasping prey, or injecting venom—the chelicerae.

The origin of this group has long puzzled paleontologists, as it has been impossible to identify with certainty any early arthropod species that shared enough similarities with modern chelicerates to be considered their ancestors. Research conducted at the University of Lausanne has identified a Fezouata animal that, for the first time, allows scientists to trace the entire lineage of chelicerates, from the appearance of the earliest arthropods to modern spiders, scorpions, and horseshoe crabs. This animal, known from hundreds of fossils, has been named *Setapedites abundantis*. Measuring between 5 and 10 millimeters, it must be studied under a microscope.

Become a scientist and use the microscope to observe the beautifully preserved anatomy of *Setapedites*, including remains of its head limbs!

THE DIVERSITY OF FEZOUATA FOSSILS

In recent years, the arthropod fossils of the Fezouata have been the main focus of research at the University of Lausanne. Their stories are revealed in the four larger display cases. The ten smaller square display cases highlight the rest of Fezouata animal diversity other than arthropods.

Ancient versions of edible shellfish are represented by orthocone cephalopods (ancient calamari) and snails (ancient escargot), different types of molluscs. The Fezouata starfish and sea lilly fossils are echinoderms that are somewhat similar to animals alive today. But unusual extinct examples of both molluscs and echinoderms are also on display. Other Fezouata animals include a variety of sponges, worms, an unusual pyramid-shaped fossil, and a variety of branching and filamentous animals. The latter are floating colonies of tiny animals, called graptolites, whose skeletons are used to give a precise age to the rocks of the Fezouata. Of particular importance is *Sagenograptus murrayi*, typical of the Tremadocian geological age, a subdivision of the early Ordovician period (~480 million years ago).