Something fishy

Introduction

In previous articles we have looked at the possible methods by which protocells could have started and later evolved into prokaryotic cells and eventually, eukaryotic life. These were very distant events occurring in the Precambrian period around 2-3 billion years ago (2-3 thousand Ma ago). Taking the view that the **Invertebrata** predates the **Vertebrata**, I have also considered some of the suggestions how **Chordates** (simpler precursors to the Vertebrates) could evolve from Invertebrates. This article continues the story and involves events sometime later. The examples of life I have selected are those of whom we have evidence of arising during the geological period referred to in the title of the sub-heading. They are also included because they help tell the story of the **Tetrapods** and/or they are interesting in their own right, I just like them!

Start Date (Millions of Years from Present)	Period
2.6	Quaternary
23	Neogene
66	Palaeogene
145	Cretaceous
201	Jurassic
252	Triassic
299	Permian
359	Carboniferous
419	Devonian
444	Silurian
485	Ordovician
541	Cambrian
4560	Precambrian

I have used **geological periods** as the titles for sections of this article, the point being that I hope you get an idea of passage through time and a feeling of how modifications are made gradually, modifications which serve the purpose for the organism, but may have more significance for those animals to inherit them in the future.

Cambrian 485-541Ma ago

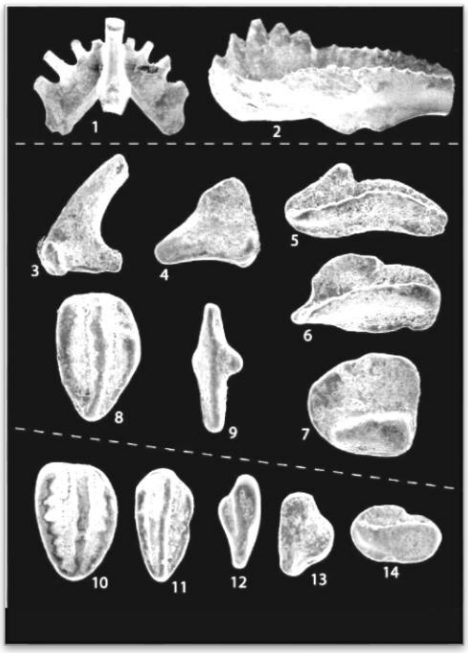
Sea floor spreading separated the North West Highlands of Scotland from the remainder of what much later would become united as the British Isles. At this time North West Scotland was part of the land mass of North East America, the remainder of what was to become Britain lay 5000km to the south, not far from the South Pole. Biologically, the beginning of the Cambrian was a particularly important period where great diversification of animal types occurred and the main groupings of body plan were established, most of these would carry forward their structural plan and underpinning genetic makeup into modern day. Because of the relatively sudden appearance of diverse animal forms, this has been called the **Cambrian Explosion**. Notable rocks containing fossil groups of animals of this period are the **Burgess Shale** of Canada and the **Maotianshan Shales** of Yunnan, SW China. These deserve a story of their own, but later.

A Geological puzzle offers a solution to timing

Limestone is a sedimentary rock; it is built from accumulations of calcareous debris on the bottom of seas and lakes. This debris is largely the skeletal remains of organisms that have lived their lives in those seas and lakes, died and once soft tissues have rotted away, the remaining shelly, bone or teeth fractions sink to the ocean floor. Over time quite a lot of this material can accumulate, sometimes to a depth of several kilometres.
The sediments will show a succession of debris from animals living in the water at different times (and also some plants which also have tough or calcified parts such as some algae). The problem for the geologist is being able to show the passage of time, essentially who was living when.
There are several methods of dating rocks and the fossils in them, a familiar method uses the radioactive decay of elements such as carbon, potassium and uranium, the appropriate element chosen so that its rate of decay is suitable for the expected age of the rock or fossil. Other methods trace the magnetic orientation of minerals in rocks. Since the Earth's magnetic poles have moved and even reversed in polarity over time, it is possible to relate magnetic orientation of the contents laid down in the rock to a period in the earth' history. This not as simple as it seems, because many rocks have moved as continental plates of which they are part have migrate over the Earth's surface.
Fossils have, since the start of Geology, been used as convenient markers to compare the relative ages of the rocks in which the fossils were found. For example: if similar fossils should be found in different

places this should indicate that rocks bearing these fossils are roughly the same age. For over 100 years these fossils (picture to the right) have been used:

These are **Conodont** fossils. Analysis indicates these structures are Apatite, a mineral comprising of Calcium and Phosphate, but without more evidence of the animal's body and presence of the internal strengthening elements of a skeleton, it was not possible to classify their origin and certainly it was not obvious that they were early examples of the Vertebrates.



Credit: Wikipedia commons

However, Conodonts survived as a body plan for 285Ma, from the mid Cambrian to the mass extinction event at the end of the Triassic. To put in such a long stint without changing their body plan is indicative of a very stable ecological niche, something we might ponder in relation to our own treatment of the planet!

Credit: Natural History Museum, London who purchased the fossil in 1980.

They were an enigma for many years, obviously teeth of some sort, but who had left their dentures on a rock after they had shuffled off? Despite enquiries the owner could not be found until fossils of the whole animal were found at last in Devonian rocks of Cheese Bay near Edinburgh in the 1980s. The fossil to the left is from the nearby Granton shrimp beds and measures 15mm, bar intervals are1mm.

This is an artist's reconstruction of the whole animal as it might have looked in life.

Promissum pulchrum

Credit:Nobu Tamura

Note the Chordate features shown in the reconstruction: head, eyes, myotomes (muscle blocks) in the abdominal region. Note also the lack of fins, there is no evidence of tetrapod features. A major drawback, probably limiting the size of these animals, was the lack of gills; presumably oxygen moved into their bodies from the water by passive diffusion.

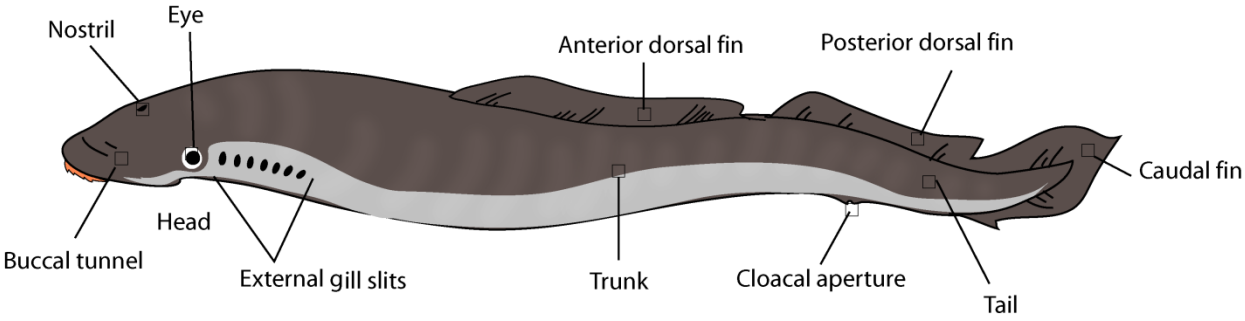
Although the Conodonts eventually died out in the Triassic, modern animals, closely related to them have continued through to the modern day. These are the **Cyclostomes**, they are important in that they are survivors from such remote times, so we will look at these next.

Fish give monarch his chips

Contemporary rumour had it that King Henry I died having eaten “a surfeit of lampreys”. **Lampreys** and their cousins, the **Hagfish**, are not the first delicacy one would think attracted a feasting king’s attention; perhaps it had been a wild night! Here are some snaps from recent celeb “Cyclostome” photo shoots:

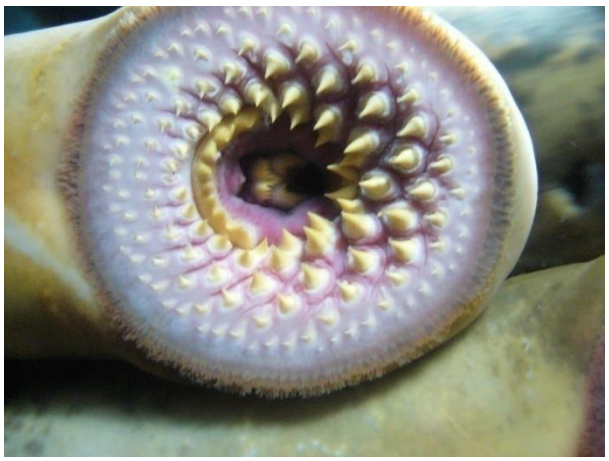
Credit (above and below): Wikimedia commons

Diagram of a typical Lamprey. Note the **gill slit openings** and lack of jaws and pectoral and pelvic fins

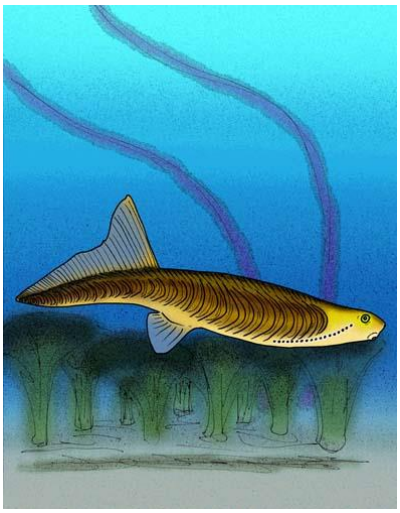


Credit: Wikipedia Commons

Petromyzon marinus (Lamprey) mouth



This is the machine end. Note the teeth; they superficially recall those of fossil Conodonts, different group of animals, but similar solution to the same biological structural problem: no jaws!



Fossil Lampreys are very rare. They do not fossilise very well because they lack bone, their body structure relying upon cartilage which is more easily broken down either by bacteria or chemical means. Fossils are found however, here is an artist’s interpretation of one such fossil *Jamoytius kerwoodi* from the Silurian period (409-439Ma ago)

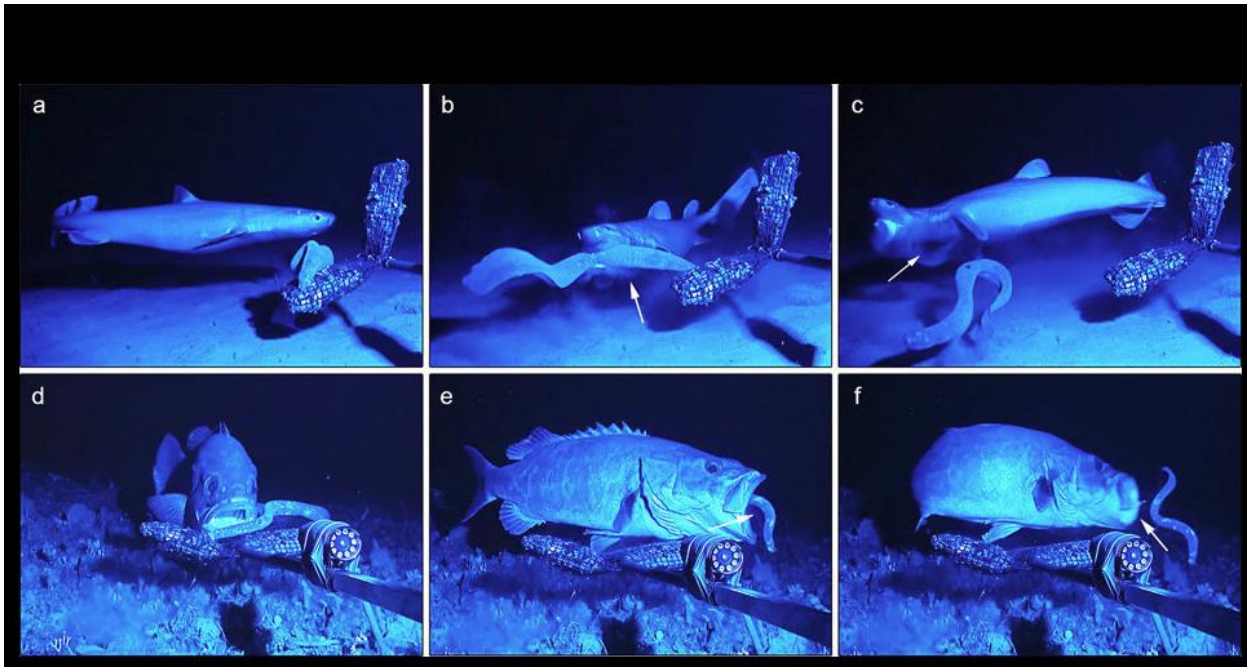
Credit: Apokryltaros, Wikpedia Commons

A Hagfish protruding from a sponge. Credit: Wikicommons

Not to be overlooked in the Cyclostomata beauty line-up are the Hagfish. These are detritivores, feed on dead and decaying fish and more or less anything else on the sea shore, rinsed down with an occasional blood meal from a passing fish or whale.

They are remarkable animals, as the next sequence of shots show. The hagfish is attacked by a Seal Shark *Dalatias licha* (a–c); you would imagine this encounter would result in a serving of hagfish calamari in rich offal sauce. Not a bit of it! Old hagfish aims a squirt of slime into the sharks open mouth and this gums up the shark's gills. The next attack on the hagfish is from a Wreck Fish *Polyprion americanus* (d–f) which suffers the same treatment vomits the hagfish and retires retching.

Credit: Wikicommons



Credit: Stan Shebs, Wikipedia commons.

Pacific Hagfish *Eptatretus stoutii*

Just when you thought photographs could not come much worse, here is a picture of a Hagfish (and friend perhaps) asleep under a rock. Ah, so sweet they look!

Note the **gill openings** visible in this picture.

Well, I expect their parents were pleased with them. These are modern animals, but their ancestors go back to the Cambrian and are examples of early Vertebrata, so early that they lack jaws, consequently called **Cyclostomes** ("round holes/mouth") and the condition of lack of jaws makes them "**Agnathan**". They live parasitically on fish, using a rasping tongue to release blood as a meal which they consume. There are improvements in design over the Conodonts: now there is an efficient oxygenation of the blood

with a flow of water through the mouth, over internal gills where gaseous exchange occurs and out through holes or slits in the thorax. With the increase of efficiency, size can increase, Lampreys and hagfish range around 500mm.

Ordovician 444-485 Ma ago

Credit: J.Giles.

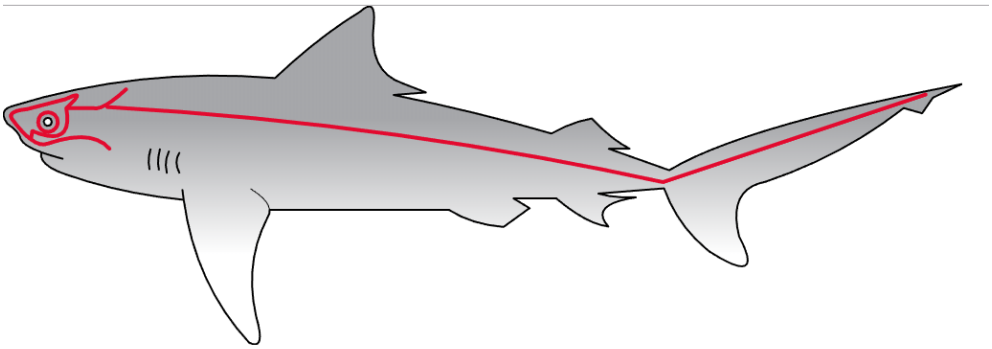
This was a time of extreme geological violence. Volcanoes in that part of the earth's crust that would eventually be the **Lake District** and **Wales** produced ash and lava on a vast scale, to accumulations often kilometres in depth. Many cliffs of these rocks are exposed today in **North Wales** and owe their origins to under water volcanoes producing jets of white hot **ash** which fused on contact into solid rock. You can see the **clasts** of unmelted debris from the volcano vent as darker pieces of rock in the picture to the left:

Rhyolytic tuff, North Wales (X1)

Spooky touch at a distance

Ordovician fish look primitive to those we see on a fishmonger's stall today. They still lacked jaws and pectoral/pelvic fins, but their fossils show evidence of the "**Lateral Line**". This is a sense organ found in all modern fish and consists of a number of pits in the skin running along each side of the animal from front to back. In modern fish there is a nerve ending within each of the pits which allows the fish to sense vibrations often arising in the water some distance away, so the sense has been likened to a "distant touch". Whether this is sensing a change in the water such as incoming tide, nearby rocks or a possible predator, it's obviously a useful sense to have if you happen to be a fish, in fact so useful that boats have their own equivalent system in "Sonar". The diagram below shows the layout (in red) of the lateral line in a modern day shark.

Credit: Chris huh – Wikipedia Commons



Ordovician fish also show evidence of internal bone and the use of dentine to armour the skin.

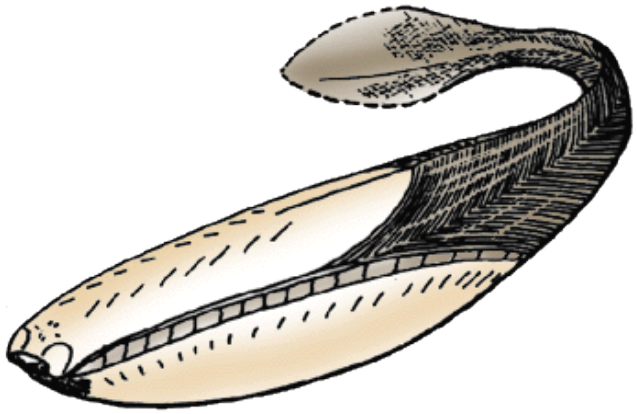
Examples of Ordovician fish

Sacabambaspis, a fossil fish discovered in Ordovician rock in **Bolivia** has paired nostrils which possibly were related to the sense of smell which must have made these fish more efficient in finding, or alternatively, becoming food! Still no paired pectoral or pelvic fins though, forward propulsion was presumably afforded by the tail (**Caudal**) fin. The next picture shows the fossil:

Credit: Ghedoghedo, Wikipedia Commons

The artist's reconstruction gives us an idea of what the animal looked like. It's perhaps tempting to question the degree of guesswork involved in converting a squashed and decomposed animal into such a clear picture. The way Science works should help to quell our doubts. The discovery and interpretation of this fossil will have been published (in this case in: Gagnier, P. Y. (1989). "The oldest vertebrate: a 470-million-year-old jawless fish, *Sacabambaspis janvieri*, from the Ordovician of South America." National Geographic Research, 5, 250-253.). When a scientist sends his report as a "**Paper**" to be printed in a Journal, the publisher sends copies of the paper to several other scientists who are experts in the field of science which the scientist's paper addresses. If they accept that the findings are new, reliably follow from the observations made, in this case from study of the original fossil, then they report their acceptance to the publisher and the paper is published in a scientific journal and becomes part of accepted canon of scientific thought. This process is called "**Peer Review**" and is one of the strengths of scientific method and even when published, the paper is likely to be questioned by other scientists working in the same field and reviewed in the light of further evidence.

Sacabambaspis janvieri



Credit: Philippe Janvier, Wikipedia Commons.

Characteristic of this species of Ordovician fish are the eyes which look like car headlamps. There is some indication of a chevron arrangement of the scales covering the abdomen. The gill openings were probably numerous but are minute and the nostrils possibly between the eyes. The Lateral Line is thought to have been beneath scales indicated in the drawing on the sides of the animal.

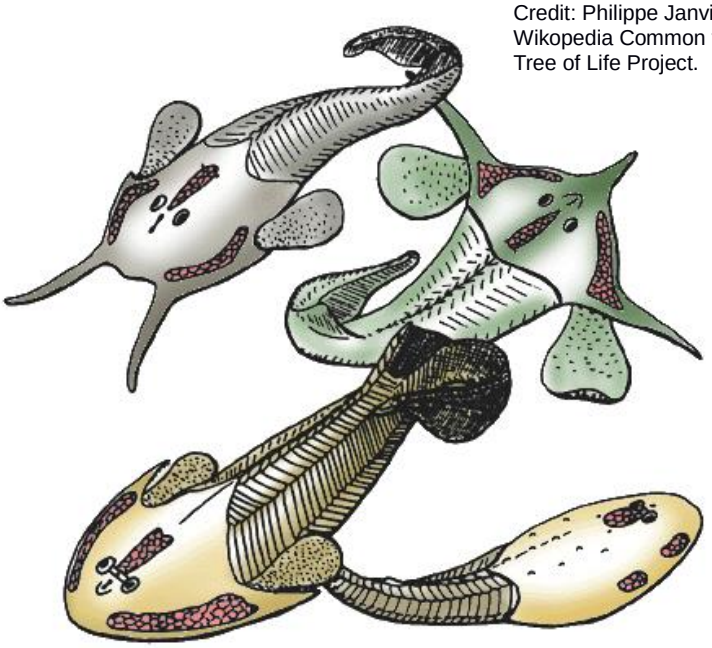
Silurian 419-444Ma ago

The region of the British Isles witnessed massive mountain building caused by collision of continental plates. The final contact between the continental plates of a preBritain land mass with preNorth American land mass caused the uplift of mountains of Himalayan proportion in the region which 419Ma later would become Scotland. Rapid erosion of the "Caledonian" mountains resulted in rivers carrying rock and silt which they deposited over the rest of the British Isles, over time forming rock today called "**The Old Red Sandstone**".

Osteostracans (Early Silurian)

These animals form a **clade**, that is they are thought to have been closely related species. They lived from the late Silurian period (about 430Ma ago) finally dying out in the late Devonian. They are characterised by large and intricately designed head shields with small eyes, evidence of lateral line and a single nostril. They did not possess jaws and could not bite, although plates lined their lips and may have been moveable to manipulate food. Their fossils show that the head was covered in two **shields**, an inner case covering the brain with a hollow space for the gills and mouth cavity and an outer dermal layer strengthened by plates of bone covered in conical projections made from a type of dentine. These animals had a "third eye", the **Pineal** which is a **synapomorphy** of the vertebrates (that is the Pineal is a structure shared by all members of the **taxon** (group), "Vertebrates").

Credit: Philippe Janvier Wikopedia Common via The Tree of Life Project.



The Pineal gland in modern vertebrates secretes **Melatonin**, a derivative of **Serotonin** which regulates patterns of sleep and behaviour, such as breeding, on both seasonal and daily cycles. There is much debate as to whether the Pineal actually functions as an **eye**, or whether, as in the Osteostracans, it is positioned so that it can monitor daylight periods. In the Osteostracans there was a hole, ("**foramen**") piercing the skull above the site of the pineal and another keyhole shaped foramen for a nostril which probably housed an **olfactory sense organ**. Since this did not lead to the throat of the animal as in later vertebrates, it is analogous with Lampreys which have a similar arrangement. As you can see from the reconstructions of the fossils, the fish had pectoral fins:

Credit: Philippe Janvier Wikopedia Commons via The Tree of Life Project.

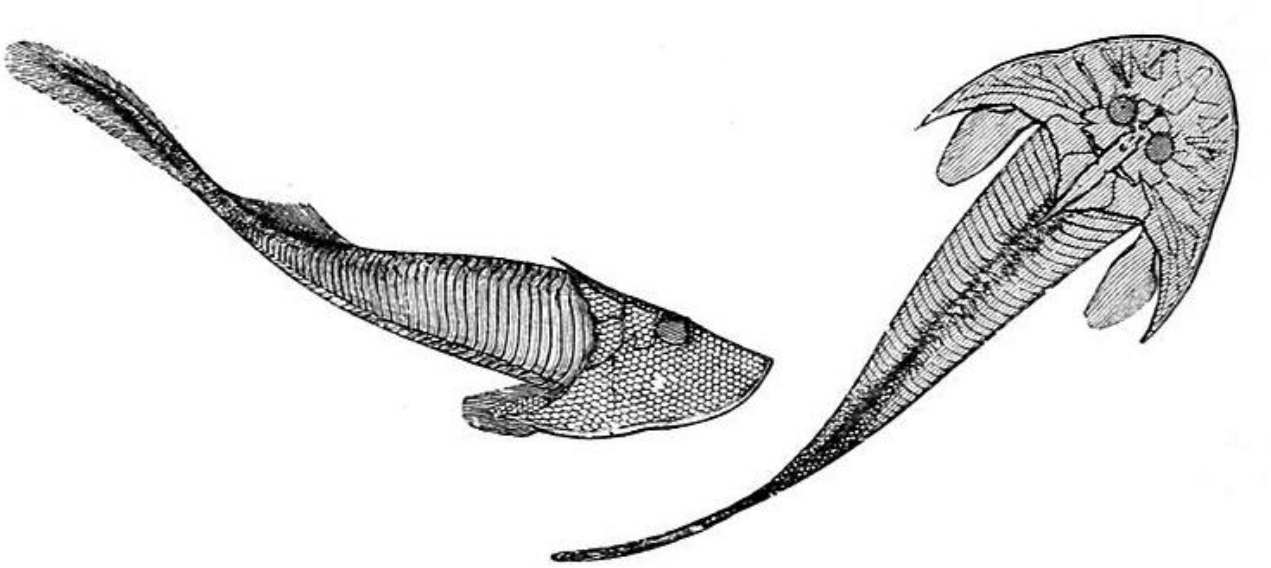
The zenaspidid osteostracan *Zenaspis pagei*, from the Lower Devonian of Scotland.

A wonderful fossil of an Osteostracan! You can clearly see the head shield, pectoral fin and markings from the scales.

The fossil was found in the Old Red Sandstone in Scotland:

Finally, here are a couple of drawings made in 1877 by Henry Alleyne Nicholson of *Cephalaspis lyellii* an Osteostracan. You get a sense of fluid motion in the left hand drawing and begin to see how such an animal was an effective feeder on the floor of an ocean unseen.

Credit: Public Domain



What beautiful drawings! You can see the limitations of these Vertebrates though, no jaws! This severely limits the types of feeding mechanisms and therefore prey and ultimately the range of such animals. Enter the **Gnathostomes**: the animals that solved the jaws problem, after that there was no looking back, and that's the next story.