ROLAND'S FORAMS

Artworks under the microscope Volume 1

Foraminifera – fossil and recent **by Roland Verreet**

Scholars have long studied the natural history of birds, dolphins, elephants, insects, fungi, and even meat-eating plants. But what about unicellular organisms? Who studies those?

At the moment, many virologists are studying the behaviour of the Coronavirus (which, according to the definitions of “life”, are not “living” organisms) and come to very contradictory results. But who else is studying creatures so small they cannot be seen?

All the creatures we can see with our naked eyes, whether they be elephants, trees, humans, fungi, insects or lion’s mane jellyfishes, only make up 10% of our planet’s biomass. If we want to see the other 90% of the biomass, we need to use a microscope.

High-quality microscopes are expensive and the expense is often the first barrier to studying such tiny organisms. The cost disadvantage, however, is offset by the small amount of space required to collect such objects. For example, a matchbox filled with foraminifera contains sufficient study material to last for many weeks.

As a long-time reader of the German publication “Leitfossil” (index fossil) I am always amazed by fossil collectors who have filled several rooms of their house with ammonites. Apparently, after every visit to a stone quarry, they must add another room to their home. In comparison, collecting microfossils is far easier.

This does not mean that you can’t get carried away with microfossils.

Figure 1: Specimen holders with mounted foraminifera

Figure 1 shows one of many dozens of shelves with mounted foraminifera specimens that I have collected over the years.

How it all began

What brings a very busy person to study microfossils and their living (recent) relatives? In my case it happened like this:

I am a self-employed engineer working as a consultant in the field of steel wire ropes; the kind of ropes used in crane, elevator, offshore and mining applications. My customers include some of the leading companies in their field, starting from “hidden champions” to some of the very large crane manufacturers or organizations like NASA. The work is much more interesting than outsiders might imagine (www.ropetechnology.com).

A few years ago, I worked on a mining project in South Africa together with a colleague who lived on Grand Cayman. We had come to a point where we had to meet in person, either in my hometown of Aachen, in Germany, or at his place in the Caymans. I ended up flying to the Caribbean and, as a souvenir of my visit, I brought home a small box of the extremely white sand from one of the Cayman beaches.

As we know, sand mainly consists of mineral grains and is usually formed when rock is weathered and subsequently transported by water (Figure2).

Figure 2: Mineral sand

Back at home I put a few grains of my sample under my microscope and noticed that there was not a single grain of sand in what was supposed to be a box of “sand”. Instead, the sample consisted of remnants of long-dead creatures (Figure 3).

My interest was awakened. What kind of creatures were they?

I read about the geology of the island, and I learned that the Cayman Islands were created by an uplift of the seabed. The “sand” on the beaches was the former bed of the sea with all its sediments.

I also learned that on Cayman there is a mineral that can’t be found anywhere else on the planet. It’s called Caymanite. The native Caymanians say that it has magical powers: it wards off the tax authorities.

Some of the objects in the sample were aesthetically pleasing (Figure 4).

Figure 3: Biological “sand” from the Cayman Islands

Figure 4: Biological “sand” with *Archaias angulatus* (Fichtel & Moll, 1798)

I realized that the creatures in the “sand” were (between fragments of coral) mostly foraminifera.

The history of foraminifera

Not long after the invention of the microscope, the first spiroidal foraminifera were described. The joy they brought to the scientists who first saw them was great: Ammonites had not become extinct at the same time as the dinosaurs, about 65 million years ago. They had survived as dwarf species!

Even Carl von Linné (Linnaeus, 1707-1778), the founder of taxonomy (whose birthplace in Sweden I once had the pleasure to visit) still classified the foraminifera as relatives of the nautilus.

But foraminifera are single-celled creatures that are neither plants nor animals. So, what are they?

In July 1837, at the age of 28, Charles Darwin drew the first “tree of life” in his notebook (Figure 5). This was the first time that a scientist developed the idea that through variation and selection one species (“1” in his drawing) could evolve into different species A, B, C, and D.

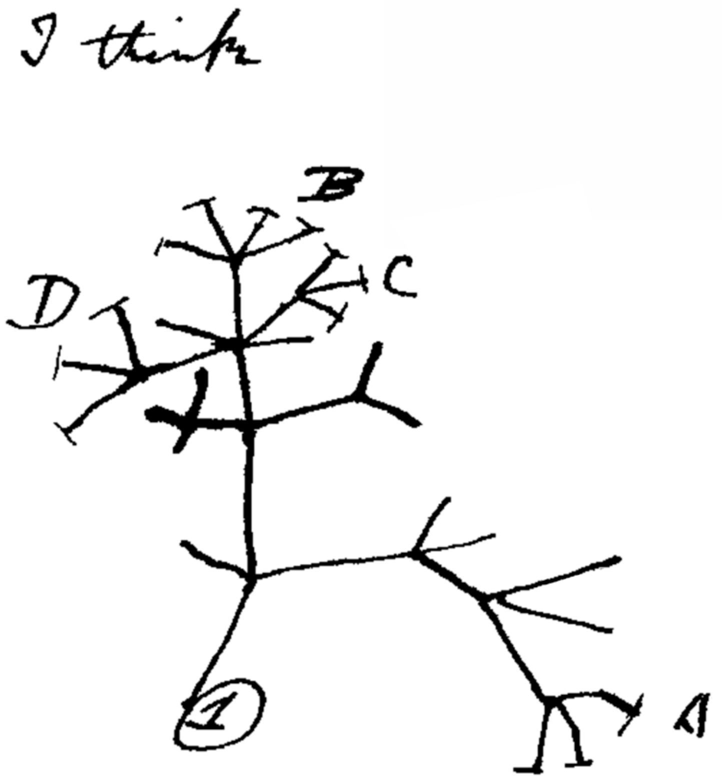

Figure 5 The first “tree of life”, drawn in 1837 by Charles Darwin

According to Darwin’s “tree of life”, not every single species was a creation of God but had evolved from previous species. This view is now commonly accepted by scientists, but 40% of Americans still hold this view to be blasphemy.

With increasing knowledge (and especially with the help of genetic sequencing) the “tree of life” became increasingly differentiated over the last 184 years. Today it is so complex that it’s hardly surprising that scientists disagree on many of its details (Figure 6).

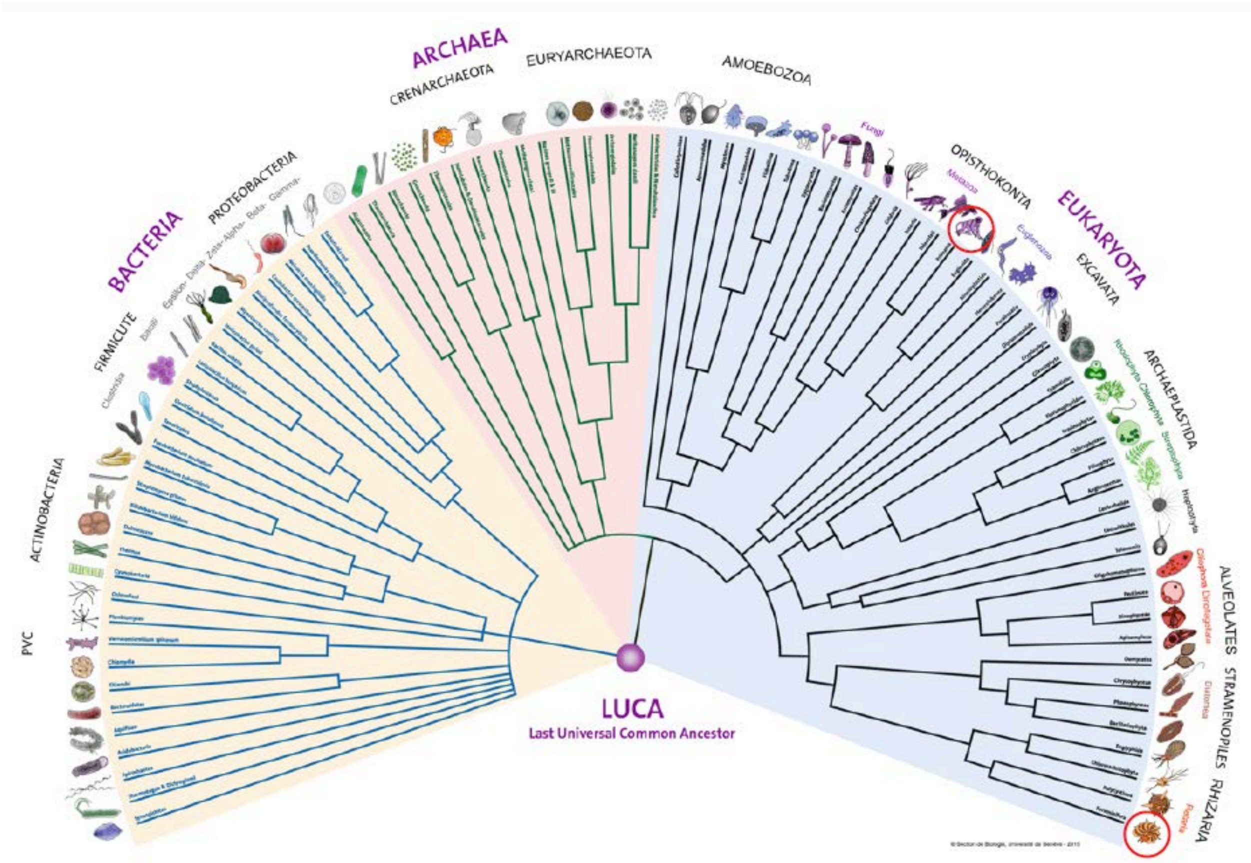

Figure 6: Modern “tree of life”

This difference of opinion mirrors today’s disagreements between virologists: ask three experts and you will get five mutually contra-dicting answers.

Aristotle, and even still Linnaeus, divided all life into two “kingdoms”: plants and animals. Today we distinguish (depending on whom we ask) between six, seven or eight kingdoms.

As an example, it was only in 1979 with the help of gene sequence analysis that it was discovered fungi are neither plants nor animals. As a result, today fungi have their own kingdom.

According to a proposal from 2015, life is divided into seven kingdoms: bacteria, archaea, protozoa, chromista, plantae, fungi, and animalia. Like it or not: you are in the animalia kingdom.

Figure 6 shows LUCA, the Last Universal Common Ancestor. This is the last creature all species alive today have as an ancestor. The descendants of LUCA split up, and their descendants split up even further.

In case you look for yourself in the “tree of life”, you are in the red circle in the upper right with the other apes. The foraminifera can be found in the red circle at the right bottom amongst the rhizaria.

You will not find Coronaviruses in the “tree of life”. According to the commonly accepted definitions, viruses do not “live” even though we are told that Coronaviruses “die” after three days. What a sad existence: they die without ever having lived!

What exactly are foraminifera?

Foraminifera are single-celled creatures. A cell consists of a nucleus, vacuoles and cytoplasm. The cell is typically protected by a housing called the “test”. The test is perforated by many small holes which give the creatures their name: Foraminifera means the “bearer of the holes”, derived from the Latin name “foramen” for “hole”.

We know about 6,000 recent and (according to different sources) between 40,000 and 80,000 fossil species of foraminifera. If you want to discover more about the diversity of foraminifera, you should visit the excellent website www.foraminifera.eu run by Michael Hese-mann.

A peculiar fact about foraminifera is that they consist of just one cell, but that cell can have many cell nuclei.

Foraminifera have existed for more than 540 million years. Most probably they are even much older, but before 540 million years ago they did not have a housing (test) and were therefore not preserved in the fossil record.

As was the case with ammonites, a housing only became necessary when the first carnivores entered the stage of life and armour became essential to protect against predators.

Interestingly, carnivores only developed at a time when the first eyes appeared. With the benefit of sight, some creatures no longer had to graze mats of algae (Ediacaran fauna) or to scavenge. With sight, they could actively hunt for living prey. Without eyes, meat hunters would certainly not have been very successful.

As a result, the development of the eye led to the development of carnivores, and both cephalopods as well as much smaller creatures such as foraminifera had to protect themselves against these new predators.

In the ensuing arms race, the cephalopods developed ever-stronger shells and, for even better protection, they rolled their housings up into a spiral so that the outer, stronger windings would protect the inner, weaker ones. The results were the ammonite shells with which fossil collectors continue to fill countless rooms.

While the shell growth in ammonites was a continuous process, the foraminifera developed individual protective chambers. Every time one chamber became too small for the growing cytoplasm, the foraminifera built a new, and bigger chamber (Figure 7), just as the ammonite collectors do by adding bigger and bigger rooms to house their collections.

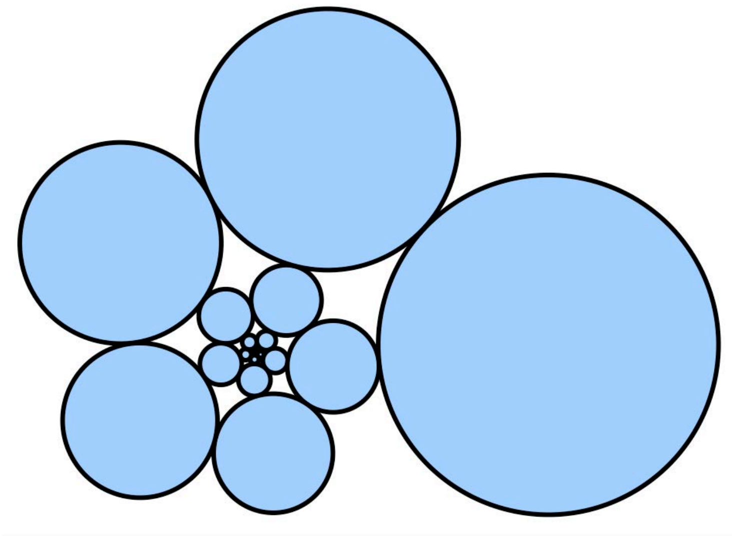

Figure 7: Growth pattern of foraminifera

D'Arcy Wentworth Thompson, the author of "On Growth and Form", one of my favorite books, realized that some foraminifera build their next chamber precisely 26% larger than the previous chamber (Figure 8). Why would that be?

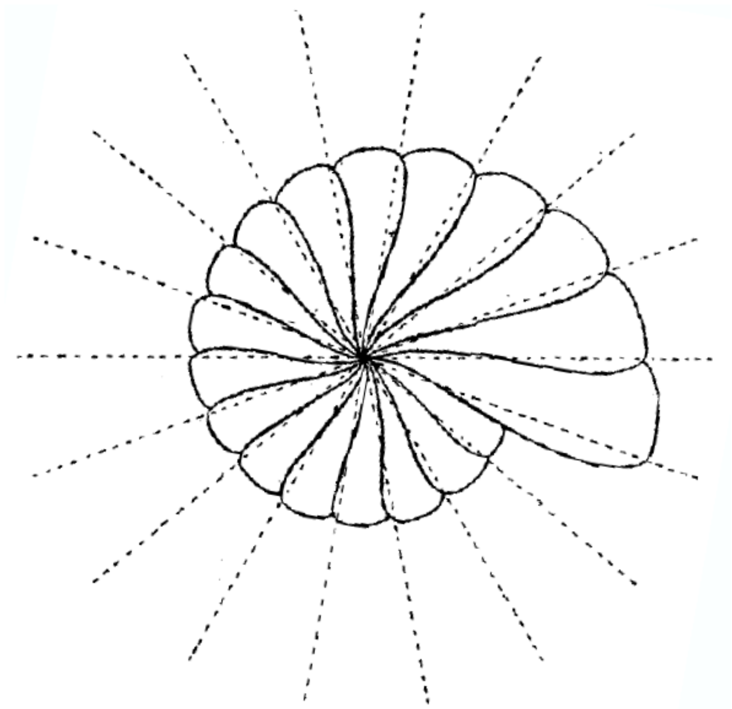

Figure 8: Chamber growth by a factor of 1,26 ©D'Arcy Thompson

If the new chamber grows in every direction by a factor of 1.26, the volume of this chamber grows by a factor of 1.26 x 1.26 x 1.26, which is exactly 2.

What would be the advantage of this? If the new chamber is exactly twice as big as the previous one, then it can hold the content of all the previous chambers taken together.

As an example, let us take a foraminifera with six chambers, each one with twice the volume of the previous one. Its total volume is:

1 + 2 + 4 + 8 + 16 + 32 = 63

Now the foraminifera adds another chamber which, in every direction, is 26% bigger than the last one. This one would then have a volume of 2 x 32 = 64. In this chamber, there is enough room for the volume of all the previous chambers taken together (=63).

This is what ammonite collectors can learn from the foraminifera; just build every new room 26% larger in every direction than the previous room! Then the collection of all the previous rooms taken together will fit into the new room. That will allow them to fill up the previous rooms all over again. And when that is done, they just need to build a new room again, 26% larger than the previous one….

The protection of the foraminifera was so perfect that their housings (tests) survived millions of years in the sediment and today they shine as photo models (without much space requirement) in my collection.

How do foraminifera build their housings (tests)?

Over the hundreds of millions of years of their existence, foraminifera have developed four different methods of building their housings:

The agglutinating foraminifera glue together particles from their surroundings. They are called Agglutinantia. Figure 9 shows an example of a miliolid foraminifera from the Cayman Islands.

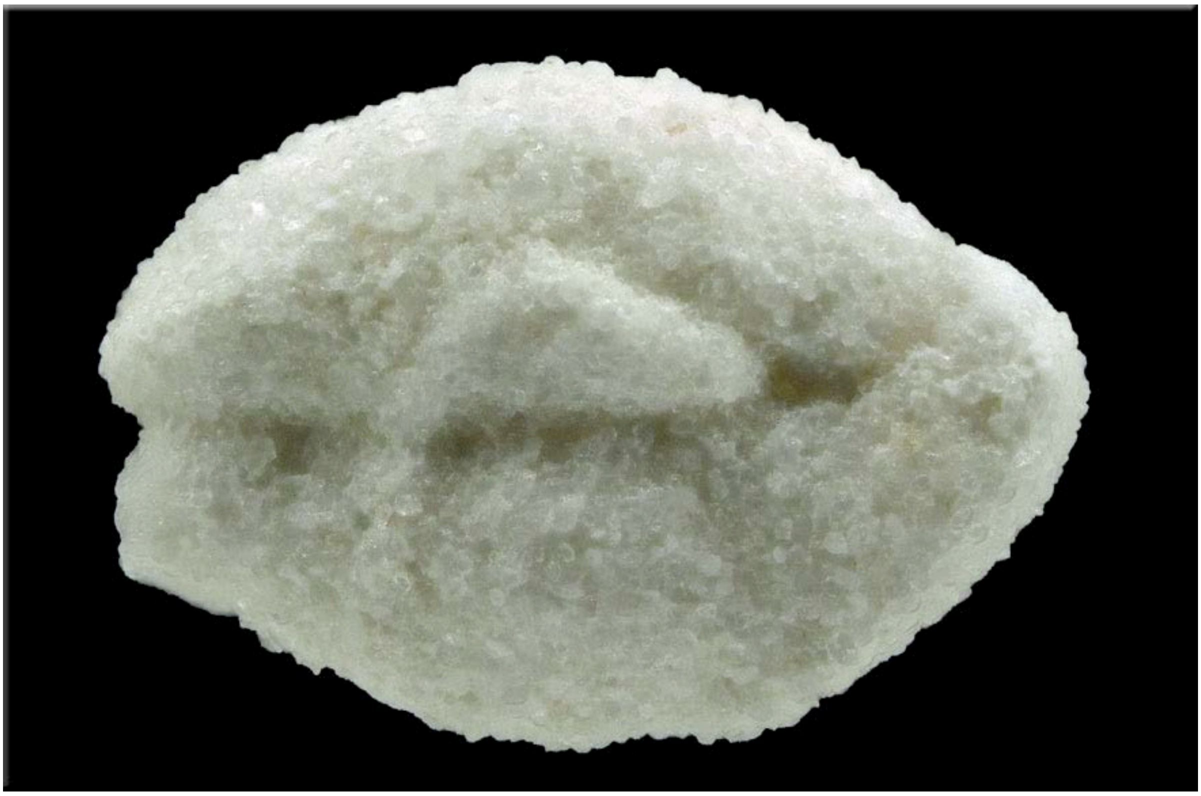

Figure 9: Miliolid foram test built from agglutinated particles

Some foraminifera build their entire test with a substance called tektin. Originally, this substance was incorrectly thought to be chitin (which is also used by insects), and therefore these species were called Chitinosa.

Figure 10 shows as an example a Chitinosa, a miliolid foraminifera from the Cayman Islands.

Some foraminifera use calcite (calcareous spar) as their building material. Their tests are not transparent. We call them Porcellanea (guess why). Figure 11 shows a bizarrely shaped example from the Cayman Islands.

A fourth group of foraminifera uses a special orientation of the calcite crystals to produce a transparent housing. These foraminifera are called Hyalina.

Figure 12 shows an example of a Hyalina, a transparent planktonic foraminifera from the Cayman Islands.

Figure 10: Miliolid foraminifera from the Cayman Islands, *Trioculina*

Figure 11: *Articulina pacifica* Cushman 1944, a porcellaneus foramini-fera

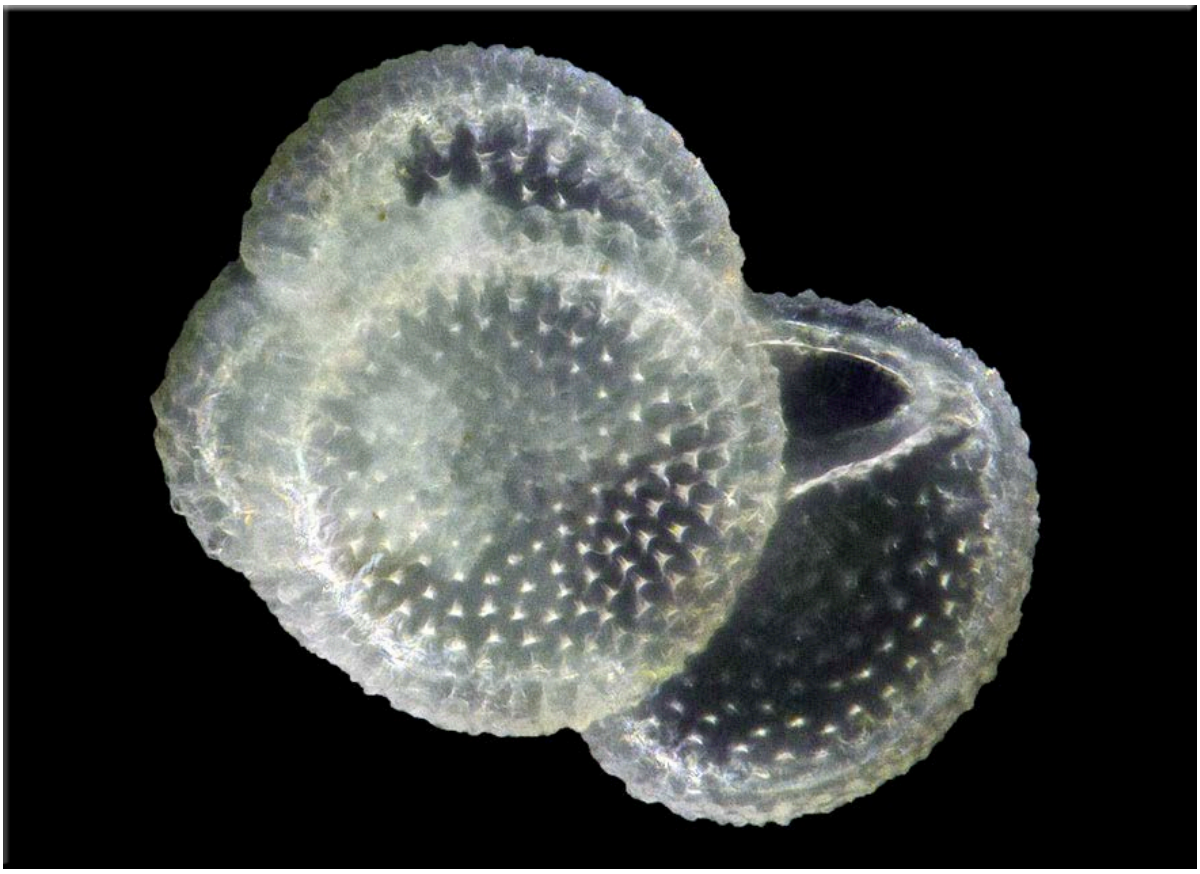

Figure 12: Planctonic foraminifera of the genus *Globigerinoides* from the Cayman Islands. *Globigerinoides* can be found in all seas around the world. The earliest forms were found in Oligocene deposits.

Nummulites

Foraminifera were first mentioned by Strabon (± 63BC 23AD). This Greek historian and geologist mistook the lentil-shaped forms that were found at the foot of the pyramids for remains of the lentil meals the workers building the pyramids had eaten.

However, the pyramids were built from nummulitic sandstone (Figure 13) which had formed from sediments of very large fora-minifera (nummulites). The pharaohs are therefore buried under millions of tons of foraminifera.

The name “nummulit” is derived from the Latin word for a small coin (Latin= nummulus). Figure 14 shows a cross-section of such a nummulite.

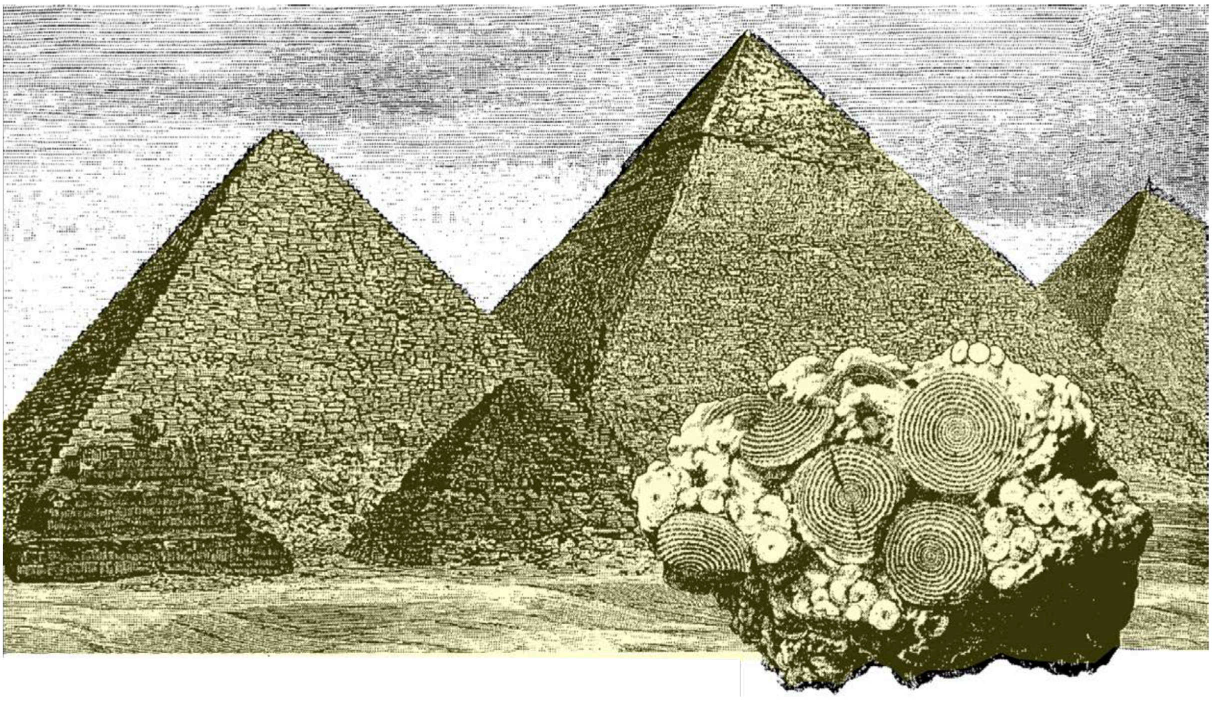

Figure 13: The pyramids of Gizeh, built from nummulitic sandstone

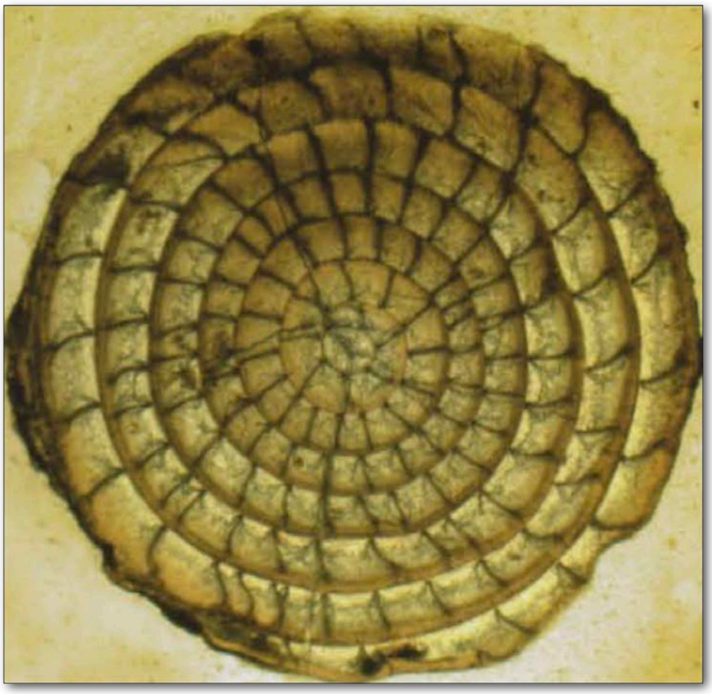

Figure 14: Enlarged cross-section of a nummulite. Many chamberlets are visible.

Cells

Although a foraminifera may consist of many chambers, its living tissue only consists of a single cell. Also, the nummulite shown in

Figure 14 only consisted of a single cell. After a hundred years of undisturbed growth, however, this cell could obtain a diameter of a few centimeters. Recent species of foraminifera have a lifetime ranging from a few weeks up to five years.

A foraminifera consists of a single cell. The human body, on the other hand, consists of about 70 billion (70,000,000,000,000) cells. Of these, about 30 billion are human cells, while the other 40 billion are foreign cells such as the bacteria which digest our food in our gut.

I don’t think I need to mention that quite a few scientists think that these numbers are fake news. According to their counts, the number of human cells is more in the range of 100 billion.

But one thing is clear: only 43% to 45% of the human body consists of human cells. And because women have a greater intestine compared to their body mass, their percentage of human cells is lower than that of men. Women are, therefore, a bit less human than men. My wife will be shocked when I tell her!

Locomotion

A few foraminifera species are planktonic and drift with the sea currents. They have very little influence on where they are going. But like nautiloidea or Cartesian divers they can change their specific gravity by compressing oil or air and thereby influence the depth at which they float.

However, most foraminifera are benthic, which means they live on or in the seabed.

In their tests, foraminifera typically have one greater opening (called an “aperture”) and many very small holes through which they can extrude their cytoplasm like spaghetti. These thread-like pseudopodia are used to catch prey, but they can also, like the name pseudo-“feet” suggests, be used for movement (Figure 15),

Figure 15: A foraminifera reminds me of a spaghetti maker.

The foram can anchor different pseudopodia in different directions and move in the desired directions by pulling on the correct “foot”. This is a cumbersome process, but it works.

Microphotography

Most foraminifera are much smaller than the nummulites mentioned above. They typically measure between 0.1mm and 1mm. This has the advantage that they do not use up much space in a collection, but it also poses a problem: How do you photograph such small creatures?

If you have ever tried to photograph an insect you know how difficult that is. An insect of e.g., 2cm length is 100 times smaller than a human (Figure 16). To photograph an insect you need a macro lens, bellows or extension rings. The depth of field of your camera will be so shallow that only a small part of the object will be in sharp focus.

How much more difficult is it to photograph the typical foraminifera which is just 0.4mm in size? This creature is 50 times smaller than the insect, and 5,000 times smaller than a human (Figure 16)!

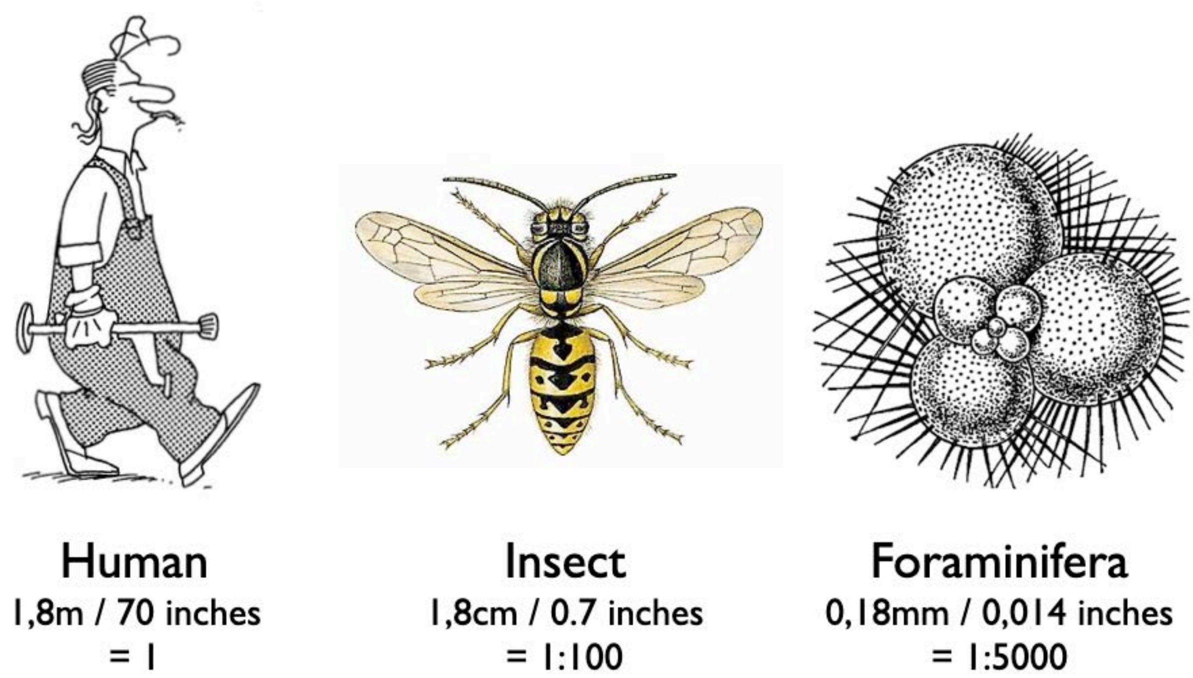

Figure 16: Size relationships between human, insect and foraminifera

The first scientists to use microscopes elegantly overcame the problem: they focused on one part of the specimen and drew by hand everything that was in focus. Then they changed the focus so that other parts of the object were sharp, and then they drew those details. They repeated this procedure until they had a complete drawing of their object.

Today, we photograph the objects under the microscope, and we proceed in a very similar way. We take a series of photographs from the deepest point of the object up to the highest point. As a result, we may have anything from 20 to 50 photos of an object, and on each photo a different part of the object is in focus. Then we use so-called stacking software to extract all the areas which are in focus and combine them into one sharp image (Figure 17).

Figure 17: First (left) and last (middle) photo of a series of 27 photographs and the stacked and “Photoshopped” resulting image (right)

The most popular software for this purpose is called PICOLAY. This software was written by Prof. Heribert Cypionka, a marine biologist who works with single-celled marine creatures. He is a gifted programmer and a very nice gentleman who shares his software for free (www.picolay.de).

Another way of photographing foraminifera with a good resolution is to use a scanning electron microscope. Admittedly, not everybody has access to a scanning electron microscope at home. However, I do; and I will share my experience working with both digital and scanning electron microscopes in a future contribution.

But I already want to mention one disadvantage of using a scanning electron microscope: if you want to use such a machine at home, you will have to add another room (like the ammonite collectors) despite the small specimen sizes. Or you might just need to get rid of your mother-in-law.

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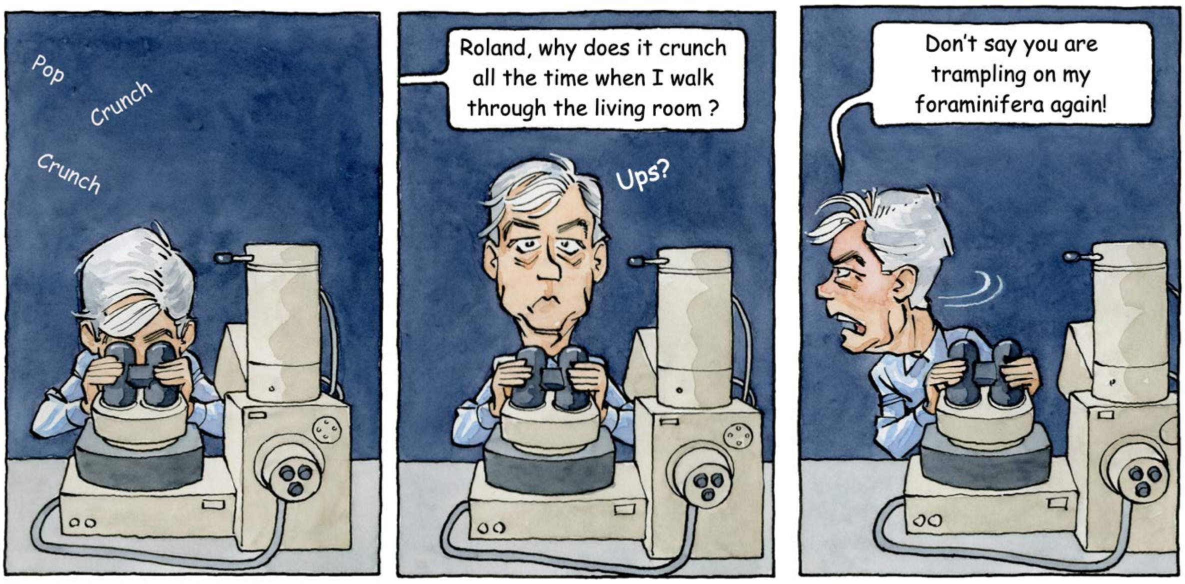
A large foraminifera from the Cayman Islands collected and photographed by the author. From the website www.foraminifera.eu.

A typical evening in the home of Regine and Roland



Cartoon by Rolf Bunse

Further reading

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Brasier, Martin. Secret Chambers- the inside story of cells and complex life. Oxford University Press, ISBN 978-0-19-964400-1

Holbourn, Ann et al., Atlas of Benthic Foraminifera, Wiley-Blackwell, ISBN 978-1-118 38980-5

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Mark Sparrow, Bath: Thank you for proof-reading the manuscript.