Tutorial Earth History and Evolution 3: Geological eras and Mass Extinctions

Geological Eras

We got to know which methods we can use to determine how old our earth is: It is around 4.5 billion years old. Such a long period of time is divided into different periods of time. Just as we divide a calendar into months, weeks and days, geologists and paleontologists also divide the earth into different time periods.

The International Commission for Stratigraphy (ICS), a permanent commission of the International Union of Geological Sciences (IUGS), defines the global standard time scale on which all global scales are based. The hierarchical structure follows two concepts that are used in parallel and are relatively similar to one another: geochronology and chronostratigraphy.

Geochronology, which determines the geological ages (Fig. 1) using absolute dating methods, divides the earth's history into the following hierarchical levels

eon

era

period

epoch

age

Chronostratigraphy, which determines the geological ages with relative dating methods, has the following names for the chronostratigraphic hierarchical levels.

eonothem

erathem

system

series

stage

Äonothem /Äon	Ärathem /Ära	System/ Periode	Serie/ Epoche	Nume-risches Alter (Mra)
PHANEROZOIKUM	KÄNOZOIKUM	QUARTÄR	HOLOZÄN	0,0117
			PLEISTOZÄN	2,58
		NEOGEN	PLIOZÄN	5,333
			MIOZÄN	23,03
		PALÄO-GEN	OLIGOZÄN	33,9
			EOZÄN	56,0
			PALÄOZÄN	66,0
	MESOZOIKUM	KREIDE	OBERKREIDE	100,5
			UNTERKREIDE	~ 145,0
		JURA	OBERJURA	163,5
			MITTELJURA	174,1
			UNTERJURA	201,3
		TRIAS	OBERTRIAS	~ 237
			MITTELTRIAS	247,2
			UNTERTRIAS	252,17
	PALÄOZOIKUM	PERM	LOPINGIUM	259,8
			GUADALUPIUM	272,3
			CISARALIUM	298,9
		KARBON	PENNSYLVANIUM	323,2
			MISSISSIPPIUM	358,9
		DEVON	OBERDEVON	382,7
			MITTELDEVON	393,3
			UNTERDEVON	419,2
		SILUR	PRIDOLI	423,0
			LUDLOW	427,4
			WENLOCK	433,4
			LLANDOVERY	443,8
		ORDOVI-ZIUM	OBERORDOVIZIUM	458,4
			MITTELORDOVIZIUM	470,0
			UNTERORDOVIZIUM	485,4
		KAM-BRIUM	FURONGIUM	~ 497
			SERIE 3	~ 509
			SERIE 2	~ 521
			TERRENEUVIUM	541
„PRÄKAMBRIUM"	NEO-PROTERO-ZOIKUM	EDIACARIUM		635
		KRYOGENIUM		720
		TONIUM		1000
	Auslassung von Proterozoikum (Teile) und Archaikum			4000
	HADAIKUM			~ 4600

Abb.1: Geological Time Scale

The individual names of the intervals are identical in both concepts. Both concepts are closely linked, because absolute (numerical) age or time data can only be obtained from geologically preserved material, usually by radiometric dating. A strict separation of geochronology and chronostratigraphy is therefore rarely maintained in practice. I will rely in my contributions on the designations of geochronology.

Earth history is divided into four eons:

The Hadean or "Aeon of Earth Formation," which began about 4.6 billion years ago and lasted about 600 million years, is the first of the aeons. Currently, there is no authoritative subdivision of the Hadean. Information about the age of the earth does not come from the rocks of the earth itself, but from special meteorites, the chondrites, which are assumed to have been formed in the same period as the earth and have not changed since then - in contrast to the earth. The age determination takes place by means of the isotope geochemistry. With it an age of approximately 4568 million years was determined.

The second eon is the Archean, with a time span of 4 - 2.5 billion years. The Archaic is divided into four eras: Eoarchaic, Paleoarchaic, Mesoarchaic, and Neoarchaic. There is no further subdivision into periods and epochs.

The third eon is the Proterozooic, also called the "eon of the unicellular organisms". It began 2.5 billion years ago and ended about 542 million years ago. It is divided into three eras: Paleo, Meso and Neoproterozoic. These three eras are again divided into 10 periods. Special mention should find here above all the last period, namely the Ediacarium. It began about 635 million years ago and ended about 542 million years ago. In this period the first multicellular animals developed. Many creatures of the Ediacara fauna hardly or not at all resemble the animals living today.

These three eons are also often summarized as Precambrian.

The fourth and probably best known eon is the Phanerozoic as "eon of visible fossils", because for a long time fossils were only known from this eon. It began about 542 million years ago and continues until today. The Phanerozoic is divided into three eras: Paleozoic, Mesozoic and Cenozoic.

Here is a subdivision into a total of 12 periods:

The Paleozoic has the periods: Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Permian.

The Mesozoic is divided into the Triassic, Jurassic and Cretaceous periods. This is the famous age of dinosaurs.

The Cenozoic is divided into the periods Paleogene, Neogene and Quaternary. Paleogene and Neogene were earlier summarized as Tertiary.

Here the individual periods are subdivided again into epochs and these into ages. To enumerate all of them would lead too far. But as an example: the Cretaceous is divided into the epochs Upper and Lower Cretaceous, which are both divided into six ages each.

The boundaries of the units or intervals of the Phanerozoic are primarily defined mostly by the appearance or disappearance of certain animal species in the fossil record (a so-called bioevent). These are always the remains of marine organisms because, first, marine sediments, especially shelf sediments, are much more abundant in the geologic record than continental sediments, and second, because shelf sediments are on average much more fossiliferous than continental sediments. So the interesting thing: the Mesozoic is paleontologically not primarily defined by the dinosaurs, but what was swimming around in the oceans.

Defined in each case is only the base, the lower boundary, of a unit, and the upper boundary is identical to the base of the next one. In addition to the primary markers, the units are additionally defined by secondary markers, which are intended to allow the unit boundary to be found in sediments that do not contain the primary marker facies-wise. Facies, in its broadest sense, refers to all characteristics of a rock that derive from its geologic history. These can be purely descriptive features (color, mineral content, fossils) or those that are typical of the formation (magmatism, sedimentation) or subsequent alteration (metamorphism, weathering) of a rock body. Thus, in addition to fossils, geochemical and/or magnetostratigraphic anomalies serve as markers.

The grouping of ages into periods and these in turn into eras is based on common features of the fossil record in the sedimentary rocks of these units. The boundaries of higher-ranking units therefore often coincide with major mass extinctions, as a result of which the composition of the fossil faunas changes markedly and especially at higher taxonomic levels. The geologic time scale thus also maps evolutionary history.

The division of the first three eons and thus of by far the longest section of the earth's history, with the exception of the Ediacarium, on the other hand, cannot be based on fossils because there are no fossils, or at least no useful fossils, in these rocks. Instead, an "artificial" classification is used, which is based on mean values of radiometrically determined age data of tectonic rest phases. These values, rounded to the nearest 50 or 100 million years, are called Global Standard Stratigraphic Ages (GSSAs).

For the older units of the Precambrian, the geological record deteriorates with increasing age. The exogenous and endogenous reworking ("recycling") of the Earth's crust, which has been going on permanently for billions of years, i.e. the rock cycle, has destroyed a large part of these early rocks.

Mass Extinction

Five major mass extinctions took place in the Phanerozoic: At the end of the Ordovician, at the end of the Devonian, at the end of the Permian, at the end of the Triassic, and at the end of the Cretaceous.

Over the course of Earth's history, more than 99% of all species became extinct. But the extinction events were by no means uniform. Some of them were regional, like the extinction of megafauna at the end of the last ice age 11,000 years ago, other extinction events were global, like the 5 global mass extinction events mentioned above. These also had global causes. The probably most well-known mass extinction took place approx. 66 million years ago at the end of the Cretaceous period: here the dinosaurs, the pterosaurs, the various marine reptiles, the ammonites and many other animal groups disappeared. The cause was a cosmic impact of an asteroid. Evidence that it was a cosmic impact is shown by the fact that in the rocks that mark the transition from the Cretaceous to the Paleogene there are elevated concentrations of the metal iridium. Iridium is relatively rare in the Earth's crust, but it is found in asteroids. In addition, the impact crater is known, the Chicxulub crater on the Yucatan Peninsula in Mexico, which has a diameter of about 180 km. The impact of the cosmic rock, which was about 10 km in size and had the explosive power of 1 billion atomic bombs, led to enormous climatic and thus ecological changes and wiped out about 70% of the species at that time.

Much more devastating, however, was the mass extinction at the Permian/Triassic boundary about 250 million years ago, which wiped out about 95% of all marine organisms. The main factor in the collapse of almost all ecosystems is generally considered to have been the large-scale flood basalt emission of the Siberian Trap, whose cycles of activity over several hundred thousand years covered an area of 7 million square kilometers with igneous rocks and caused a series of serious consequential damages. The volcanic eruptions responsible for this constitute one of the largest volcanic events known worldwide in the history of the Earth. The mega-volcanism emitted significant amounts of carbon dioxide, fluorine, hydrogen chloride, and sulfur dioxide, which damaged oceanic and continental biotopes alike as sulfuric acid in rainwater. Due to the high CO2 outgassing from the trap, global temperature increased by 5 °C within a geologically very short period of time. This significant warming directly initiated the core phase of the mass extinction.

Paleoclimatological analyses of oxygen isotopes document a warming of the upper ocean layers by at least 8 °C by the end of the event (Joachimski et al. 2012). Mass extinction in the oceans began with the formation and spread of anoxic zones and the rapid drop in pH. Ocean acidification is considered one of the main causes of the widespread disappearance of marine life forms (Clarkson et al. 2015). This trend has been exacerbated by very rapid erosion processes under the greenhouse climate, leading to overfertilization (eutrophication) of the oceans with terrestrial weathering products such as phosphates (Jurikova et al. 2020).

The other three global mass extinctions are less well understood. The mass extinction at the end of the Ordovician correlates with climate change. A first phase of extinction began with Upper Ordovician glaciation and a second phase of extinction ended with glaciation. In this mass extinction event, many bivalves, bryozoans, and corals were affected. However, there were no strong ecological impacts, not least because there was very little life on land.

In the Late Devonian, another mass extinction occurred, caused by changes in ocean chemistry.

50 million years after the Permian mass extinction, another mass extinction occurred at the end of the Troad, about 201 million years ago. There were huge volcanic eruptions as the supercontinent Pangaea broke apart and the Atlantic Ocean began to form. Eleven million km^2 of basalt lava erupted within half a million years, forming the so-called Central Atlantic Magma Province, which stretched from present-day France to Brazil. Carbon isotopes indicate major changes in ocean productivity, and there were significant extinction events in the oceans. On land, some groups of reptiles and plants became extinct. The large lava fields and volcanic eruptions release large amounts of CO_2 and sulfur gases, similar to the Permian extinction event, but they were not as severe in their amount and intensity.

As serious as the mass extinction events were, after them ecological niches became free and new species took the place of the old ones. If the dinosaurs had not become extinct, mammals, and thus we, would not have had the opportunity to play the dominant role we ascribe to them. Based on the faunal changes, paleontologists distinguished three faunas, or animal worlds: the Cambrian fauna, the Paleozoic fauna, and the modern fauna. The faunas overlap in time and the names are for convenience only. But they reflect the fact that different groups of organisms had very different histories. This faunal classification was made using marine organisms by Jack Sepkosi to see if there were subgroups of organisms that had similar diversity patterns.

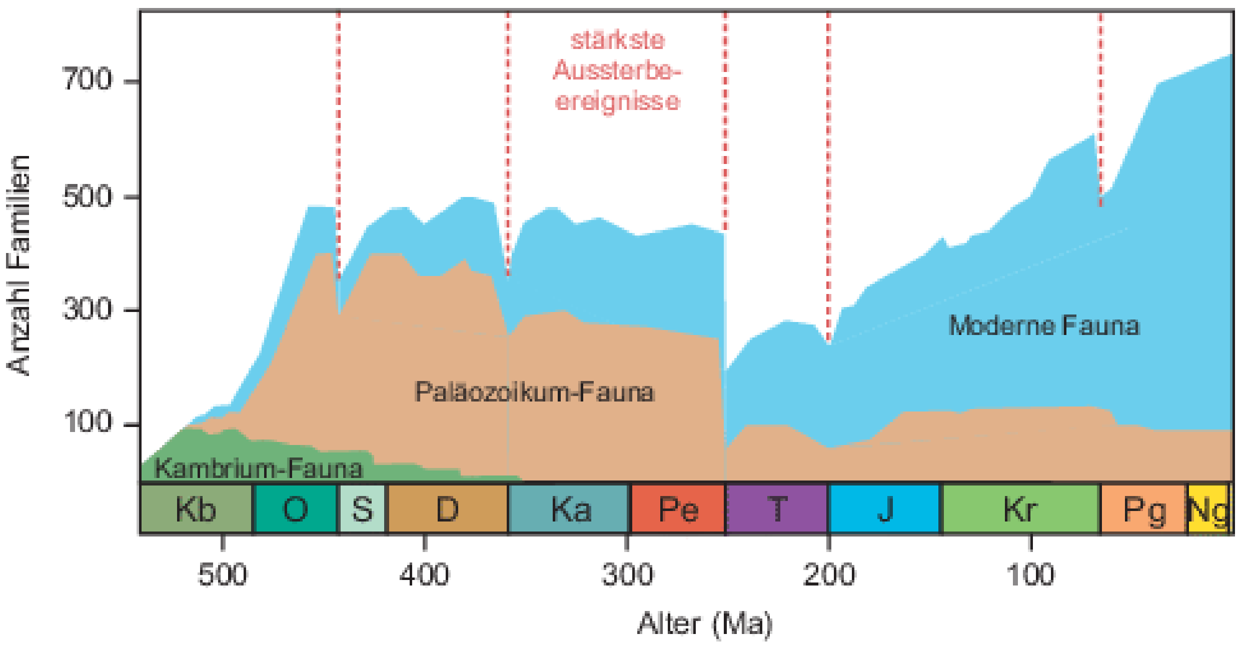

Abb. 2: cambrian, paleozoic and modern fauna

Epiloge

I would like to conclude this article with a personal statement:

Currently, we are facing a sixth global mass extinction. The cause is not cosmic impacts or volcanic eruptions, but the increasingly destructive and irrational economics of our species, which is focused on short-term profit for a few. Climate change, overfishing, plastic waste, destruction of rainforests and other habitats, the spread of pesticides and other toxins, military armament and destruction of our livelihoods through wars and an inadequate global health and supply system are effects of this economic activity. Profiteers of this are only a few unintelligent designers of our species and it seems absurd that the survival of 7.5 billion *Homo sapiens* and the other 20-100 million animal and plant species of this planet depends on these few.

Certainly: the world will not end. Life as a whole will probably survive this mass extinction. New creatures will occupy the old ecological niches and life will evolve. The question is whether we will be among the survivors or suffer the same fate as the dinosaurs.

At the same time, this mass extinction has a light on the horizon, a glimmer of hope. We can hardly prevent meteorite impacts or the eruption of super volcanoes. But if our way of doing business is the cause of the current mass extinction, it is also up to us to change this way of doing business. Our species has produced very clever minds with very clever ideas to give all humans a secure livelihood without immediately destroying the livelihoods of other species or our descendants. These ideas must prevail - if necessary against the will of the few who profit from the current system. Think about it!

Literatur:

Allgemeine Lehrbücher zu den Erdzeitaltern:

Benton, M. et al. (2020): Cowen's History of Life, Sixth Edition. Wiley Blackwell, Kapitel 2 (S. 19 – 22)

Futuyma, D. J. (2007): Evolution. Spektrum Akademischer Verlag, Kapitel 4, S. 68-70

Kutschera, U. (2006): Evolutionsbiologie, 2. Auflage. UTB, Kapitel 4, S. 85-88

Oschmann, W. (2016): Evolution der Erde. Utb, Kapitel 1.2 („Zeit“); S. 16-20

Ochmann, W. (2018): Leben der Vorzeit. Utb, Kapitel 7 („Stratigraphie“), S. 85-92

Prothero, D. (2017): Evolution – What the Fossils say and why it matters. Second edition. New York: Columbia University Press, insbesondere Kapitel 3 „The Fossil Record“

Prothero, D. (2021): The Evolving Earth. Oxford University Press, Kapitel 3 („Dating Rocks“) und Kapitel 4 („Stratigraphy“)

Prothero, D. & Dott, (2004): Evolution of the Earth, Seventh edition. McGrawHill, Kapitel 4 und 5

Storch, V., Welsch, U., Wink, M. (2001): Evolutionsbiologie, Kapitel 1.2.2.1 Methoden der Altersbestimmung, S. 34-35

Zitierte Spezialliteratur

Clarkson, M. O. et al.(2015): Ocean acidification and the Permo-Triassic mass extinction. Science 348 (6231): 229–232.

International Commission on Stratigraphy https://stratigraphy.org/

Joachimski, M. et al. (2012): Climate warming in the latest Permian and the Permian–Triassic mass extinction. Geology. 40 (3): 195–198.

Jurikova, H. et al. (2020): Permian–Triassic mass extinction pulses driven by major marine carbon cycle perturbations. Nature Geoscience. 13 (11): S. 745–750.

http://www.si-journal.de/index2.php?artikel=jg23/heft2/sij232-3.html

Anhang: Lebensbilder der Erdgeschichte

Abb. 2: Hadaikum

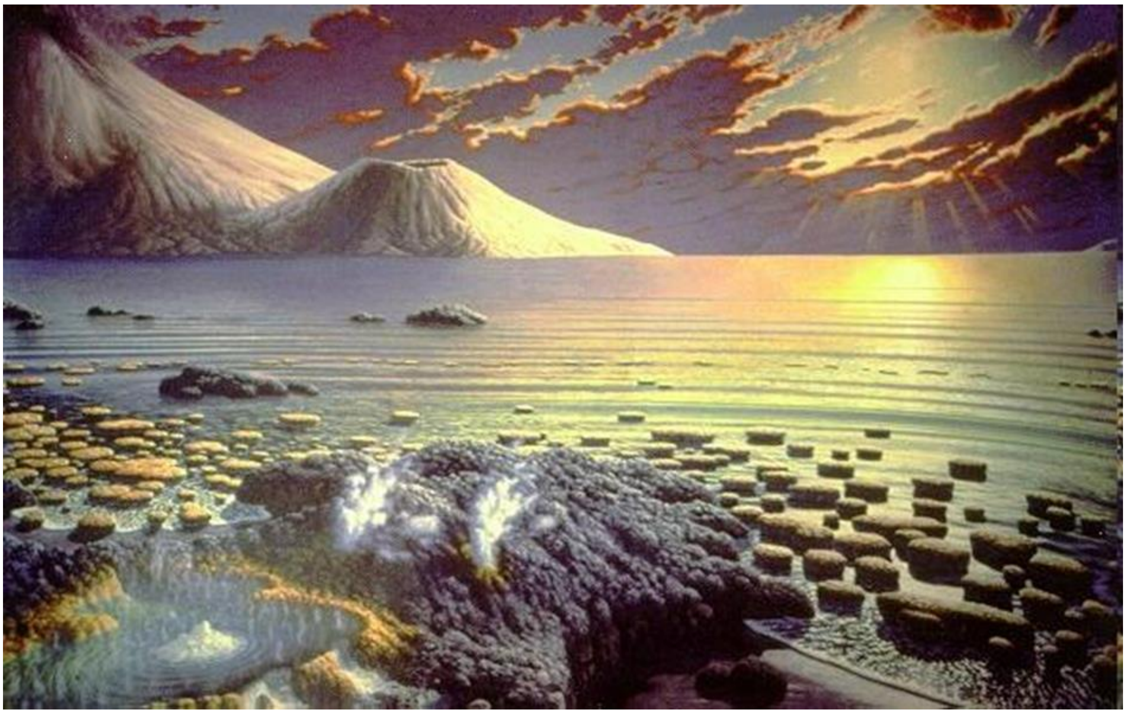

Abb. 3: Archaikum

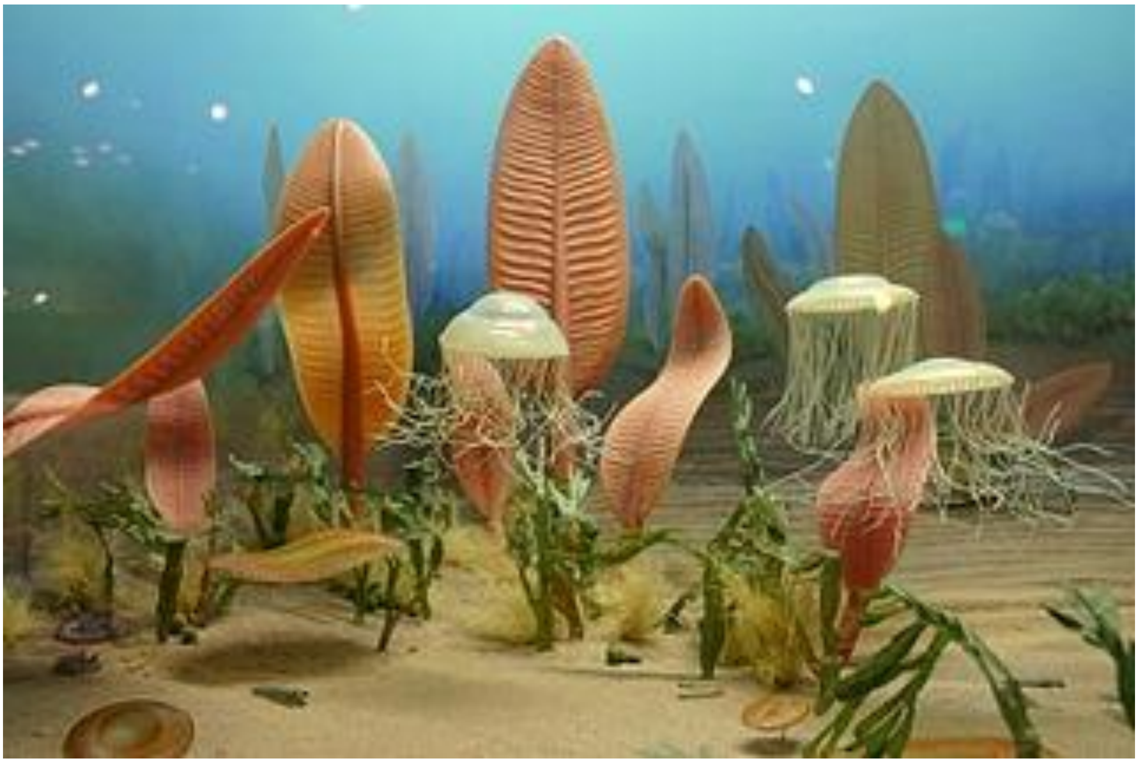

Abb. 4: Ediacarium als letzte Periode des Proterozoikums

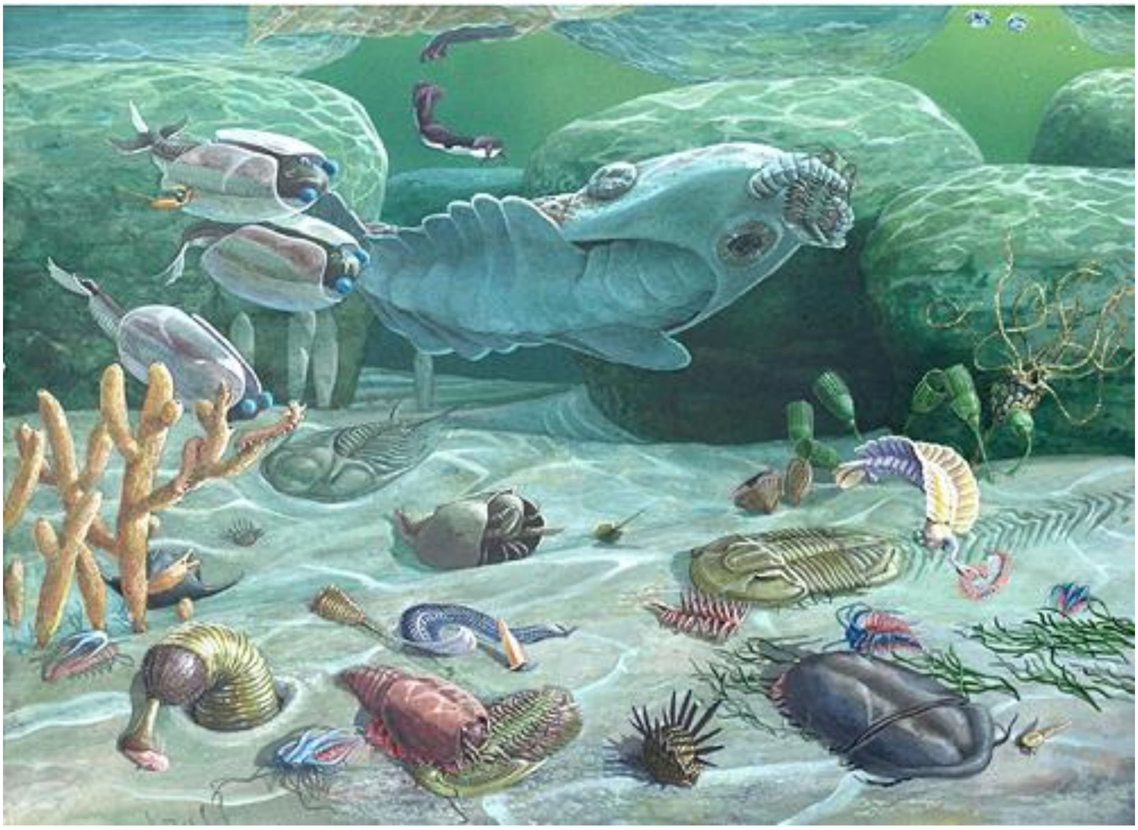

Abb. 5 Kambrium

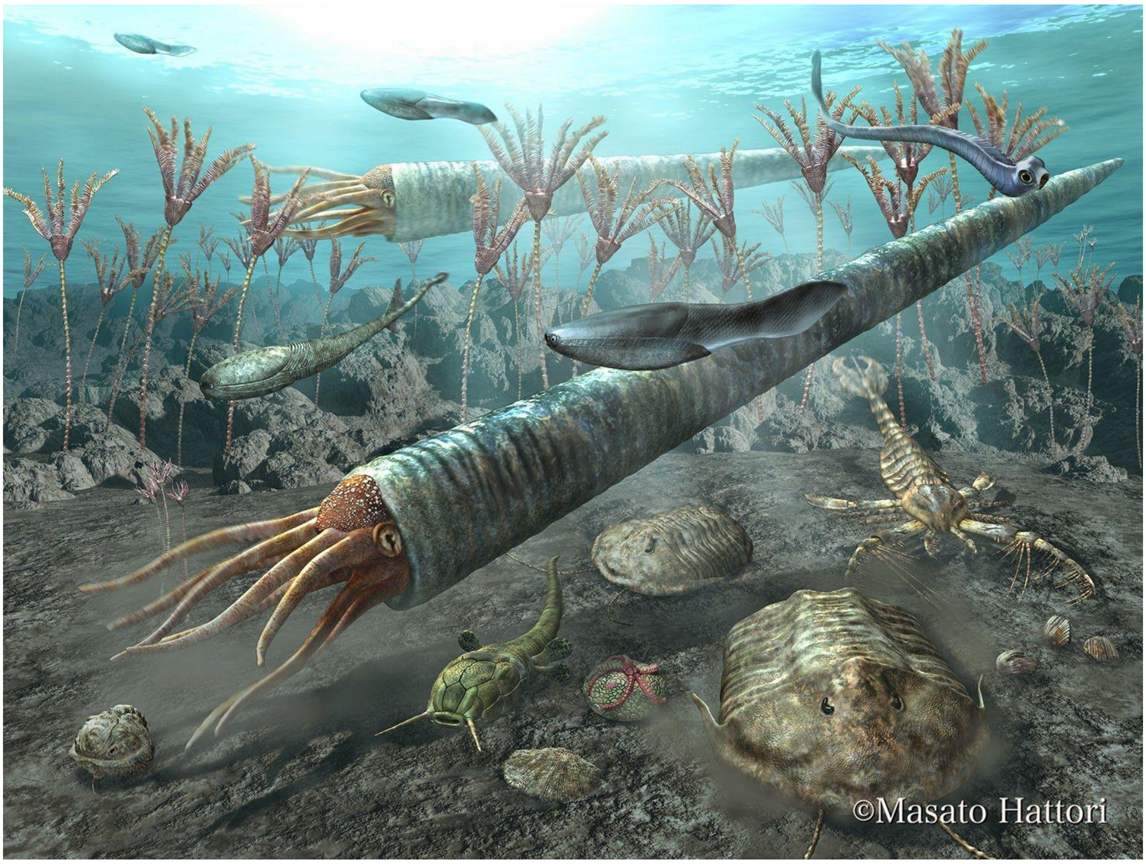

Abb. 6: Ordovizium

Abb. 7: Silur

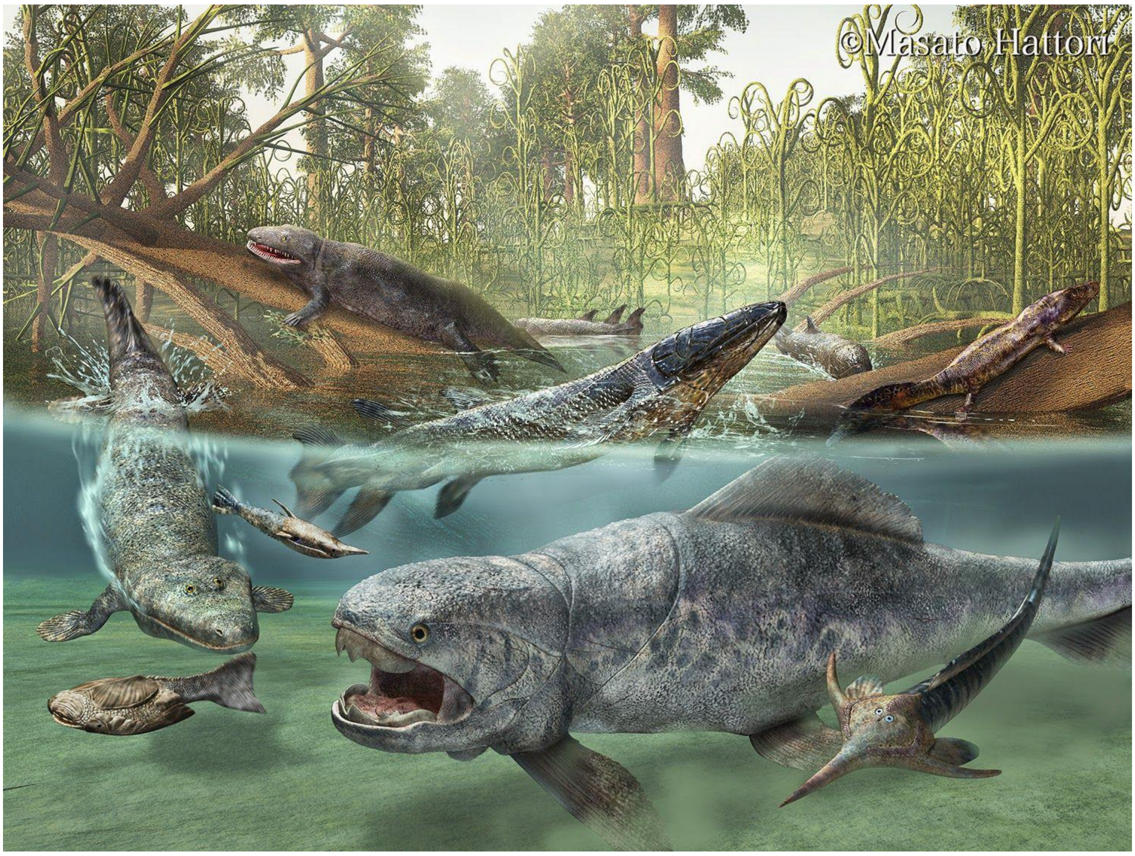

Abb. 8: Devon

Abb. 9: Karbon

Abb. 10: Perm

Abb. 11: Trias

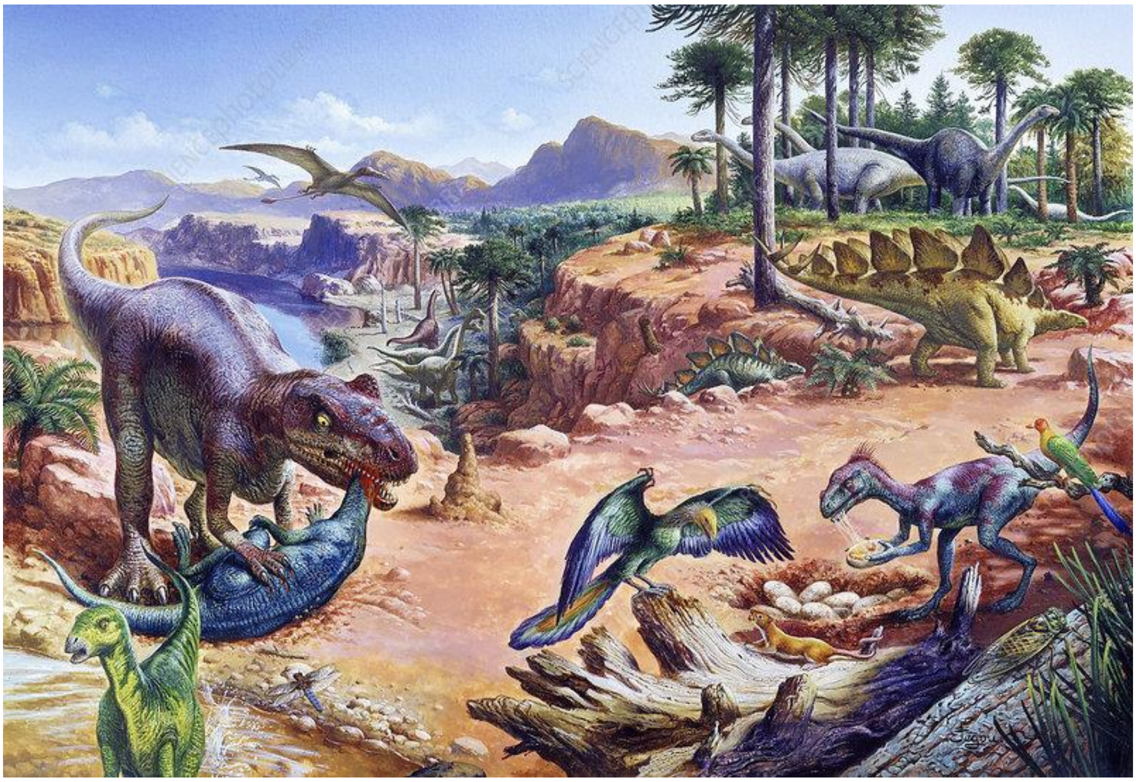

Abb. 12: Jura

Abb. 13 Kreide

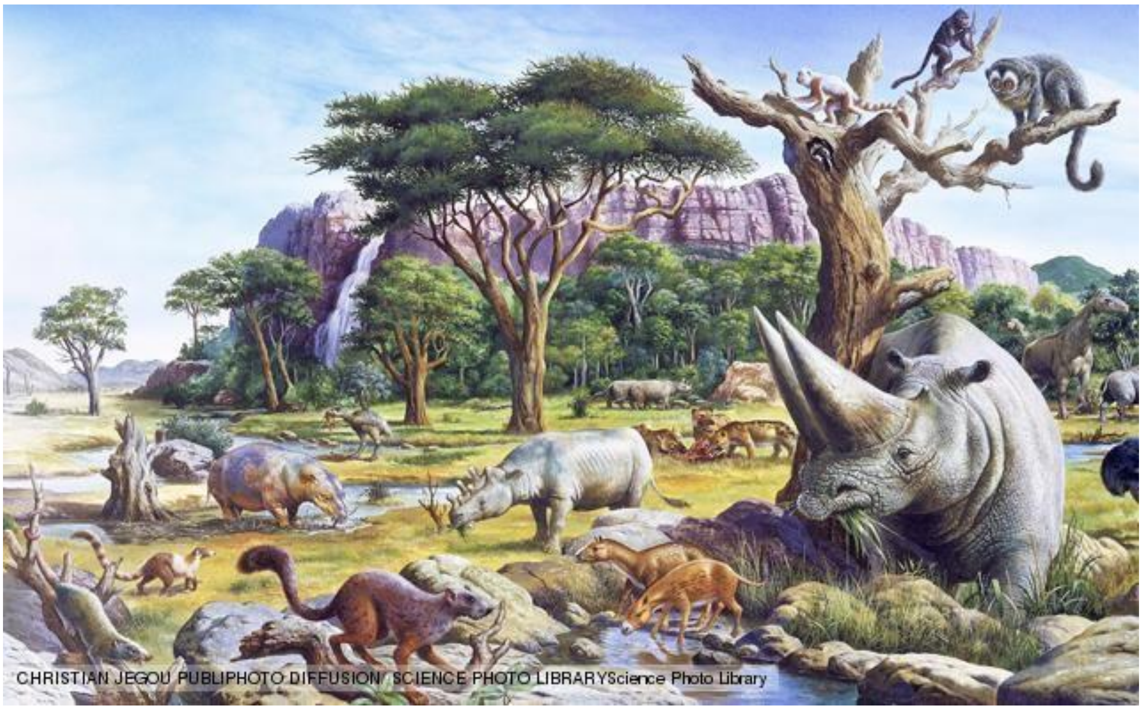

Abb. 14: Paleogen

Abb. 15: Neogen

Abb. 16: Quartär