Evolutionary History: Crash Course Biology #16

[CHAPTER 1 - INTRODUCTION: HOW LIFE BEGAN]

When Earth first formed 4.6 billion years ago, it wasn't the cozy, oxygen-filled, water-abundant home we know and love today. Well-stocked with all the ingredients for living, breathing, and singing.

In fact, you'd barely recognize it. The Earth back then was a hot mess, literally: a cataclysm of dust, rock, and ice. And that early atmosphere, fuggedaboutit, it was so thick with water vapor and ash from volcanic eruptions that you wouldn't have been able to see a bottle rocket popping off two feet from your face.

Now, after a few hundred million years, the volcanoes simmered down, the temperatures cooled, and the water vapor settled to form Earth's vast oceans. But that all paled in comparison to what happened next: life. And to understand the science of life--in all its beautiful, varied forms--we really need to know how it all began.

Hi, I'm Dr. Sammy, your friendly neighborhood entomologist, and this is Crash Course Biology. Hey Patti, what're you digging up there? Is that…theme music?

INTRO

[CHAPTER 2 - MACROEVOLUTION]

This weird thing that we call life has been around for about 3.8 billion years. So it has been witness to a lot of Earth's history. In a way, they're dance partners—as Earth has changed its rhythm, so has life — and vice versa in one long tango.

And the steps to this dance are in macroevolution, the big patterns of how living things evolve above the species level. So instead of talking about the emergence of, say, a particular species of bear, we're talking about creatures with four limbs in general.

In this way, macroevolution helps us trace the evolutionary history of life. Scientists are able to understand this history by studying things like geology, the climate, and most importantly, fossils.

Now, for life to arise in the first place, there needs to be tons of energy. Energy that could create the perfect environment for large organic molecules to form naturally, leading to carbon compounds that life is made of. There are a few different ideas about how this might have gone down.

One is that life arose from the power of lightning, volcanoes, and radiation from space, brewing the oceans into a nutrient-rich soup of organic molecules. Another possibility is that those first organic molecules formed in deep-sea vents with the perfect temperature and chemical balance. Others think that those first compounds might have even been brought by a meteorite. The point is: there's more than one way life's soup can brew. Mm tasty.

[CHAPTER 3 - RNA & DNA]

But life needs more than a strange broth of organic molecules. It also needs ways of copying genetic material, or biological information passed down from parent to offspring. Biologists think that probably began with strands of RNA, which today transfer genetic information in cells, but may have originally formed in tidal pools.

Molecules at the bottom of these pools may have gone through cycles of baking, dehydrating, and binding together during low tide, and then cooling and partially dissolving with high tide. The molecules that could withstand repeated cycles of heating and cooling would have accumulated and stuck around becoming RNA, like how gummy bears will sometimes melt together in the bag if you leave them in the car. Except, instead of a glob of gummies, this would eventually pave the way for strands of DNA.

DNA is a molecule that carries genetic information in all organisms on Earth and it can be copied lots of times with pretty amazing - but not perfect - accuracy. It's these slight differences that set the stage for more diverse forms of life to emerge.

[CHAPTER 4 - THE TIMELINE OF LIFE]

But changing conditions on Earth have shaped life over billions of years. And I don't know about you, but it's hard to wrap my head around all that time. So let's scale down those eons to something easier to understand, a 24-hour clock.

No one is around at midnight, but the Earth isn't quiet. It's a bombardment of asteroids and exploding volcanoes. And then, around 4 am, things cool down, and Earth's first residents emerge: single-celled organisms called prokaryotes. These early forms of life float through the Earth's oceans.

The prokaryotes are replicating their genetic information and dividing to produce more of themselves. One makes two, two makes four, until there are billions. Then, around 5:30 am, some of these early organisms begin photosynthesizing, harnessing solar energy from a faint, young sun.

Around 11 am, oxygen from photosynthesis starts to show up in the atmosphere, and by noon, it has transformed Earth's atmosphere into a mix of gases that allow larger, more complex life to develop. So, by 2 pm, the first eukaryotes burst onto the scene: more complex cells that will eventually support more complex life.

It isn't until around 5 pm, with over three-quarters of the day gone, that the first multicellular forms of life join in. And by 9 pm, things are really getting rowdy as predatory animals begin to evolve, creating a new relationship between predator and prey. This drives some less formidable organisms to extinction.

Up until now, all of life's drama has happened in the ocean, but around 9:30 pm, the first plants set their roots on shore. At 10 pm, insects — my favorites — and four-legged creatures follow. Dinosaurs show up soon after, and they prove real party animals before going extinct around 11:40 pm – about an hour after arriving on the scene.

Mammals join the party around 11 pm, but it's only in those last twenty minutes before midnight, that they really start diversifying. As for humans? almost all of this single, spectacular day happens without us. It's not until that final second, right as midnight approaches, that we show up. Fashionably late, as always.

[CHAPTER 5 - STROMATOLITES & FOSSILS]

Now, the farther back in life's evolutionary history we go, the trickier it is to reconstruct its course. But scientists have found direct and indirect evidence of life's history.

Like, you might think that the oldest signs of life would be in fossils, right? But actually, the most ancient signs of life can be found in traces of carbon molecules trapped inside plain old rocks.

You see, around 3.5 billion years ago, or about four in the morning on our Eons Clock, some of Earth's very first prokaryote residents left behind stromatolites, or fossilized mounds formed from thin layers of sediment. The prokaryotes fused these layers together themselves, kind of like the microbe version of a paper-mache project. Except way older than that bowl I made in third grade, and probably more structurally sound.
Later, when some prokaryotes evolved the handy-dandy trick of photosynthesis, it spurred a chemical reaction that produced layers of iron oxide. Those layers settled at the bottom of the sea—and today, they're found as very old, very instructive rocks.

Now, all the oxygen released by that early photosynthesis fundamentally changed the Earth's atmosphere. And as much as we, literally, live and breathe the stuff today – it wasn't exactly a welcome change for the prokaryotes back then. It probably poisoned many of them, damaging their cells and causing them to die out. But an oxygen-rich atmosphere also pushed the survivors to evolve new ways of harvesting energy — that's where fossils come in handy.

Fossils tell us that the leap from single-celled organisms to multicellular ones allowed life to evolve new shapes and bigger sizes. At first, these organisms stayed squishy and pretty small, with the biggest ones measuring only about one meter long. But, eventually, more and more diversity arose.

Like, as hunters with claws evolved, so did armored prey with hard shells and outer skeletons. These are examples of adaptations, or heritable traits that increase an organism's chances of survival and reproduction.

For example, we know that our backboned ancestors came from the oceans thanks to fossils of fish-like animals that evolved legs and lungs, and gradually moved from sea to shore. But figuring it out has involved tracking down puzzle pieces strewn all over the globe. Let's learn more over in the Theater of Life.

[CHAPTER 6 - DR. MEEMANN CHANG]

It's hard to say what Chinese paleontologist Dr. Meemann Chang is better at: puzzles or persevering. Chang first started puzzling over fish fossils in 1955. And the more she studied ancient fish, the more captivated she became by their mysteries—especially how they evolved into the land-walking, air-breathing beings that led to us.

Unfortunately, her studies came to a halt in 1966, when the government censored academic research, including Chang's. But she persevered, and eventually was able to return to her research.

At the time, scientists thought a group of lobe-finned fish that lived millions of years ago and may have had inner as well as outer nostrils might be key to solving the puzzle. They thought these adaptations might have led to the ability to breathe air in later species.

Humans have this trait, as well —two nostrils on the outside, and two on the inside, that pass air from our nose to our lungs. But Chang found that fossils from these fishes didn't have inner nostrils. Just two outer pairs.

And then, she found yet another type of fossilized fish. This one had a pair of outer nostrils and a pair between its front teeth. It was like a snapshot in time— nostrils midway to where they would eventually end up, in land-walking, air-breathing creatures like us.

It took careful observation, and some serious perseverance, but Chang pieced together one of life's big puzzles: For every breath you take, you've got fishy ancestors—and a pair of traveling nostrils—to thank.

[CHAPTER 7 - DRIVERS OF MACROEVOLUTION]

The Theater of Life sure "nose" how to tell a story, right?! You get it? You'll get it later, it's a thinker. Anyway, as scientists find more fossils, they continue unraveling how life's history fits together.

Of course, the fossil record will never be fully complete, but scientists are on the lookout for those species that represent major steps forward in evolution. And along the way, they've found evidence of some major drivers of macroevolution.

For example, there's plate tectonics—or, the sliding and floating of Earth's surface plates on the molten-hot mantle below. As these plates have shifted and collided, they've driven macroevolution by forming mountain ranges, splitting continents, and spurring life to evolve as a result.

Changes in the atmosphere have also been major drivers of evolution—like, when that early surge of oxygen pushed some organisms to extinction, and others to adapt new ways of using oxygen for energy. Similarly, when Earth has moved between climate extremes, organisms have either adapted or died out.

And mass extinctions themselves have driven evolution. In fact, five times in history, over three-quarters of the world's species have disappeared. But every time life has taken a hit, it has bounced back and diversified.

Like, when early mammal-like species dwindled, reptiles arose. And when many of those reptiles were wiped out, new reptiles emerged called dinosaurs. And when the dinosaurs left the scene, the mammals came back stronger than ever. So whenever some species have gone extinct, others have risen to prominence, evolving new ways of living, moving, and getting energy.

These cycles of living and dying, extinction and recovery, might seem like they are following some grand design to us humans – but evolution has no goal or plan. It's just following the rhythms of life's dance. And while we've covered a few of life's slickest evolutionary moves today, you can learn even more if you check out this mini-series from our friends over at SciShow.

[CHAPTER 8 - REVIEW & CREDITS]

The dance between life and the planet has been going on for a long time. Earth’s changing conditions have triggered game-changing leaps for life. Life, in turn, has shaped the Earth right back, even altering its atmosphere. We wouldn’t be the same without each other.

And as much as we humans like to think that we’re the pièce de résistance when it comes to evolution, we’ve been around for less than a geological second. We’ve got a lot to learn from all the life that’s come before us.

In our next episode, we’re going to break down the ways evolution connects us all, and how scientists keep track of evolution's many moves. I’ll see you then! Peace!

[OUTRO]

This series was produced in collaboration with HHMI BioInteractive. If you’re an educator, visit BioInteractive.org/CrashCourse for classroom resources and professional development related to the topics covered in this course.

Thanks for watching this episode of Crash Course Biology, which was filmed at our studio in Indianapolis, Indiana and was made with the help of all these nice people. If you want to help keep Crash Course free for everyone, forever, you can join our community on Patreon.