From 1600 to 1800, European physics and chemistry went through revolutions that made them quantitative, or numbers-based.

Meanwhile, biology remained with natural history, and stuck with observation-based knowledge. But what about the study of the earth?

In this field, natural philosophers were asking questions like, what's up with fossils? Are they the remains of extinct organisms? Or are they so-called "sports of nature"—rocks that just happen to look like living things but don't mean anything?

And most importantly, how old is… everything? I gotta say, as disciplines of science go, this one has pretty much everything awesome in it. Vast eons?

Check. Mega floods and supervolcanoes? Got those!

Dinosaurs? Uh, huh! A hunt for living mastodons?

Buddy, you know it. Geology, paleontology, oceanography, meteorology, and others—the earth sciences are fascinating, and so is their history. Let's rock! [OPENING MUSIC PLAYS] If you're looking for the foundations of geology, one place to start is with mining.

Archaeologists have shown, for example, that indigenous populations around the Great Lakes mined and used the copper near modern-day Lake Superior for over six thousand years. And in Europe, mining took off along with colonization. In the sixteenth century, colonial empires exploited the precious metals of Central and South America, relying on the geological knowledge and technical skills of indigenous communities—not to mention their labor.

But, despite gathering a lot of new data about the Earth in this way, natural philosophers kept banging their heads against one question: how can we reconstruct the earth's history, or geohistory? No one could confidently know the age of the earth before the discovery of radioactivity and the development of radiometric dating in the early twentieth century. Today, by the way, we think the earth is around 4.543 billion years old.

But since at least the seventeenth century, people have compared layers of rock and declared them younger or older, depending on their positions relative to other layers. This was a qualitative, or value-based practice: it was hard to date rocks just by looking at them. But this didn't stop people from trying.

In seventeenth-century Europe, it was commonplace to believe that the age of the earth and the age of human species were about the same. So to know the age of the earth, historians tried to create a quantitative chronology of human history. This meant comparing all known ancient sources—such as texts from China, Greece, or Babylonia—as well as things like the records of eclipses and comets.

All these events were placed into a detailed chronology: a linear narrative that ran from the creation of the universe to the present. In 1654, Bishop James Ussher—a scholar and the top religious leader of Ireland—calculated the age of the earth to be about six thousand years old, based on textual evidence from the bible. Other historians reached different conclusions and argued over the reliability of different sources, but in general they reached a date for the beginning of time somewhere around 4000 BCE.

By the late seventeenth century, some European naturalists, such as polymath Robert Hooke, argued that natural objects, like fossils, should also be used like historical texts to shed light on early human environments. For example, many believed that the biblical Flood had scattered organic remains globally, which explained why we can find seashells on the tops of mountains. This attention to fossils would set the stage for new theories of organic development, such as those of Charles Darwin.

Between Hooke and Darwin, several eighteenth-century French thinkers played a critical role in speculating about fossils and finding ways to calculate the age of the earth. These were the "Transformist" natural historians who developed proto-evolutionary theories. The Comte de Buffon, for example, argued that the earth was progressively cooling.

According to Buffon, during this cooling process, the earth underwent phases or "epochs," which were roughly parallel with the six Biblical days of Creation from the book of Genesis. And since humans appeared only in the seventh and final epoch, Buffon's history of the earth was mostly pre-human—which was a totally new idea! To determine the age of the earth, Buffon conducted what might be described as "cooling" experiments.

He timed the rate at which heated balls of different sizes and materials cooled down. Publicly, Buffon estimated the earth was around seventy-five thousand years old. But privately, based on his experiments, he speculated that it was up to ten million years old!

So, although most European geologists in the 1700s were devout Christians, they found—like Buffon—that the Genesis narrative could be read as more of a metaphor that complemented, rather than contradicted, scientific evidence. This allowed Christian thinkers to come to terms with a vast, pre-human history. Still, fossils remained a questionable form of evidence for understanding the history of Earth.

Did they represent the remains of pre-human worlds, or were those creatures still roaming wild spaces somewhere? Georges Cuvier thought he had the answer. Help us out, Thought Bubble: Cuvier argued that each epoch of earth history had its own distinctive flora and fauna. And these epochs were separated by global catastrophes such as tsunamis, meteorites, or earthquakes. Life forms did not persist after the catastrophes, he thought. They went extinct with the end of their worlds. We call this theory catastrophism. And according to it, fossils reveal a linear sequence, which can be used to reconstruct the earth's past.

This wasn't a new idea: in 1696, for example, William Whiston published A New Theory of the Earth from its Original to the Consummation of All Things. And in it, he attempted to explain the history of earth in terms of catastrophes, too. Like, Whiston thought that a comet hitting earth must have caused the Flood of Noah. What Cuvier did differently was amass fossil evidence of changes in organisms. Studying the geology of central France, Cuvier noticed gaps where the fossils would simply disappear, only for new kinds of fossils to appear a little bit higher up, in new layers of rock. He recognized these gaps as extinction events.

To make things easier, Cuvier decided to focus on really big bones—mastodon and mammoth skeletons. He figured these animals would be hard to miss if they were still roaming the earth. (Spoiler: they were, in fact, extinct.) But Cuvier compared the teeth of elephants and those of other animals like them. And in doing that, he established that African and Indian elephants are different species, and that mammoths were not the same as either of them. Thanks Thought Bubble.

Now, how did Cuvier get all of these fossils? Well, the new Revolutionary government in Paris secured Cuvier a position at the Museum of Natural History, which gave him the power to establish a global fossil delivery service for other natural philosophers. So, those big mastodon fossils that he studied came from North

America. And it's worth pointing out that, because of that, Cuvier became fascinated with Native American ideas about creation and extinction.

He went out of his way to buy fossils from tribes such as the Iroquois, Shawnee, and Lenape to learn what they thought about these old, gigantic bones in the ground. Cuvier couldn't have come up with new theories about fossils—or even collected so many fossils—without the help of many indigenous knowledge makers.

So by 1800 or so, geologists had reached a consensus on some wild ideas: the earth had undergone gradual change over an incredible amount of time before the appearance of humans. And Earth's history was punctuated by sudden episodes of violent change. Life had either adapted to new environments or gone extinct. And so the fossil record was progressive: wimpy little trilobites died out, and humans came into the story at the end, ready to build robot musicians.

But not everybody loved Cuvier's theories. Scottish geologist Charles Lyell instead argued for a slow, "steady-state" theory of geological change that would become known as uniformitarianism. He famously had two specific bones to pick with Cuvier. First, Lyell thought the French had relied too much on catastrophes to explain geological history. He argued that observable geological processes—like erosion and deposition caused by wind, rivers, rain, or the occasional volcanic eruption—were the only explanations that geologists should consider reasonable or scientific. Second, Lyell argued that extinctions were spread evenly across geological time—not clustered together in mass-extinction events. This steady extinction rate was balanced, he thought, by the steady creation of new species, according to global climate conditions.

So, for Lyell, geohistory wasn't linear, but cyclical and ... uniform. It pretty much worked the same in each epoch. Lyell's big book, Principles of Geology, published from 1830 to 1833, became a Principia for earth scientists. And I should note here that we've been saying "Prince-uh-pee-uh" for the whole History of Science so far But, one of our writers is in the room and has told us it's "Prin-KIP-ee-uh." In 'Principles of Geography" he argued that the earth is immensely old, and that, as he put it, "the present is the key to the past." The debate between catastrophism and uniformitarianism would go on for a long time. But while Lyell's position on extinctions was dismissed by older geologists as too extreme, his emphasis on the power of gradual change inspired many younger scientists.

One of them was Charles Darwin, who read Lyell's books and later became his good friend. Lyell could never quite figure out how fossils and living organisms were related, but— like, for now, get out of here, Chuck! We're gonna get to you in a couple episodes. Another influence on Darwin, in the realm of fossil collecting, was Oxford geologist William Buckland. Buckland led trips to caverns and abandoned mines, where he found remains like cave bear bones from the Pleistocene. For evidence of even more ancient life, we turn to English paleontologist Mary Anning. Anning walked the beaches after storms to find and excavate fossils, which she then sold, mostly to Buckland. In 1811, she even found a spectacularly well-preserved ichthyosaur. Anning was a keen observer and talented nature writer. An 1830 painting of "ancient Dorset" based on her work brings to life an entire Jurassic… world (Universal Studios, please don't sue me!), filled with marine and flying reptiles. In the vision of Buckland and Anning, the reptilian past was separated from the modern world by the Flood, after which humans were created.

The new theories about the earth, circa 1800, all required what is perhaps the most important idea of earth science: "deep time," or "geological time." This is the notion that, before humans, the earth had already been around for an unimaginably long time. And this great expanse of time is, like human history, full of sudden events and patterns that persist over epochs. So, deep time implies that geohistory can be reconstructed in the same way that historians reconstruct the human past. Except, instead of relying on vases, ruins, and letters, geo-historians rely on fossils, volcanoes, and rocks. This epistemic mode of thinking about the earth's history emerged thanks to the technÄ" of industrializing Europe. And so the earth sciences became more regular as professions in the late 1700s and early 1800s.

In industrializing nations, governments and landowners started investing in geological surveys and mining academies. In these academies, earth scientists were trained to generate new ways to satisfy a world increasingly dependent on one mineral resource, coal. New visual technologies for geological mapping, and a new system for tracking rock groupings across vast distances, emerged from the works of Abraham Gottlob Werner and his students at the mining academy in Freiberg, Germany, in the 1770s. In Britain, mineral surveyors and civil engineers, such as William Smith and John Farey, started using fossils to improve the accuracy of their geological maps. This technique soon became standard practice.

Smith was also one of the first people to use a thematic map, a map showing something about the earth other than its shape, to classify different rocks across Britain. And he was one of the first to use fossils to map rock formations for practical ends, like civil engineering and mineral prospecting. His maps were very useful to the geologists reconstructing the earth's history: they helped fossil hunters arrange their finds according to rock strata and thus age. Innovations created by Smith and others like him set off a wave of geological exploration around the world, backed by governments and industries. And, by the early 1800s, the industrial world was gobbling up coal at an unprecedented pace… Quick note that this episode would not have been possible without the expert advice of Gustave Lester, a Ph. D candidate in the Department of the History of Science at Harvard University. Thanks, Gustave! Next time—the history of technology is going to get steamy: that's right, it's the Industrial Revolution!

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