Tutorial Earth History and Evolution 04 - Hutton, Lyell, Naturalism, Neptunism, Plutonism

We dealt with the age of our Earth. We learned about the methods scientists use to examine rocks to determine their age. In particular, radiometric dating allows us to determine the great age of the Earth as accurately as possible. In this paper, we want to provide a brief overview of the origins of geology as a science, a discipline that is just 200 years old.

Although there were some scholars among the ancient Greeks and Romans who thought the Earth was really old, our modern knowledge about the age of the Earth dates from the late 18th century, from the Age of Enlightenment. It was an age of scientific discovery, and scientific research was less constrained by the influence of the church or the nobility. Enlightenment thinkers such as Voltaire, Montesquieu, Jean-Jacques Rousseau, and Denis Diderot in France, and philosophers such as George Berkeley, Jeremy Bentham, and John Locke, as well as scientist Isaac Newton in England, were very influential, focusing on circumstantial evidence and reason, and favoring the scientific method over the supernatural and myths that had been handed down for centuries. One of their central premises was naturalism: it is better to explain things (especially scientific results) by natural laws than by supernatural causes. In fact, science cannot function without naturalism because supernatural explanations for events cannot be tested or evaluated by scientific evidence. A statement like "God just did it that way" slows down scientific development because there is no way to verify that statement.

Surprisingly, Edinburgh in Scotland was one of the hotbeds of intellectual enlightenment. Although it was not a large country, Scotland had one of the highest literacy rates in the world at that time. This was because the Presbyterian Church, which ruled parts of Scotland, believed that everyone should be able to read and interpret the Bible for themselves and not have to rely on clergymen to read it for them. So the churches established public schools and tried to ensure that every Scot could read and write. The Scots had a thirst for knowledge, with large libraries and many publishers putting out books and newspapers.

Thanks to the relatively weak influence of the churches in Scotland, there was no oppression by clergy as in much of Europe. Consequently, Edinburgh was the capital of the remarkable "Scottish Enlightenment" in the late 18th century.

One of its Enlightenment leaders was James Hutton (Fig. 1), who lived from 1726 - 1797. Hutton was a famous chemist and naturalist and is commonly referred to as the father of geology. Although trained as a lawyer and physician, his greatest passion was the study of nature.

Fig. 1: James Hutton

As a landowner who had several large farms in Scotland, he used his knowledge of chemistry to fertilize his fields. He also traveled extensively, looking for new methods to improve farming practices. Meanwhile, his curiosity led him to make many observations about the slow process of weathering, how soils form, or how sediments are slowly washed out to sea and then accumulate layer by layer. Eventually he leased out his land and returned to Edinburgh, where he interacted with other great thinkers such as Adam Smith and Joseph Black, two of his closest friends. He traveled extensively throughout Scotland, adding to his fund of observations and seeking answers to his questions about how the earth works. He finally published his ideas in 1788 in a scientific paper entitled "Theory of the Earth; or an Investigation of the Laws Observable in the Composition, Dissolution, and Restoration of Land Upon the Globe."

Hutton recognized that the Earth's geological processes were very slow and gradual. It took years for thick soils to form; it took centuries for sedimentary layers to form at the bottom of a lake. For example, he visited Hadrian's Wall (Fig. 2), which had been built over 1500 years earlier by the Romans throughout Scotland, and saw no evidence that the stones had changed or weathered much in all those centuries.

Abb. 2: Hadrian‘s Wall

Moreover, he applied naturalism to geology, arguing that the natural processes we see going on today - slow weathering, erosion, transport of sediments - must have worked the same way in the geologic past. Ancient rocks can be explained by observable processes, and these processes now at work on and in the Earth have operated with slow, steady uniformity over immensely long periods of time. This has become known as uniformitarianism - the uniformity of natural processes over time.

Uniformitarianism is also important in other scientific disciplines. Especially when we need to infer processes that occur on time frames or scales that we cannot directly observe. Until recently, we could not see atoms or molecules and had to infer their properties from their behavior in experiments. Stars and galaxies are hundreds to millions of light years away, which means that the light we see from them today was created hundreds to millions of years ago and is just now reaching us. We cannot observe these processes in real time, but must infer how the universe works from the natural laws of physics. In chemistry and biology, we couldn't see much below the cellular level until the last few decades, so we had to figure out the processes of biochemistry and molecular biology and the nature of molecules and atoms indirectly through experimentation. Geology is just another science that depends heavily on the unified approach that is universal in all sciences. Hutton focused on the naturalistic approach to the Earth and tried to move away from unscientific, supernatural explanations, often called catastrophism (such as Noah's Flood).

But these ideas contradicted the dogma of the day. Leading church scholars had declared that the earth was only 6000 years old, and few people dared to question it. Some scholars thought that all the layered rocks of the earth were deposited in Noah's Flood, although there were serious problems with this idea. One school of thought, led by German mineralogist Abraham Gottlob Werner at the Freiburg Mining Academy, declared that all rocks are sedimentary rocks. That is, all rocks, even lava flows, were deposited from water in the oceans. This idea became known as Neptunism (after Neptune, the Roman name for the god of the sea).

But Hutton could see that lava and other igneous rocks were formed from molten rock or magma that had risen from the Earth's hot interior, and that the rock layers were not formed by sediment deposition from water. Where he discovered flowing magma that intruded through older rock, he could see evidence that it had forced its way up through cracks as molten rock, then baked the rock with its intense heat around it, and then cooled to a solid where it came to rest.

Salisbury Crags and Arthur's Seat, south of Edinburgh, are extinct volcanoes with intruded lavas (Fig. 3).

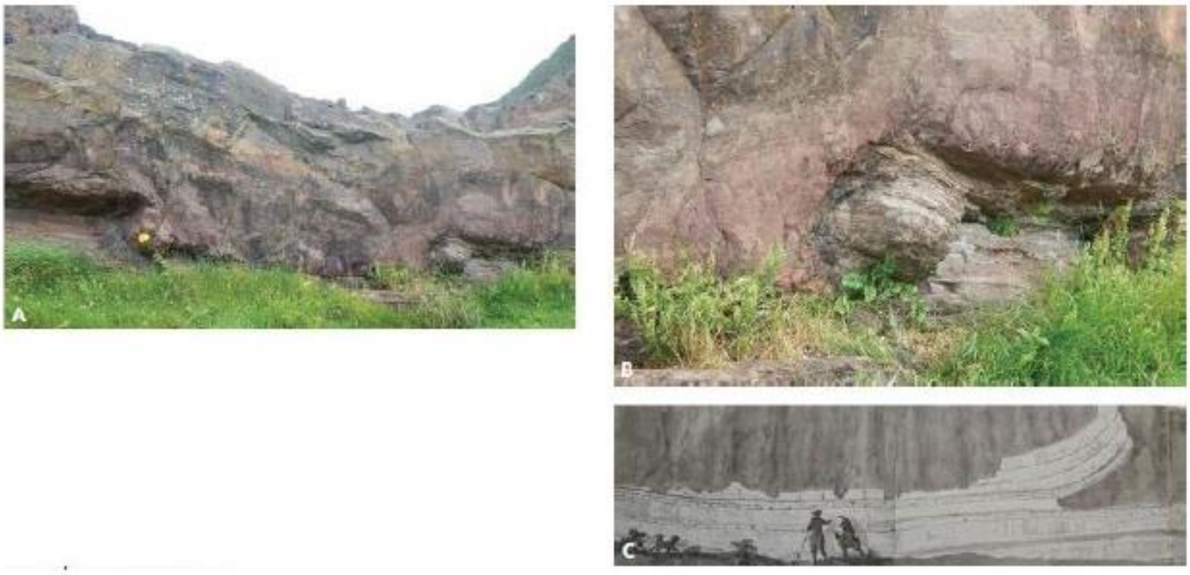

Abb. 3: Salisbury Crags

Hutton walked with his dog Missy there and saw clear evidence that the granite rock was once a molten magma mass that penetrated older sedimentary layers. Hutton was also able to make the same observations at other sites. To Hutton, this was inescapable evidence that the Earth was dynamic and changing, with molten rock rising, as Hutton put it, from "the great heat engine of the Earth" deep beneath our feet. By advocating the igneous origin of rocks such as lava flows, Hutton's ideas became known as Plutonism (after Pluto, the Roman name for the god of the underworld).

How could it have been imagined that lava flows originated from sediments in water? In the 21st century, we are used to seeing videos of erupting volcanoes like Kilauea in Hawaii. But back then, few people traveled outside their home country, let alone to other countries, and almost no northern Europeans had ever seen a volcanic eruption. The nearest volcanoes were Vesuvius and Etna in southern Italy, and they produce mostly ash, not lava flows. Moreover, the study of chemistry was still very primitive, so early mineralogists like Werner had no idea how much heat it takes to melt a rock or crystallize magma, and under what conditions magmas are formed.

Hutton's thoughts were particularly stimulated when he saw outcrops of what is now known as angular unconformities (Fig. 4).

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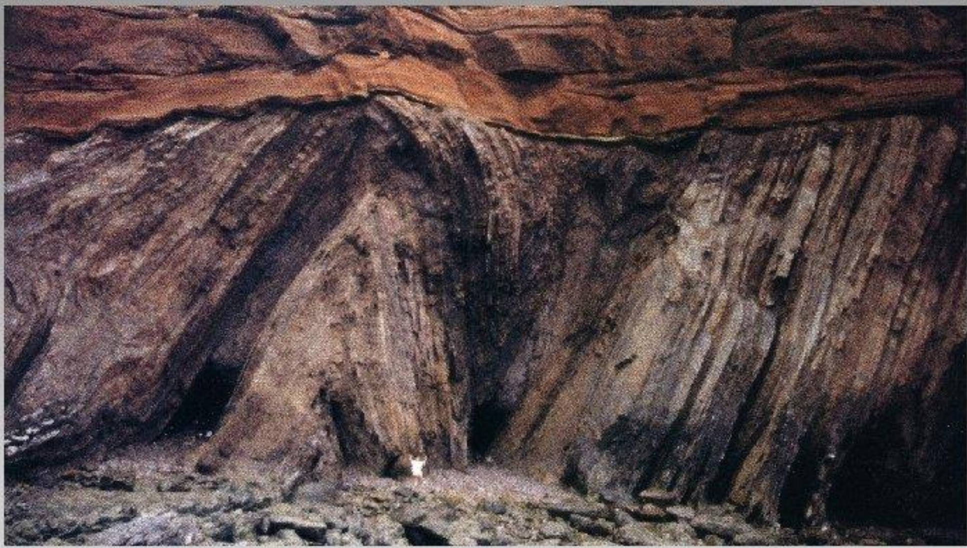

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Formation of an angular unconformity

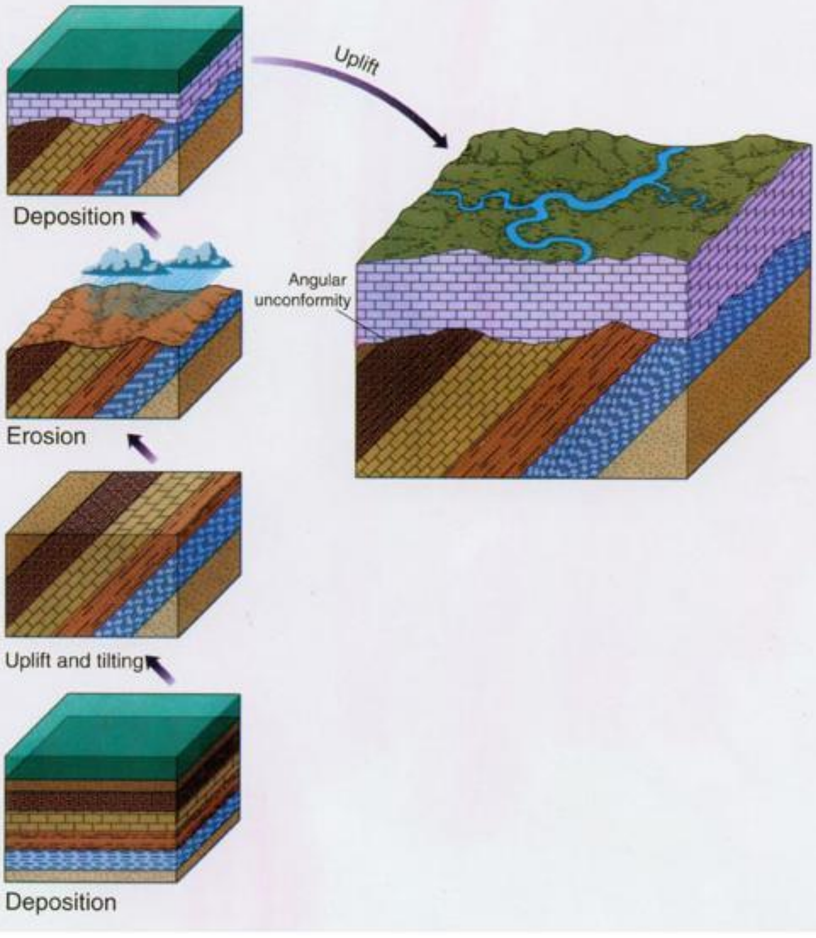

Abb. 4: angular unconfromity

An angular unconformity usually forms in sedimentary rocks that are tilted by tectonic movements, such as extension, compression, folding, uplift, and subsidence, or by singular volcanic events. The uplifted rocks are then eroded, for example, during a drop in sea level (regression). Later sediments, which may be deposited when sea level rises again (transgression), lie horizontal again and consequently form an angle with the older rock layers (Fig. 4). Accurate reconstruction of the relationships of deposits and unconformities to each other is of great importance in understanding the evolution of a mountain range over time (orogeny).

Knowing how slow modern weathering and erosion rates were and how long it must have taken to deposit thousands of layers of sediment, Hutton realized that an angular unconformity must represent thousands to millions of years, not the mere 6000 years that religious scholars assume. The Earth was unimaginably old and operated on time scales that humans could barely comprehend. Hutton claimed that the totality of these geological processes could fully explain the present landforms around the world and that no biblical explanations were necessary in this regard. Finally, he stated that the processes of erosion, deposition, sedimentation, and uplift were cyclic and must have been repeated many times in Earth's history. Given the enormous time spans required by such cycles, Hutton claimed that the age of the Earth must be unimaginably great.

Hutton's ideas were radical for his time and difficult for most people even today to understand, let alone accept. Moreover, Hutton was not a very clear or vivid writer, so few people fully understood his ideas even when they read his works. In 1802, 5 years after Hutton's death, his friend John Playfair published illustrations of Hutton's Theory of the Earth that explained Hutton's ideas much more clearly.

But it would take another generation for such revolutionary ideas to become accepted in the geological community. The person who made it happen was a young man named Charles Lyell (Fig. 5).

Abb. 5: Charles Lyell

Originally trained as a lawyer in law, he soon tired of the legal profession and instead pursued young geology as a hobby. (This, by the way, was not the first time someone tired of law school and switched to another profession that interested him more). Lyell traveled widely throughout Europe and witnessed many different geological phenomena through the uniformitarian eyes of Hutton. Eventually he wrote his masterpiece, Principles of Geology, which was published in three volumes from 1830 to 1833. He collected all the observations he had gathered from his travels and reading, and used his skills as a lawyer to employ all the necessary arguments and rhetorical tactics to discredit his opponents, the adherents of catastrophism, while presenting overwhelming evidence for his own case. He tried to rule out any possibility that the old unscientific supernatural catastrophism would ever be taken seriously again. He was so convincing that within a generation the last of the old catastrophists and Neptunists died or gave up, and geology became a modern science.

Lyell argued that to be a good geologist one must accept not only the uniformity of natural laws and processes (actualism), but also the slow, gradual uniformity of rates (gradualism). The struggle against supernatural, unscientific ideas had led Lyell to take an extremely contrary position, and most geologists for the rest of the century would not accept any process that seemed to violate gradualism.

However, we know that there are natural processes that can be rapid, that is, non-gradual, but at the same time do not violate actualism and uniformitarianism. The impact of an asteroid from space is not a gradual event, but it is certainly natural and happens. So is a huge landslide or a huge volcanic eruption.

This confusion of gradualism and uniformitarianism led many geologists in Lyell's day to have difficulty accepting major natural disasters such as a meteorite impact or a massive ice age flood.

Geologists, like all scientists, must work within the scientific method: Observe and record data, hypothesize, collect relevant data, then test that hypothesis and try to falsify it. In particular, we should keep several working hypotheses in mind when trying to explain natural phenomena. When enough testing has been done, a hypothesis that has survived thousands of experimental tests and explained almost all of the evidence becomes a theory, a more comprehensive explanation of natural phenomena that explains a wide range of data.

For this reason, scientists must embrace naturalism and reject supernatural explanations because they are not testable and cannot lead to further scientific knowledge.