IGNEOUS DIKES

The volcano was not created to scare superstitious minds and plunge them into fits of piety and devotion. It should be seen as the vent of a furnace.

—JAMES HUTTON

NEPTUNISM VERSUS PLUTONISM

In the late 1700s, the early natural historians of the Enlightenment were still strongly influenced by the Genesis accounts and the myth of Noah’s flood. Early scholars such as Giovanni Arduino (1714–1795) tried to shoehorn all the rocks they could see into a simplistic sequence of hard crystalline “Primary” or “Primitive” rocks (granitic rocks and metamorphic rocks like schist or gneiss), supposedly formed when the earth was created. These were covered by “Secondary” rocks, which were fossiliferous layered sedimentary beds, often folded and deformed. (Today, most of these “Secondary” rock strata are assigned to the Devonian through Cretaceous Periods.) According to some naturalists, the “Secondary” beds were the main deposits formed by Noah’s flood. Above these were loosely

consolidated sediments and sedimentary rocks called “Tertiary” beds, which were supposedly post-flood deposits.

These simplistic ideas of the rock record could be entertained as long as you didn’t go out in the real world and look at real rocks too closely. But most geologists at that time did not travel very far or check their ideas against the outcrops, instead forcing the limited rock exposures of northern Europe into their previously accepted dogmas. This scheme of all the rocks supposedly formed by water (usually interpreted as Noah’s flood) became known as Neptunism, after the Roman god of the sea. The Neptunists argued that even lava flows were once laid down in water. Their opponents, however, argued that lava flows were once formed of hot molten rock, not from water, and so were called “Plutonists” (after Pluto, the Roman god of the hot volcanic underworld).

Among the most prominent Neptunists was German naturalist Abraham Gottlob Werner (1749–1817). A professor of mineralogy at the Freiburg Mining Academy, Werner was said to be a spellbinding lecturer and a powerful personality who made devoted converts of nearly anyone who heard him speak. His concepts were among the most popular in Europe, primarily because of the force of his arguments and personality, and were not based on close examination of outcrops over a wide area. (He did not, however, specify that layered sedimentary rocks and lava flows were deposits of Noah’s flood, as many of his contemporaries believed, but simply that they were laid down in water.) His disciples were found in all the major European universities, including the University of Edinburgh, where Robert Jameson was a convinced Neptunist who also became the archrival of James Hutton. Even the great poet and naturalist Goethe was a convinced Neptunist. In the fourth act of *Faust*, there

is a dialogue between a Neptunist and a Plutonist, wherein Mephistopheles is clearly a spokesperson for the evil Plutonist viewpoint.

You might ask yourself, “How could anyone think a volcanic rock was formed in water?” Remember, chemistry was in its infancy at this time, so no one knew anything about the heat and pressure needed to melt rocks. Few Europeans had ever seen a lava flow. We are used to watching videos of glowing hot molten lava flowing in active volcanoes like Kilauea, but in Hutton’s day, few Europeans traveled far from their hometowns, and none had seen a volcano erupt unless they had been to southern Italy at a time when Vesuvius, Stromboli, or Etna might be erupting—and those volcanoes mainly produce ash, not lava flows. It was a French geologist, Nicolas Desmarest (1725–1815), who pointed out in 1774 out that the extinct volcanoes of Auvergne in southern France showed all the evidence of having once been actively erupting volcanoes, based on their volcanic cones and many weathered lava flows. This evidence alone should have proved the case for Plutonism, although the Neptunism were the dominant theory for many more years.

Yet as James Hutton thought about his grand scheme of mountains being uplifted and eroded away, he became convinced that rocks such as granites and the basalt that formed lava flows were produced by hot molten rocks known as magma, not laid down in water. But there were no active volcanoes anywhere in northern Europe, and Hutton had never seen a lava flow move across the landscape. In the absence of this evidence, Hutton looked for places where granitic rocks or basalts had melted their way, or intruded, through preexisting rock and baked the rock surrounding them with

their enormous heat.

GLEN TILT AND SALISBURY CRAGS

Hutton got his first clues when he noticed that the gravels in the River Tilt, flowing south out of the Cairngorm Mountains in the Highlands north of Edinburgh, were full of both granitic pebbles and older metamorphic rocks. From this, he knew that both kinds of rocks must be exposed in the riverbed, and he might possibly see where one contacted the other. In 1785 he rode up the valley of the Tilt and stayed overnight at Forest Lodge. The next day, exploring the exposed rocks in the bed of the River Tilt at Dail-an-eas Bridge near Forest Lodge, he found what he had been looking for: veins of brick-red granite cutting through older metamorphic rocks and baking the zones around them (figure 5.1). Here was proof that granites were once molten magmas, not formed in water! Not only that, but the granites must be younger than the schists, and therefore not all had been formed during the original Creation of the earth as described in Genesis.


A


B

Figure 5.1

The granitic intrusions at Glen Tilt that helped confirm James Hutton's Plutonist viewpoint of the earth: (*A*) The outcrop as it is today above Dail-an-eas Bridge, looking northeast up Glen Tilt, showing the white veins of granites intruding through the dark Precambrian schists of the Scottish Highlands. (*B*) An illustration drawn by John Clerk from a posthumous edition of Hutton's book, showing the dikes intruding through the older rocks. ([*A*] Courtesy of British Geological Survey; [*B*] Courtesy of Wikimedia Commons)

But Hutton needed something even more convincing: lava flows that were intruded through layered sediments that had been formed in water. As Hutton wandered around the hills south of Edinburgh with his dog Missy, he also came to realize that the mountain that towers above the city, Arthur's Seat, was the throat of an old volcano (figure 5.2), and the Salisbury Crags on the north flank of the mountain are a ledge of old volcanic rock. Finally, on the southwestern slopes of the Crags, he found what he was looking for: intrusions of basaltic lava that had melted their way through layered sediments and even deformed them in the process (figure 5.3). This spot is so famous that it is now known as "Hutton's Section," and geology classes visit it on a regular basis. In 1786 Hutton found another example in Galloway, and in 1787 he located yet another on the Isle of Arran.

Figure 5.2

Arthur's Seat, the throat of an extinct Carboniferous volcano, towers above the south side of Edinburgh. The ledges in the foreground are the Salisbury Crags, volcanic sills that intruded parallel to the bedding in the Carboniferous sedimentary country rocks. Hutton lived in a house at the base of the Salibury Crags to the right in this shot, and frequently hiked in the area with his dog Missy. This shot is taken from near Edinburgh Castle, which sits on another vent of the same volcano. (Courtesy of Wikimedia Commons)

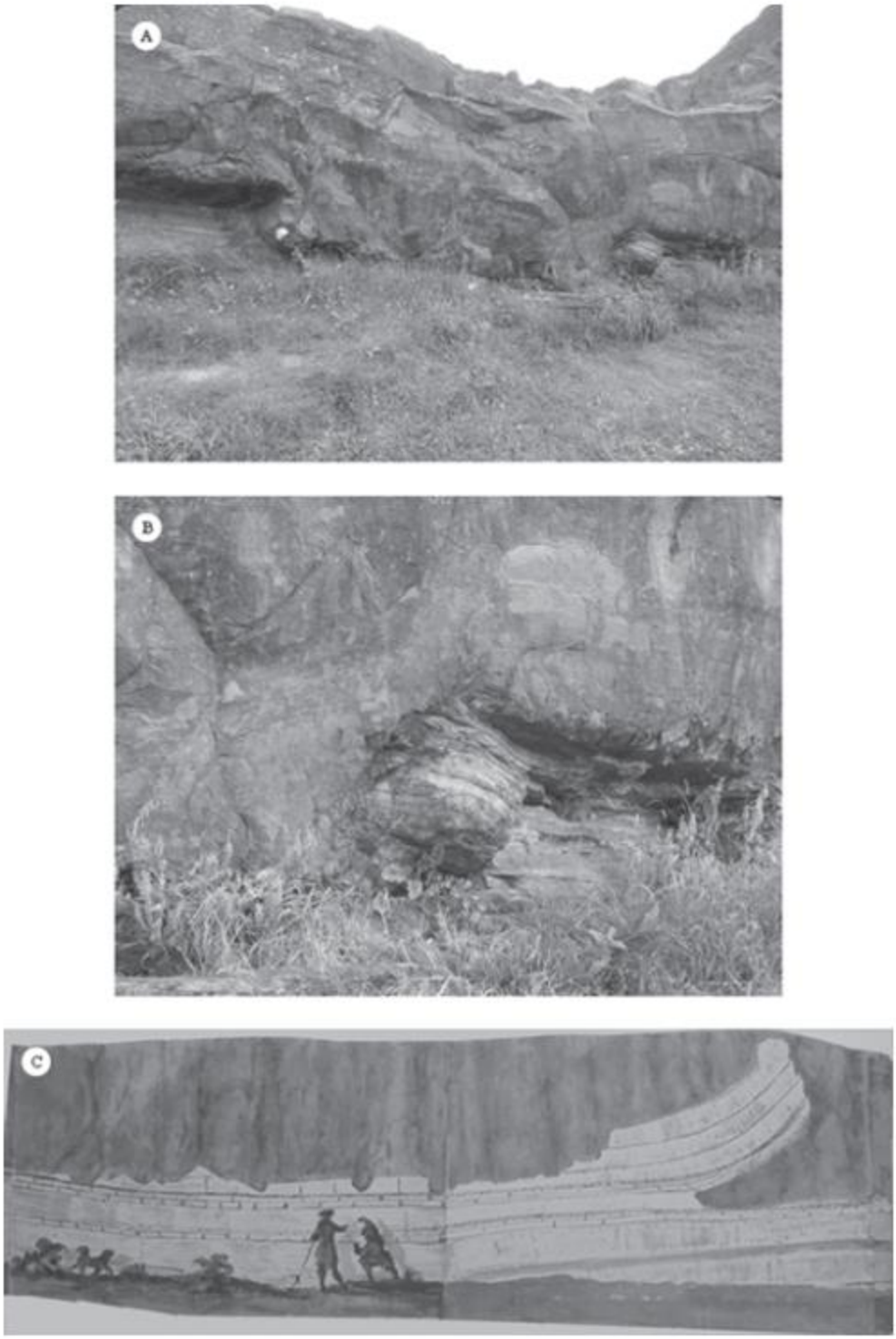

Figure 5.3

Hutton's Section at the Salisbury Crags: (*A*) The outcrop as it looks today, showing the baked and deformed sedimentary layers (bottom) with magma surrounding them (top). (*B*) Close-up of the right side of the outcrop, showing the bent sedimentary layers surrounded by intruding magma. (*C*) A diagram drawn by John Clerk and published in a posthumous edition of Hutton's book with the same outcrop rendered on a completely wrong scale. ([*A*] Photo by the author; [*B*] Photo by the author; [*C*] Courtesy of Wikimedia Commons)

Hutton and his chemist friends, Joseph Black and Sir James Hall among them, also had much better insights into the chemistry of rocks than anyone else at that time. Hutton knew what minerals (such as salt) formed by chemical precipitation from water looked like, and he could see that magmas were not formed in water. When Hutton moved to Edinburgh in 1768, he worked with Black, who shared his love of chemistry, a key tool to understanding the effect of heat on rock. Black deduced the existence of latent heat and the importance of pressure on heated substances. Water, for instance, stays liquid under pressure, even when heated to a temperature that normally would transform it to steam. Those ideas about heat and pressure would become key to Hutton's theory about how buried sediments became rock. In 1792 Hall performed an experiment in which he melted a piece of basalt at temperatures between 800°C and 1,200°C, and it recrystallized into basalt again when it was cooled slowly. This was one of the first examples of experimentation in geology and proved what molten rocks would look like in nature.

THE DYNAMIC EARTH

Having read accounts of hot springs and volcanoes (but never having visited them), Hutton was convinced that the earth was hot

and molten in its center, powered by what he called "the Earth's great heat engine." In his words, "The volcano was not created to scare superstitious minds and plunge them into fits of piety and devotion. It should be seen as the vent of a furnace." His ideas were further confirmed by coal seams that had been baked by lava that had intruded through them. He believed that this heat engine was responsible for the uplift and building of mountains, which then became the sediments that were washed to the sea. These processes went on in an endless cycle of uplift, erosion, deposition, and uplift again. All of these ideas were part of a broad overview of a dynamic Earth that was incredibly old and constantly remade and recycled—not a young Earth that had remained essentially unchanged since its creation 6,000 years earlier.

With the publication of his essays in 1788 and his book *Theory of the Earth* in 1795, Hutton put forth his concepts for the rest of the world to see. Yet Hutton's ideas were not immediately accepted, partly because his writing was so difficult to read and understand. When Hutton died in 1797, he was still not widely appreciated, although in 1802 his protégé, John Playfair, published *Illustrations of the Huttonian Theory of the Earth*, which made the case clearer and was more widely read (and had illustrations by Hutton's friend John Clerk, which further helped people understand what Hutton had seen).

It would take another generation for such revolutionary ideas to win acceptance in the geological community. This happened thanks to a young man named Charles Lyell (figure 5.4), born in 1797, the year Hutton died. Originally trained in the law to become a barrister, he soon became bored and instead pursued the young field of geology as a hobby. He traveled widely over Europe, witnessing

many different geological phenomena with the uniformitarian eyes of Hutton. Eventually, Lyell wrote his masterpiece, *Principles of Geology*, published in three volumes from 1830 to 1833. The book is written essentially as a legal brief (which as any lawyer can tell you, is never actually "brief"). Mustering all the observations he had gathered from his travels and his reading, he used his skills as a lawyer to argue a decisive case for the uniformitarian view of the earth. Like any good lawyer, he used any tactics necessary to discredit his opponents, the catastrophists, while presenting overwhelming evidence for his own case. He confirmed Hutton's ideas of "Earth's great heat engine" with multiple accounts of volcanic eruptions and hot springs, especially in southern Italy. Within a few years, the last of the old-line catastrophists and Neptunists had died or given up, and geology became a modern science.

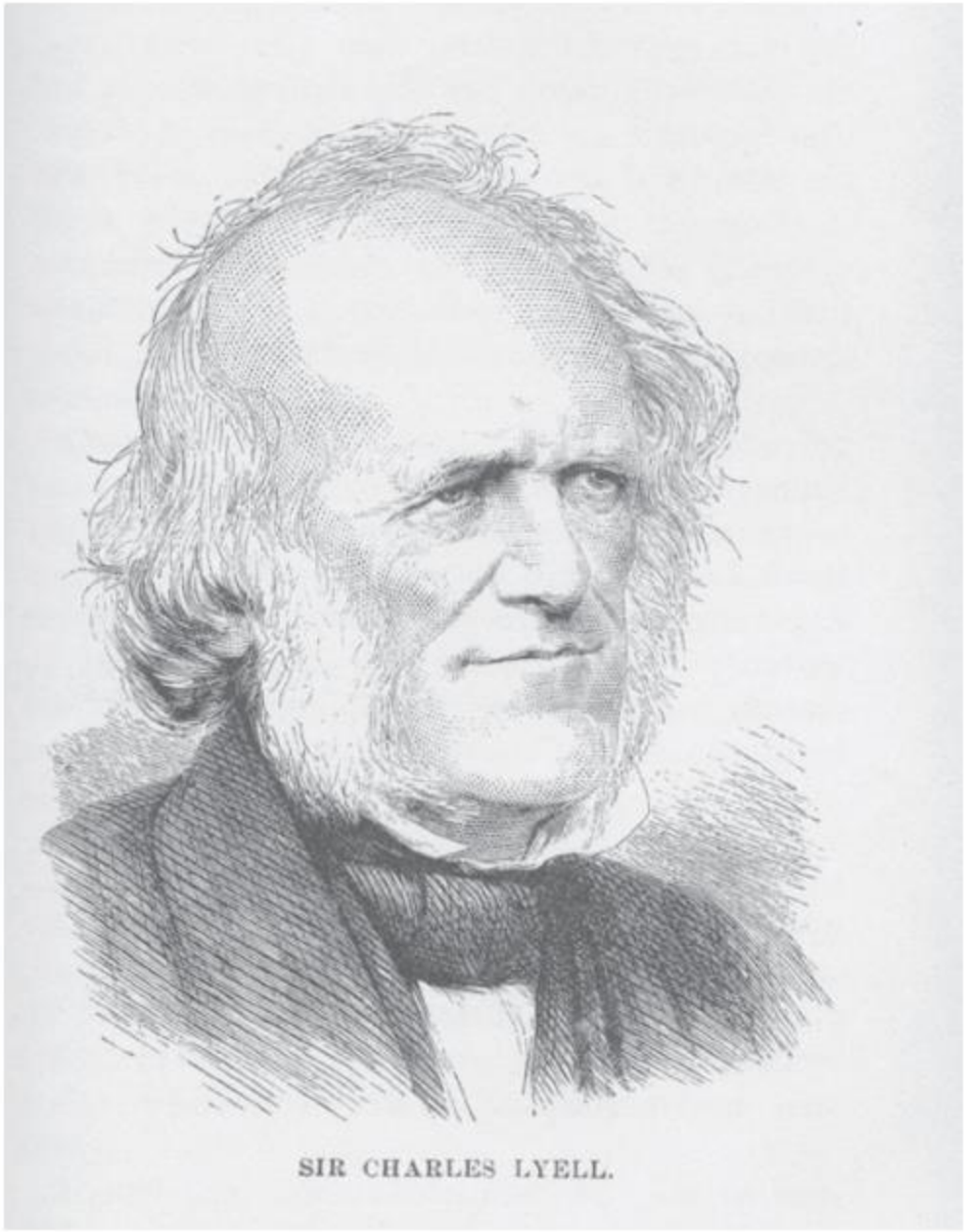

Figure 5.4

Charles Lyell, in his later years, after he had been knighted and had become one of the most respected figures in all of science due to his books on uniformitarian approaches to geology. (Courtesy of Wikimedia Commons)

FOR FURTHER READING

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