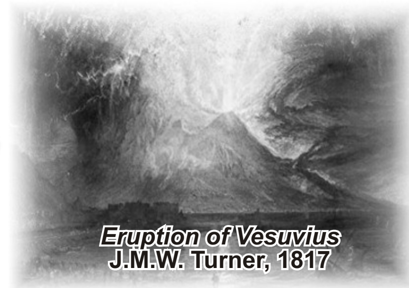
Determining How Volcanic Activity Fit into the Greater System of the Earth



Eruption of Vesuvius
J.M.W. Turner, 1817

In April 1815 in Indonesia, the volcanic island of Tambora erupted more powerfully than any recorded volcanic event in modern human history. What was once a 4,000 meter mountain east of Java shot off over half its mass in the course of a week. Its rumblings were heard over a thousand kilometers away. Hearing the booms, the British governor of Java dispatched patrol ships looking for revolutionaries. Around Tambora, ash and soot shot 40 kilometers into the atmosphere. The sky was blackened for a week. Upon arrival, European ships found the area completely devastated: cities buried in lava flows, tsunami-damaged villages, poisoned rice fields, and a mere 26 survivors. In the outlying areas, a massive refugee movement began as islanders fled their devastated home. Captains and crews did their best to record the devastation and the resulting new geography, but ultimately they lacked the skill to really understand what had happened. Eventually, a report would be made to a scientific academy in the city now called Jakarta, and very slowly news of the eruption would travel back to Europe.

The effects on European climate, however, arrived much faster. The summer of 1816 was cold and wet. Crops failed and famine swept through major cities. Nations already unsteady after the 1815 Battle of Waterloo ended the Napoleonic Wars now faced the environment as their enemy. The British poet and politician Lord Byron took residence in a Swiss villa. There he wrote one of his more haunting poems, "Darkness," that reflected on the days:

I had a dream, which was not all a dream.
The bright sun was extinguish'd, and the stars
Did wander darkling in the eternal space,
Rayless, and pathless, and the icy earth
Swung blind and blackening in the moonless air;
Morn came and wentand came, and brought no day,
And men forgot their passions in the dread
Of this their desolation…

During his stay, Byron spent the cold nights talking with his neighbors, the poets Percy and Mary Shelley. One night they sat down determined to write horror stories. Inspired partly by the desperate state of the continent and partly by the wonder of being human, Mary wrote the story of a failed creation haunting its maker, *Frankenstein*.

Modern science can reconstruct Tambora and its geological and meteorological effects by comparing literature, archeological evidence across the globe, and analysis of the volcanic remnants around the modern-day Tambora. In 1815, though, naturalists lacked the necessary scientific knowledge and technology to understand these far-reaching consequences. However, they had accumulated volumes of observational evidence on volcanoes and had traveled great distances to try and understand how volcanic activity fit into the greater system of the earth. Were volcanoes a safety valve for releasing internal water pressure, a mechanism that produced entire continents, or were they just menacing natural events?

Like most scientific knowledge, the answer didn't come nicely packed in one episode, or with the acceptance of a single author's point of view. Rather, the process required a lot of exploration, argumentation and publication over many years. In this story, we're going to examine how naturalists went about studying volcanoes from 1760-1840. It's neither an easy story to follow nor one in which there's a conclusive ending, but that's how science really works. In this time period, many naturalists struggled to understand the natural world using different theoretical models. Much can be learned about how science works by understanding how they compiled evidence and interpreted it within these models.

To understand how naturalists of this time viewed volcanoes, we must understand how they viewed their world, and it's best to begin with mineralogy. For centuries, the collecting and cataloguing of rocks had been a professional and amateur hobby. As the Industrial Revolution took off in Britain and France in the mid-1700s, a demand developed for individuals who could identify ores and metals. A small industry developed that employed these knowledgeable people to travel the countryside and locate suitable locations for mining. Ideally, one of these "surveyors" could develop a model to predict the locations of the richest ores and metals. Most often, this was done by identifying both the types of rocks in an area and how they positioned themselves in relation to each other.

However, one problem continually stumped surveyors. Both in Britain and in France, mineralogists found a rock, which they called "basalt," that they could not easily categorize into specific locations. These basalt rocks appeared in contradictory locations. Some were isolated on high cliffs and others next to water on beaches. It resembled the rocks found near known volcanoes, like Vesuvius, except there were obviously no volcanoes now working in Britain or France. Furthermore, a famous natural wonder in Northern Ireland, named the Giant's Causeway, seemed to be made of basalt, but of a very different kind. The Giant's Causeway sat resting on the shore of Northern Ireland, its "prismatic" basalt seemingly cut into rigid geometrical shapes and jutting into the sky like spires. Naturalists had a mystery on their hands. Was basalt of aqueous origin, formed by sedimentation and then ground down by water, as would appear to be the case with the Giant's Causeway? Or was it igneous in origin, produced in the heat of a volcano? Regardless of its origin, how could many basalt rocks come to be located on isolated cliffs, far from both observed bodies of water and volcanoes?

Let's take a look at some of the more popular models of understanding the Earth as a system of natural processes in the mid-to-late-1700s. In France, George-Louis Leclerc, the Comte de Buffon envisioned a largely stable and static Earth system. He postulated the young Earth as a giant globe of hot iron that cooled over time, resulting in the exterior being composed of rocks. In this system, volcanoes had very little useful role and were hardly mentioned. He amended his system in 1788, however, following criticism from his colleagues that his earlier system wasn't specific enough, and also in response to the recognition made in the early 1770s that extinct volcanoes existed in France. In this new system, he divided the Earth into "epochs," which were like geological eras of immense time. He now envisioned the young Earth to have been entirely immersed in a primordial ocean that slowly slipped away into subterranean caverns. He then postulated that active volcanoes existed only near water (like Vesuvius and Etna), while extinct volcanoes could be found inland (like France). This then implied that in the past, when water was more prevalent, many more active volcanoes existed than today. While Buffon's system was almost entirely conceived in his library, its powerful reasoning and exhaustive scope gave it a fair amount of influence among European naturalists.


Giant's Causeway, Northern Ireland

Meanwhile, in Britain, James Hutton produced an influential system largely drawn from his fieldwork experiences tempered with his own reasoning. His first publications hit the scientific community in 1788, and his broader (and very confusing) book hit shelves in 1795. Hutton likened the Earth to the steam engines he saw proliferating around his country, lifting and moving objects far beyond their point of origin. The Earth-machine worked very slowly, however, and changes in topology would only happen over many millennia. Thus, basalt could be a volcanic rock and be pressed upward to an isolated cliff by natural forces over very long periods of time. Furthering the steam engine metaphor, Hutton argued that there needed to be a way to release pressure from inside the Earth, and volcanoes played that role. Hutton's belief in this machine-like system was somewhat tied to his religion. He was a Deist and believed that the Judeo-Christian God created the world with a plan in mind, but no longer interacted with it. For Hutton, God designed the machine and let it run, lifting, pressing, and releasing exhaust over countless millennia. His theory was very influential, but only after the turn of the century, when his friend John Playfair wrote an explanatory volume clarifying Hutton's points.

Lastly, there was the very influential system of the German scholar Abraham Werner. Born into a mining family, he became one of Europe's most renowned mineralogists. In 1774 he published an exhaustive text which became mandatory reading for all schooled naturalists. However, he was not of good health and after 1775 very rarely left his teaching position at Freiberg Mining Academy. This meant his ideas spread through detailed writing and devoted students. While he wasn't the first to propose such a theory, Werner came to be associated with what he called "Neptunism," or the importance of water in creating and changing geological features. His view was named after Neptune, the Roman god of the sea. Werner argued for the existence of an all-encompassing primordial ocean, very similar to the one used in Buffon's Epochs, in which water receded into subterranean caverns and left behind the dry land. Werner claimed that as the water receded, it left sequential layers of strata forming from sediments and minerals in the ocean. He had five layers: 1) Primitive (granites), 2) Transition (limestones and greywackes), 3) Secondary (sedimentary and erosive rocks), 4) Alluvial (sands, gravel, clays, and other surface rocks), and 5) Volcanics (lavas associated with volcanic vents). Werner's system emphasized the universality of these positions, because the all-encompassing ocean receded more or less equally in all areas. His system, however, had the major problem of not being able to explain the connection between basalts and lavas. Werner argued that the positioning of basalt on mountaintops was evidence of its sedimentary origin in the primordial ocean. Volcanoes, meanwhile, he argued to be positioned on top of burning coal beds, the products of which came out at lower elevations as lava. Due to the popularity of Werner's books and the devotion of his students, his theory became a dominant force moving into the nineteenth century.

1. When considering how science is actually practiced, keep in mind that data don't speak for themselves. In this case, we have three different systems of understanding the same evidence coming from three different countries. Each system was developed in a different way, and popularized by different means. For instance, a naturalist following Hutton's system would see events very differently than one who followed Werner's system. Because of this complex interaction, why is the view that one discovery or one scientist "overturned" a theory almost always incorrect?

France and Italy became the hotbeds of volcano study in the late 1700s and early 1800s, the former being home to many extinct volcanoes and the latter being home to active volcanoes. First, we're going to look at central and southern France, in the mountainous regions of Auvergne and Vivarais. Here, the geologist Jean Etienne Guettard had first proposed the existence of extinct volcanoes in 1748, and as such later naturalists visited the area with an eye toward this claim. It's important to note that as we begin with our first naturalist, only basic outlines of the above theories existed. For example, there were naturalists that argued for a primordial ocean, but none had as of yet argued it to be responsible for the positioning of strata. Nonetheless, the basic conceptions of the above theories existed in one form or another.

In the late 1760s, Nicolas Desmarest entered Auvergne on a job as an industrial engineer. He had a background in geology, but had never been a true fieldworker. In 1753, he presented an article before the Academy of Science in Paris that proposed an ancient land bridge between France and England. At the time of writing, however, he had never actually seen an ocean. His report was entirely based on the work of others. While visiting Auvergne on business, he became fascinated by the basalt rocks in the region, supposedly laid there by the now extinct volcanoes proposed by Guettard. He then practiced fieldwork extensively and earned a reputation for thoroughness, so much that the luminary naturalist Georges Cuvier once said of him:

> *His friends used to jocularly affirm that he would have broken the most beautiful statue in order to ascertain the nature of an antique stone, and his character was so widely given to him that at Rome the keepers of the museums felt some alarm in admitting him. In society, too, things, whatever they might be, affected him on one side only. For instance, when an Englishman was recounting at the house of Duchesse d'Anville the then recent thrilling incident in Cook's first voyage, when his vessel, pierced by a joint of rock, was only saved from sinking by the stone breaking off and remaining fixed in the hole, everyone present expressed in his own way the interest he felt in the story. Desmarest, however, quietly inquired whether the rock was basaltic or calcareous [sedimentary rock].*

What captured Desmarest's attention most was “prismatic basalt,” the kind he saw in paintings of the Giant's Causeway in Northern Ireland. Such paintings had recently been selling well in France, and Desmarest recognized similar rocks in the Auvergne region. Desmarest's response to finding prismatic basalt in Auvergne is telling of how evidence works within theories. Guettard had viewed basalt as being aqueous in origin, so basalt in mountains and on shore were both products of sedimentation from a primordial all-encompassing ocean. He had no motivation, then, to differentiate the types of basalt. Desmarest, however, believed basalt to be an igneous rock, forged from the heat of volcanoes. If he took Guettard's proposal of the existence of extinct volcanoes in Auvergne to be true, then the presence of prismatic basalt was connected to ancient volcanic activity. This must also have been true in Ireland, despite the dramatic differences in location and seeming absence of Irish volcanoes. Desmarest drew up a proposal in 1765 and presented it to the Academy of Sciences before leaving on an extensive research trip to Switzerland and Italy.

For the next six years, Desmarest drew detailed maps, honed his fieldwork, and drew up a longer paper linking basalt to volcanic activity. However, little to his knowledge, his 1765 paper had already taken hold amongst the Academy, and his stance on basalt had been published in the 1768 version of Denis Diderot's Encyclopedie. His 1771 article outlined his explanation of prismatic basalt and connected it to the larger theory of volcanic action, in his words:

> *Water from rain and melted snow appeared to me as agents quite capable of working a large part of these degradations. Prisms, detaching easily from one another, can collapse by the removal of unsteady and light materials that serve as their base; for burned earth, pumice, scoriae, and porous lavas yield with the greatest ease to the action of the least trickle of water; and this play of water, whose last traces and most recent marks I had examined, once recognized, helped me, in my thought, to replace all the removed materials into their primitive state, and to restore without effort the ancient configuration of the terrain, as it was after the volcanic eruptions.*

Essentially, he recognized the role played by water (like rains and floods, but not a primordial ocean) in erosion and denudation. Again, in his words, about valleys:

> *I noticed that the deepening of these valleys was in proportion to the antiquity of these flows and to the abundance off the stream's waters; that the streams that separated the different parts of the old flows had achieved the excavation of very deep cuts between them, whereas they were only rough-hewn and studded with falls and cascades when they were found cutting between parts of the more modern flows.*

In other words, basalt rocks were volcanic in origin, and like many other rocks, could be positioned among different strata through erosion and movement of water.

Desmarest went on to explain volcanoes through an innovative system. He adopted a view (not held by many) that the Earth's interior was aqueous. Not particularly interested in outlining an entire history of the Earth, he didn't bother to detail the origin of lava, instead arguing that once cooled it formed the Primary strata of granite, from which other strata then accumulated. What Desmarest did, essentially, was go back to a point in history that he could build upon (the Primary strata), and then did not hazard a guess as to what came before. He emphasized that volcanic activity in the past was very similar to modern activity. It was neither more active nor more catastrophic, but practically identical. One could separate the ages of activity through recognizing the processes of erosion and denudation.

It's interesting to note how history remembers Desmarest. Because of his emphasis on volcanic activity in human history, he is often remembered as a "vulcanist," or one who thought that heat was the major agent of change. He was, however, truly a "neptunist," one who thought that water was the main agent of change. He did point out the usefulness of volcanoes in the system of the earth, but nonetheless attributed the differentiation of rocks and geographical formations to water. He did not, however, adhere to the claim that an all-encompassing ocean once covered the Earth.

In 1789, the French Revolution put a halt to scientific exploration in the Auvergne region. During the Reign of Terror, many academics were put to death for being "threats" to the revolution, and few Europeans wished to sacrifice their heads in the name of studying extinct volcanoes. Influenced by Hutton's system of the Earth, many British naturalists wanted a look at Auvergne, but they would have to wait until after the downfall of Napoleon in 1815, the same year as the eruption at Tambora. With the Napoleonic conquests ended, several British naturalists made their way to Auvergne.

The first was Charles Daubney, who, like Desmarest, came to be fascinated with the prismatic basalt. While Daubney agreed that all basalts were igneous, he concluded from erosional evidence that there were separate "epochs" of volcanic activity – ancient and modern. After all, if lava were to flow into a valley, there must be a valley in the first place. Daubney's argument was that long ago volcanoes had been more active and their products then underwent massive erosion to create the peaks and valleys we now see, and then gave way to a calmer period of volcanic activity occupying the present time period.

Shortly after, George Poulett Scrope arrived in the region and completely disagreed with Daubney's assertion of two epochs of volcanic activity. Upon investigation, Scrope found no concrete evidence for drawing a line of ages between the mountains. For his example he used the nearby Puy Rouge region, where it seemed that an eruption had taken place long ago followed by significant erosion. He argued that if a single massive deluge had produced all the observed erosion, it would have wiped out the entire mountain as well. The mountain being present, it was then much more likely that erosion occurred gradually over a very long timeline. He did, however, still have use for catastrophic events. He attributed the formation of mountains to major earthquakes and volcanic activity occurring intermittently throughout time.

Scrope's work caught on with Charles Lyell. Lyell hailed Scrope's style of reasoning, his elimination of the ancient-modern distinction, and removal of deluge-like events to account for observed erosion. However, Lyell preferred his own "uniformitarian" view, in which geographical features developed gradually over time not through intermittent catastrophic events. He was so fiercely possessed by this idea that prior to writing his landmark book, *Principles of Geology*, he determined to tour the volcanic regions of Europe gathering observational evidence. He visited Auvergne and Vivarais in the late 1820s, using Scrope's sites as evidence for the uniformity of the past and present, and then headed for Mount Etna in Italy.

Lyell chose Etna for two reasons: 1) it was an active volcano, and 2) he thought it would provide evidence for a connection between earthquakes and volcanic activity. Lyell thought that if minor earthquakes were associated with volcanic activity, it would essentially kill two birds with one stone. That is, regions would gradually rise through quaking, while volcanic activity accounted for the observed rocks. Once in Italy, he climbed a number of volcanoes and found evidence of alternating lava and ash, implying a gradual build-up or layering over time. Furthermore, he found elevated marine fossils on these volcanoes, both of extinct and extant species. He used evidence of extinct fossils to show that uplift occurred in the past, and the evidence of extant fossils to show that recent uplift had occurred. Furthermore, he found a total of 80 volcanic cones in the region of Etna, yet only one had been active recently. To produce such a massive mountain, it must have taken countless years of activity from both the visible cones and the ones that they had surely covered with lava. This implied that volcanic activity acted more or less the same now as it did in the past. Very excited by his findings, Lyell returned to write his 3-volume *Principles of Geology*, making sure to include the findings of his journey, as well as commenting on the 1815 eruption in Tambora.

We'll finish the story with a man who became greatly influenced by the work of Desmarest, Scrope, and Lyell and became a transition into the next generation of geologists: Charles Darwin. Many people forget that Darwin had a very broad academic training. He began as a physician, realized he hated it, reenrolled for theology and finished his degree at Cambridge. All the while, he had been intensely interested in natural history and taxonomical collections. Some of the natural history professors at Cambridge had themselves been clergy, and Darwin made an impression upon them. He was recommended to be the naturalist/physician aboard the HMS Beagle, and began his very famous voyage late in 1831. Before boarding, he took a crash course in geology from Adam Sedgwick, the President of the Geological Society of London. On launching, the ship's captain gave Darwin the first volume of Lyell's *Principles of Geology*, which outlined the author's uniformitarian views. While on board, Darwin had a selection of about 250 books in the ship's library, including Daubney's *Description of Active and Extinct Volcanoes*, Scrope's *Considerations on Volcanoes*, and many other hallmark texts of natural history. Scrope's book had come highly recommended by Sedgwick because it was exhaustive and considered the role of chemical interactions inside volcanoes. Darwin studied intensely as the Beagle crossed the Atlantic and began its voyage across the globe.

Sailing around South America, Darwin found evidence for Lyell's system of gradual environmental change and Scrope's volcanic system. First, he became an eyewitness for Lyell's claim of earthquakes being the primary cause of uplifted terrain. Along the coast of Chile, he experienced a number of earthquakes powerful enough to devastate nearby villages. As he continued his journey along the coast, he noticed that the local terrain had been raised by about ten feet, enough to expose fossilized shells from the ocean bed. He recognized this as the hallmark of Lyellian gradualism – over countless years, earthquakes changing the landscape ten feet at a time could create an entire mountain range.

Second, he found evidence for Scrope's system of volcanoes. Doing investigations in the Galapagos Islands, he found that on one island, the entire southern half was composed of volcanic basalt, while the northern half was composed of volcanic trachyte. The difference between these rocks was the amount of silica present. As Scrope summarized in his book *Considerations on Volcanoes*, either there was "an original difference" in volcanic lavas or natural processes affected how the lava formed rocks. An "original difference" implied that there would be different reservoirs of lava underneath the volcanic cone, and that somehow the volcano switched between them. However, if the volcano had lava of more or less uniform composition, its resulting rocks could be greatly affected by variables like pressure, method of elevation, and reconsolidation. Scrope favored natural processes affecting how lava cooled into different kinds of rocks, and after observing evidence on Galapagos, Darwin also favored this stance.

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Notice how Darwin worked within models of the natural world and "eliminated" models that didn't work. This doesn't mean, however, that he immediately "vanquished" his opponents. Darwin was, after all, two years from arriving home with his evidence. He then had the challenge of communicating his findings to colleagues and having them interpret his data. In turn, Darwin recognized how events like volcanoes and earthquakes (and floods and droughts, etc.) could affect native wildlife populations. His theory of natural selection argued that these "natural pressures" weighed heavily upon the success of a species and its ability to continue to produce offspring in a changed environment. This is an excellent example of how science works: discussion of evidence, movement of ideas between lands and groups, and the inclusion of important evidence into wider theories.

By 1840, the first grasses and wildlife had been returning to Tambora and its effect on the world's climate had largely diminished. Naturalists understood its destructive power, in that it destroyed and poisoned thousands of kilometers around the volcano. However, it also had the power to create, as it left two volcanic islands in its wake. In the coming years, European presence in Southeast Asia would greatly increase, and the Opium Wars between Britain and China gave Europe a foothold in the region. When the famous volcano Krakatau (commonly misspelled "Krakatoa") erupted in the late 1880s, Indonesia had telegraph cables to communicate news of the disaster. The group of scientists who would arrive to study the region was familiar with Lyell, Darwin, and Scrope's books and would use their arguments as a base from which to launch new understanding of volcanoes.

Naturalists like Desmarest, Hutton, Scrope, Lyell, and Darwin only touched on the surface of understanding the role of volcanoes in the system of the Earth. Many more would follow in their footsteps, putting their lives at risk by camping out on active craters and working hard in the lab analyzing volcanic products. In this early period of volcanic exploration, however, naturalists fought hard to understand what we consider common knowledge today. Modern textbooks introducing geology and mineralogy practically start with volcanic activity and its production of igneous rocks like basalt, and this has been a story of how that seemingly simple observation began its way to scientific fact.

Science textbooks often provide currently accepted knowledge without telling the story behind its development. What have you learned from this story about:

2 How scientific knowledge comes to be accepted?
3. The role of the political landscape and greater society in the development of scientific knowledge?
4. The role that a person's prior knowledge plays in what he or she investigates, and how he or she interprets the data?

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