

The end-Cretaceous mass extinction and the Deccan Traps eruptions

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What are Flood Basalts?

At least three of the five biggest mass extinction events occurred at the same time as flood-basalt eruptions. These were extensive volcanic eruptions that occurred over millions of years. Most of the lava flowed from fissures or vents in valleys or plains rather than from volcanic mountains, and crystallized into a rock called basalt as it cooled. Even after millions of years of weathering and erosion, layers of basalts from these eruptions extend over an area tens of thousands to millions of square kilometers across and several km thick. Some of these deposits are large enough to be seen on a world map (Fig. 1). In addition to flood basalts on continents, there are large basalt plateaus in the ocean, including the Kerguelen and Ontong Java Plateaus, which may be the result of sub-marine flood-basalt eruptions.

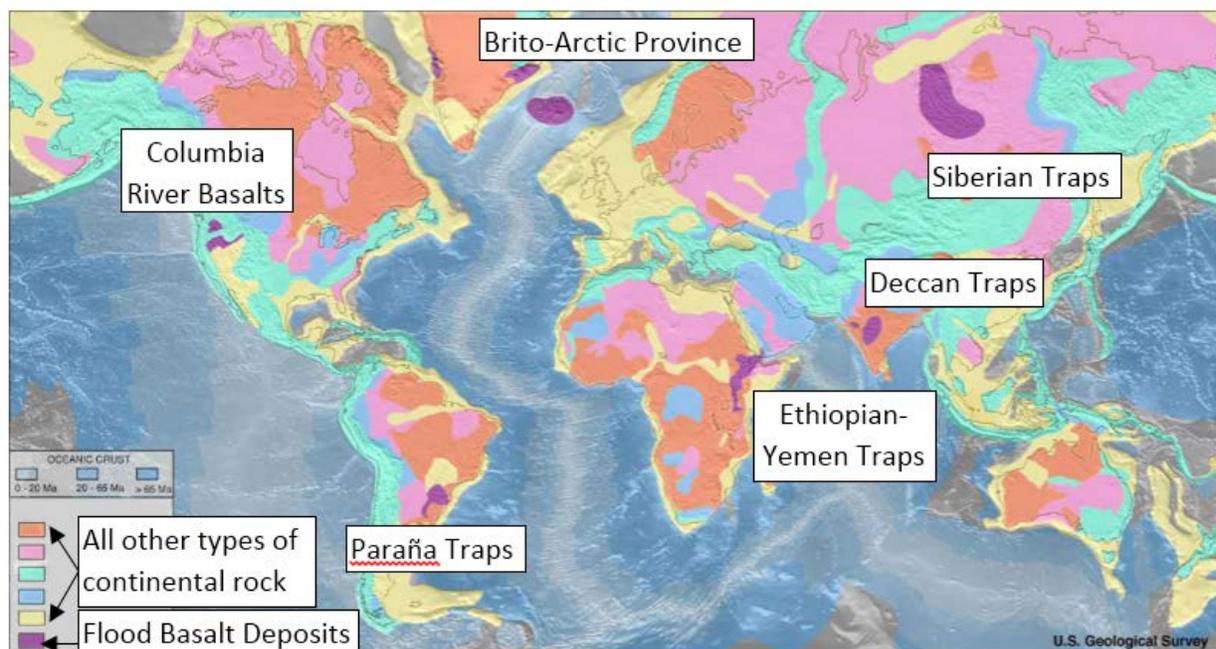


Figure 1: Major geologic provinces across the world (base map from the USGS, 2005). Note that some continental crust is currently flooded, including the continental shelves.

Flood basalt eruptions are poorly understood because they occur rarely, even in the geologic record. The most recent one ended over two million years ago, so they've never been directly witnessed by human beings.

These extensive basalt plateaus are often called "traps" from an old Germanic word for stairs, because weathering carves the rocks into formations that look like giant stairs (Fig. 2). Individual vent eruptions often lasted tens or perhaps hundreds of thousands of years, and these plateaus were

deposited by multiple eruptions. For comparison, the longest continuous volcanic eruption in human history is still going on at Kilauea in Hawai'i, but it only began in 1983.

One feature they share is that the minerals that make up continental flood basalts have an unusual



Figure 2: Three Devils Grade on the Columbia River Plateau (public domain).

chemistry. The lavas that crystallized into these basalts contained a lot of material from the Earth's mantle, which is very unusual for continental eruptions. Under the continents, Earth's crust is thick, about 30-40 km thick on average. Consequently it's very difficult for magma from the mantle to force its way to the surface without being heavily diluted by molten continental rock. Most flood basalt eruptions are believed to have occurred over "hot spots" in the mantle, like the ones under modern-day Hawai'i and Yellowstone. The causes of these "hot spots" are under debate by the geological community.

How Could a Flood-Basalt Eruption Cause a Mass Extinction?

Magma is a mixture of molten rock and hot, pressurized gas. If magma erupts from a volcanic vent, the gas is released to the atmosphere, and the remaining material, called lava, eventually crystallizes into glass or igneous rock. It is this gas, even more than the huge lava flows from a flood-basalt eruption, that can cause a global extinction. It's a mixture of water vapor, carbon dioxide, sulfur-rich gases, and a variety of others (but never free oxygen). Carbon dioxide absorbs heat and later releases it, warming the climate.

At the same time, the sulfur-rich gases become tiny particles of sulfate. These are usually suspended in the atmosphere as aerosols. On their own, they reflect some sunlight back into space before it reaches Earth's surface so that it doesn't get as warm as it usually does, especially in summer. Those aerosol particles provide a surface where water vapor can condense, forming clouds that will also reflect sunlight, and dissolve the sulfate, creating sulfuric acid. As this acid, even heavily diluted, falls as rain, it can dissolve the calcareous shells not just of familiar marine creatures like clams, but also of tiny plankton that are the base of the food web, killing them. As plankton populations decline, many other marine animals starve. The warming caused by carbon dioxide and the cooling caused by sulfate aerosols aren't likely to cancel each other out evenly.

Although human beings have never witnessed a flood-basalt eruption, we do have records of a very destructive set of fissure eruptions on a much smaller scale in Iceland from June 1783 to February 1784. The lavas themselves erupted in an isolated valley called Lakagígar and did little, if any, direct damage to the human population. But the gases, particularly hydrogen fluoride and the sulfate gases, were deadly in both the long and the short term. At least half of the livestock, grazing out in the open, died over the next several months, poisoned by the acids formed by these gases. When inhaled, hydrofluoric acid reacts with teeth and bones, starting to dissolve them. The dissolved material can be absorbed into the bloodstream, where it can then block blood vessels. Sulfuric acid, even diluted, makes it difficult for plants to take up nutrients with their roots, and over time can burn plant leaves.

Many of the people of Iceland starved over the next several months, and they still refer to this disaster as the Mist Hardships. Millions of tons of sulfate spread across the whole Northern Hemisphere.

Sulfate aerosols were visible as brown clouds in Europe, and the 1783-84 winter was extremely cold in Europe and North America according to Benjamin Franklin and other writers of the time. And that eruption lasted less than a year. Imagine if it had lasted for hundreds or thousands of years. Fortunately, Lakagígar was not a true flood-basalt eruption.

History records a number of “years without a summer” when stratovolcanoes like Mount Pinatubo or Krakatoa erupted, forcing tons of ash into the atmosphere, where it can be suspended for months after the eruption, and not just reflect, but also block incoming sunlight. The mineralogy of stratovolcanic eruptions is very different from those of flood-basalt eruptions. Scientists who argue that flood-basalt eruptions are not major causes of mass extinctions in the past point out that basaltic eruptions in general produce very little volcanic ash. However, the sulfate aerosols alone reflect a lot of sunlight. Moreover stratovolcanoes generally disrupt only one or two summers in a row, whereas individual flood-basalt eruptions continue for thousands of years, and flood-basalt deposits are made by multiple eruptions spanning millions of years.

Name	Age (millions of years ago)	Approximate Remaining Area (km ²)	Associated Extinction Event
Columbia River Basalt (N.W. U.S.)	17-15 & 14-5	200,000	none
Ethiopian and Yemen Traps	28-31	800,000	none
Brito-Arctic Province	59-56	1,500,000	end-Paleocene (minor)
Deccan Traps (N.W. India)	67-63	500,000	end-Cretaceous
Paraña-Etendeka Traps (E. S. America, W. Africa)	131-134	750,000	none
CAMP - Central Atlantic Marine Province (Morocco, E. Canada & U.S., Brazil, W. Europe)	200-201	uncertain	end-Triassic
Siberian Traps (Russia)	249-252?, 240?	2,000,000	end-Permian
Emeishan Traps (China)	258-260?, 251?	250,000	possibly end-Permian

Table 1: Characteristics of several relatively well-known continental flood basalt deposits – buried deposits add great uncertainty to estimates of modern areas.

Another problem is that some large flood-basalt deposits are not associated with extinction peaks (Table 1). One example is the extensive Columbia River Basalt, which formed from a set of eruptions that occurred 16 million years ago. The effects of these eruptions on the biosphere may depend on other factors, such as:

- global air and ocean circulation patterns
- climate (global and in the regional),
- other environmental stresses on critical communities such as continental-shelf plankton,
- or the composition of the gases that came out of the magma, particularly their sulfur levels.

The older mass extinctions, the end-Ordovician and Devonian, are not associated with known flood basalts, but this may be because basalt weathers easily compared to most surface rock types. If there had been a flood-basalt eruption during those times, most of the basalt is likely to have been buried or eroded away by now. Older flood-basalt deposits are rare, small, and often hard to identify. For

example, the Yakutsk-Viluy igneous province contains basalts that erupted as lava during the late Devonian mass extinction (Ricci et al., 2013), but much of it may be buried under the Siberian Traps, making its size difficult to estimate.

What is the Evidence for a Flood-Basalt Eruption at the End of the Cretaceous?

People generally focus on the dinosaurs when they mention the extinction event at the end of the Cretaceous Period, 66 million years ago, but mass extinctions are recognized based on rates of losses of marine taxa. The end-Cretaceous mass extinction involved many different kinds of organisms, including about 75% of all marine species. A number of large aquatic organisms died out: great reptiles like the mosasaurs and shelled squids like the ammonites, but so did many smaller organisms that played important roles in their ecological communities, such as reef-building clams, most coral species, and many species of plankton with calcareous shells.

During the end-Cretaceous mass extinction, huge flood-basalt eruptions were taking place in what is now northwest India. These formed the Deccan Traps and presumably emitted huge quantities of the gases described above. India was not part of Asia at the time. It was an island continent in the southern hemisphere. The hotspot believed to have caused the Deccan eruptions is now underneath the volcanic island of Réunion, near southern Africa. At least half a million cubic kilometers of Deccan basalt still remain in India, even after 66 million years of weathering and erosion. Volcanic ash within the basalt can often be dated by measuring ratios of amounts of radioactive elements to their decay products. The Deccan Traps are made up of multiple flood-basalt deposits from eruptions that happened between 67 and 63 million years ago.

Given the long duration of the Deccan eruptions, many researchers expected the extinction rate to rise 67 million years ago and to continue being high for millions of years. The larger organisms do disappear from the fossil record gradually over the course of the Cretaceous, but this doesn't mean that each of those species became extinct at the time that last known fossil was deposited. Most dead organisms decompose rather than forming fossils, and relatively few of those fossils are found and described by scientists. So among fossil taxa, there can be a substantial time gap between the deposition of the last fossil specimen and the death of the last individual. Paleontologists turned to plankton with calcium carbonate shells to learn if the end-Cretaceous extinction was gradual or abrupt. These shells are easily preserved. Before the extinction, there were large populations of these tiny organisms, so their fossils are relatively common compared to those of larger organisms, which were rarer even before the extinction. There was a sharp increase in the number of calcareous-shelled plankton species going extinct 66 million years ago in many records, indicating a sudden mass extinction. Deccan flood-basalt eruptions may still have caused the extinction, however. The eruptions that formed the Deccan Traps varied in intensity, and there were large individual eruptions accounting for most of the lava that took only hundreds of thousands of years about 66 million years ago, when the mass extinction occurred (Schoene et al., 2015).

Could flood-basalt eruptions be caused by massive asteroid impacts? It would depend on just how massive the impact was. In the case of the Deccan Traps, definitely not, because the eruptions started millions of years before the massive impact that formed Chicxulub Crater. There are only two verified impact craters on Earth bigger than the one at Chicxulub, and they are over a billion years older. It's difficult to try to compare the effects of massive impacts with those of flood-basalt eruptions, since human beings have never observed either of those events directly.

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