Proposed Kill Mechanisms of the Permian Mass Extinction

Kathryn Jefferson
Honors Geology 110
Spring 2009

Abstract
The Permian mass extinction was the greatest extinction Earth has seen, with up to 95% of the species becoming extinct. There is not a great deal of evidence that points to one kill mechanism, but several maintain followings. Possible kill mechanisms include an extraterrestrial event, the eruption of the Siberian Traps, a mantle plume event, global climate change, creation of Pangea, or a combination of many factors. The most viable and comprehensive theory at this time seems to be a mantle plume event.
Introduction

When a non-geology scholar thinks about extinctions, they think of dinosaurs dying and fading from the landscape. However, the Permian extinction was a much larger extinction than the dinosaur extinction, and nearly all of the species living at the time became extinct during this time. (Steele, 1999) 248 million years ago, the Permian extinction whipped out up to 90-95% species living on Earth at the time. A very important factor to keep in mind while thinking about the Permian extinction is that there was only one supercontinent, Pangea, as opposed to the seven continents we now have. A result of this was that there was also only one huge ocean in which there was many species, who were all affected by the cause of the Permian extinction. Many species flourished during the Permian period, many of which came extinct later (Hooper, 1996).

In this paper, I will discuss possible kill mechanisms and causes of the Permian extinction. First, I will discuss extraterrestrial events. Then I will move on to earth processes as possible kill mechanisms, focusing on the Siberian Traps. Mantle plumes will be discussed after the Siberian Traps. Finally, I include a few fringe hypotheses that have been posed.

Kill Mechanism 1: Extraterrestrial Event

Description

There is much evidence supporting an extraterrestrial event being the cause of the Cretaceous extinction. Because of this overall support, it is not surprising that scientists have looked for otherworldly explanations of the Permian extinction as well. If a comet,
asteroid, or meteorite bigger then 10 kilometers in diameter hit the earth, this could have
cauised the major extinction. Although there has not been a crater found that could have
cauised the Permian extinction, an asteroid could have left no mark if it vaporized.
Scientists who say that there is a lack of evidence that the volcanic activity in the Siberian
Traps caused the extinction point to this as an alternative explanation (Steele, 1999).

Because of recent studies that estimate the time in which the major extinction took place
vary, with some evidence that they occurred in as little as 8000 years, the impact
hypothesis is further invoked. Many of the earth’s processes, such as the Siberian Traps
causes, would take much longer to cause the major extinction. In addition, an impact
collision is the commonly accepted cause of the Cretaceous mass extinction, and this has
led researchers, such as Alvarez et al. to propose that all mass extinctions are caused by
an impact collision (Becker et al, 2003).

Evidence
Becker et al. presents research of fullerenes. Fullerenes come from sediments that have
trapped extraterrestrial materials, such as helium and argon, and have been associated
with two different impact collisions. They are formed in an extraterrestrial environment,
and when they are found on earth, they have been vehicled there in the form of an
asteroid or comet. Evidence of fullerenes at the P-T boundary would be further evidence
for the impact cause of the Permian mass extinction. The researchers took samples at
three P-T boundary places: South China, Southwest Japan, and Northern Hungary. They
then measured the helium content. Based on their findings, they estimate that the size of
the impact was 9 (+/-3) kilometers, comparable to the KT Chicxulub impact. The researchers believe this to be consistent with the rapid extinction, and use this evidence to contribute to the impact hypothesis of the Permian Extinction (Becker et al, 2003).

Luanne Becker of University of Washington in Seattle and NASA claimed they had found evidence in Japan and China of a meteorite striking the earth at this time. They said they had found extraterrestrial helium and argon in the Permo-Triassic (P-T) boundary (Benton, 2003).

**Contradicting Evidence**

Although there has been one independent Japanese scientist who has contributed to Becker’s findings of extraterrestrial helium and argon in the P-T boundary, overall other geologists have not been able to replicate their findings. Furthermore, one geologist has part of the piece of rock that Becker uses as evidence doesn’t even include the P-T boundary. In comparison to the evidence supporting the theory that an asteroid being the cause of the Cretaceous extinction there is a distinct lack of evidence to support the same theory for the Permian period extinction (Benton, 2003).

Langenhorst et al. also have researched for evidence of an extraterrestrial event (comet or asteroid) causing of the Permian extinction. If an asteroid or comet struck the earth, there would be shocked quartz grains, as has been reportedly found in Australia and Antarctica. The researchers examined 50 quartz samples previously collected at Graphite Peak, Antarctica. They found no evidence of shocked quartz, but rather found
evidence that the samples had went through slow plastic deformation. They cited tectonic activity combined with water to be a probable cause of the slow plastic deformation. This article provides evidence that is inconsistent with the previous findings of shocked quartz at the P-Tr boundary. This evidence of shocked quartz is very important to the extraterrestrial cause of the Permian extinction hypothesis/explanation. If this hypothesis was true, the quartz should have been found to be shocked at the location where the samples were collected. This contradiction to the limited evidence that has been presented to support this hypothesis has led to the overall dismissal of an extraterrestrial cause of the Permian extinction (Langenhorst, et al, 2005).

Other evidence was presented by Andrew Knoll and colleagues. He concentrates on the carbon dioxide increase. Simply, there was a build up of carbon dioxide in the deep ocean. As the surface waters became denser, they sank, and the build up of carbon dioxide was released into the atmosphere. This release would have caused significant greenhouse warming, leading to the mass extinction. According to data from China, Samuel Bowring showing that there was a spike of carbon at the boundary, probably coming from some non-organic carbon source, adding to the organic carbon. In addition, Greg Retallack found evidence in Australia that the greenhouse warming was right at the P-Tr boundary. This could contribute to Bowring’s findings, leading to three possibilities for the build-up of carbon. One possibility is an extraterrestrial event, of which there is no evidence whatsoever, and two possibilities lead to the Siberian Traps, which we will discuss next (Cowen, 2000).
Kill Mechanism 2: Siberian Traps

Description

The Siberian Traps are focused on because of the evidence that the volcanic area, which spans the size of the United States, was active during, and possibly before, the Permian extinction. In total, the Traps could have caused at least 1 million cubic kilometers, or 240,000 cubic miles, of lava to be erupted. According to a USGS article, the flood basalt would have released much more SO2 and CO2 than volcanoes release today, creating perilous conditions. In fact, humans have never experienced a super volcano as was happening during this time (USGS, 2004).

The gases that volcanoes spew could cause different reactions, and these are the basis for different theories. Paul Renne, an expert on the Siberian Traps, offered two explanations. The first was that the gases spewed by the volcanoes in the Siberian Traps would have caused the earth to have a higher albedo, and therefore less sunlight would have been let in to our atmosphere. This would have caused the earth to cool, which would have caused a build-up of ice at the poles and could have changed ocean circulation. This would have been very disruptive to life and caused mass amounts of extinction (Steele, 2003).

Another explanation posed by Renne also involves gases, particularly carbon dioxide. Volcanoes expel a great amount of carbon dioxide, which thickens the atmosphere and doesn’t allow the long-wave radiation to leave the earth as easily. The long-wave radiation is then trapped, and the earth warms because of the greenhouse effect. This could have caused the earth to become too warm to sustain life, causing the 95 percent
extinction of species. Besides the volcanic activity, there is evidence that animals at higher latitudes survived longer than the animals closer to the equator. This makes sense with this theory because the tropics are so much warmer that the animals would not be able to survive with so great of a heat change that a great amount of carbon dioxide could produce (Steele, 2003).

Evidence

Besides the obvious dangers the effusive lava seeping through fissures (long cracks in the ground) that eventually created the Siberian Traps – 3 million cubic kilometers in volume and covered 3.9 million square kilometers of the basaltic lava, a large amount of carbon dioxide that would be released with the lava could also cause a slight but catastrophic temperature increase. After China began to politically open up, geologists went there and found an intact, complete, undisturbed rock record. Prior to layer 25, the rock record showed an abundance of life signified by a diverse collection of fossils in the thick limestone layer. But then, at layers 25, 26, and 27 the end of the Permian Period is shown (Benton, 2003).

In layer 25, fossils became rare and tuff (which an igneous rock formed from a n explosive volcanic eruption) is found. This layer also shows the disappearance of 116, or 94%, of marine species disappear. As you move up through they layers, the marine species reappear and drop out again frequently. 45 more species end up gradually dropping out (Benton, 2003).
Combined with layer 25, layer 26 forms an ash band, distinctive by it’s dark-on-light band, that is found throughout China – found in up to 12 provinces altogether. This means that whatever released this ash (presumably the Siberian Traps) was a large and very influential event. Layer 27 then shows a resurgence of life with a 17-centimetre-thick layer of limestone, and at the top of this layer the Triassic period begins. The younger layers in the Triassic period are quite limited in life compared with the earlier pre-layer 25 layers (Benton, 2003).

**Diagram**

**Figure 1:** Wignall, P.B. Editorial: “The End-Permian mass extinction – how bad did it get?” Geobiology (2007). Vol. 5. Pp.303-309.

Wignall compiled this flow chart that can help us understand the processes the Siberian Traps could have set off, ending with the extinction. The flow chart is useful in understanding the extent and the processes that could have led to the end of the Permian era. The author poses that the Siberian Trap eruptions caused the Permian mass extinction, primarily by the release of the gases SO2, CL1F, and CO2 (Wignall, 2007).
CO2 could have caused warming and SO2 could have caused longer-term cooling. This is the process that is presented in Figure 1 of this article. But at the end of the article, Wignall adapts Figure 1 to conform to new evidence, all still revolving around gas emissions from the Siberian Traps. CO2 emissions are left as the cause of global warming, which then would have caused oceanic anoxia, which is the depletion of oxygen in oceans. Ocean anoxia would have directly led to a marine mass extinction.

There is also tentative evidence proposed that ocean anoxia could have led to some other water events, such as elevated surface water pCO2 leading to hypercapnia and a calcification crisis, which are still not clearly evidenced and are just proposed hypotheses at this time. These events would have also contributed to the marine mass extinction (Wignall, 2007).

In addition to global warming (which was caused by CO2 emissions) causing ocean anoxia, it also could have caused the dissociation of methane reservoirs. I think this means that large amounts of methane were released into the air, although I am not clear as to why global warming caused this. Regardless, these methane dissociations damaged the ozone layer, which was also being damaged by CL, F, CH3CL emissions coming directly from the Siberian Traps. In addition, ocean anoxia could have caused H2S to be released from the ocean, which would have also contributed to ozone depletion. The damaged ozone layer would have led to an increase in ultraviolet radiation from the sun, which contributes to the terrestrial mass extinction (Wignall, 2007).
The CL, F, and CH3CL emissions would have also been a contributing cause, along with SO2 emitting directly from the Siberian Traps, to acid rain. The acid rain could have then led directly to terrestrial mass extinction. The H2S released, as a byproduct of ocean anoxia, would have also contributed to the terrestrial mass extinction (Wignall, 2007).

So, overall we have three possible direct causes of the terrestrial mass extinction: H2S gasses released because of ocean anoxia, acid rain caused by CL, F, and CH3CL emissions, and an increase in ultraviolet radiation because of the damage to the ozone layer. We have one major cause of the marine mass extinction, ocean anoxia, with two possible contributing factors; hypercapnia and calcification crisis. It is interesting that while the Siberian Traps could have caused these gases to be released, being the sole cause of the mass extinctions, the processes leading to the marine and terrestrial extinctions generally separate from each other. After looking closely at this flow chart, it is easy to see why the lack of evidence calls into question the legitimacy of the Siberian Traps being the sole cause of the Permian extinctions (Wignall, 2007). In the next proposed kill mechanism, mantle plumes, this disparity could possibly be explained.

**Kill Mechanism 3: Mantle Plume**

*Description*

The cause of the Siberian Traps would have probably been a mantle plume, which is the next kill mechanism discussed. In reality, mantle plumes are a most comprehensive or deeper explanation of what could have occurred.
Plume events are very unusual, only occurring eight times in the last 250 million years. The author recognizes that there have been similar events to the Siberian Traps, albeit smaller, that has not caused a massive, worldwide extinction comparable to the Permian extinction. Eruptions such as Krakatau (1883 island eruption that destroyed all life on the island, but life has rebounded back in 100 years), Toba (an eruption that occurred 75,000 years ago that left no biological trace), Jurassic Karrow Basalts of South Africa, or any North American eruptions do not coincide with mass extinctions or significant geological disruptions. While there may be a threshold effect that was not met in these previous examples that the Siberian Traps may have crossed, it is still unclear that such a massive event would cause such a global extinction (Cowen, 2000).

Renne wrote an article about the causes flood volcanism, or flood basalts that argued this as a kill mechanism. It uses the Siberian Traps to demonstrate flood volcanism, as it is the biggest continental flood basalt known. Flood volcanism is a relatively short amount of time when there is a great amount of volcanic activity, transferring mass and energy from Earth’s core to the lithosphere. Renne discusses different techniques used for dating the eruption of the Siberian Traps, and how knowing accurate timing of the eruption is very important to establishing how drastic the consequences of a basalt flood could be. The general conclusions follow: The larger a basalt flood is, the more gases it would release, including CO2 and SO2. These gases can cause global warming and global cooling, respectively. While scientists search for a unifying theory to explain the three major mass extinctions, such as a large meteor impact, the article concludes that while this is desirable, the large basaltic floods are difficult to ignore (Renne, 2008).
Cowen also provides an overview of several different theories about the end of the Permian period. In the beginning, it provides an overview of plume tectonics and its relationship to the Siberian Traps. When the athesenosphere becomes heated and the core begins to melt the crust, a huge basalt magma can occur, which in turn cause huge volcanic eruptions that cause flood basalts, spreading over a very large area. One of these events is temporally linked to the P-Tr boundary, which we know as the Siberian Traps. He proposes processes in which this eruption could have caused an extinction, very similar to what has been discussed (Cowen, 2000).

Evidence

Renne posits that the flood volcanism found in the Siberian Traps could have been caused by a hot spot. Jan Mayen is a still active hot spot volcanic island found in the North Atlantic. This hot spot could have originated under the Siberian Traps, causing a huge mantle plume (Renne, 2008).

After this hot spot was identified as a possible beginning point for the Siberian Traps, another theory developed linking flood basalts to hot spots created by superheated mantle plumes. The theory says that when the hot spot allows the lithosphere rift to rise, the mantel can rise up more easily. When the mantle rises buoyantly, a greater amount of volcanism would occur because of the proximity of the magma to the surface. This immense energy radiating from the mantle plume would have caused not only intense
volcanism, but could have caused big rifts that gradually torn the continents apart (Renne, 2008).

Diagrams

Heydari offers an explanation in the form of two diagrams that includes but is not limited to the Siberian Traps being the kill mechanism of this extinction. The researchers look deeper into the earth, and propose that an active mantle plume caused the extinction. This deep-seated mantle plume in turn caused both the Siberian Traps flood basaltic eruptions, and the oxidation of the ocean (Heydari et al, 2008).

![Diagram of mantle plume and its effects](image.png)


The active mantle plume caused igneous intrusions that spread to the continental crust causing flood basalts, which we know as the Siberian Traps. The eruptions would have released CO2 and SO2 into the atmosphere. Previous article summaries have discussed
what chain events could have spread from this, and these eruptions would have played prominently into the terrestrial mass extinction (Heydari et al, 2008).

But the mantle plume explanation does not solely rely on the Siberian Traps as a kill mechanism, but provides for a way that mantle plume would have caused the marine mass extinction as well. The mantle plume would have caused a build-up of igneous dike swarms under the continental margin and ocean crust. This would have caused the continental margin to heat, and gases, such as CH4 and CO2, would have been released into the ocean. Not only does this cause further release of CO2 into the atmosphere, but would have caused oxidation in the ocean and increased CO2 within the seawater. This would have caused an increase in acidity, bicarbonate ion concentration, decreased carbonate ion concentration and marine carbon, and warmed seawater. All of these things direction lead to a marine mass extinction (Heydari et al, 2008).
Taken together, the mantle plume kill mechanism uses the Siberian Traps evidence to explain the terrestrial mass extinction, and also ocean anoxia evidence to explain the marine mass extinction (Heydari et al, 2008).

Kill Mechanism 4: “Murder of the Orient Express”

In the absence of definitive evidence, several other hypothesis’ have been proposed to explain this extinction. One of these is known as “Murder on the Orient Express”,

proposed by Douglas Erwin, which says that a variety of factors all led to the mass extinction. While this seems to be a pretty good summary of past articles that I have read, Cowen dismisses this hypothesis because it is difficult to accept or to test, and it is also not very definitive (Cowen, 2000). However, Renne also posits this as a viable theory, while not especially interesting, and says it could be a combination of factors that could have led to this extinction. Because it was such a mass extinction, it would make sense to have a contribution from a variety of factors, rather than just one asteroid, or one volcano (Renne, 2008).

**Other Kill Mechanisms**

Another hypothesis, presented by Yukio Isozaki, proposes that the world was warming prior to the eruption of the Siberian Traps. He has studied deep-sea floor sediments laid down on the floor of Panthalassa (the ocean when Pangea was still the supercontinent). His evidence shows that deep ocean water became anoxic around 260 million years ago, while surface waters did not become anoxic until 255 million years ago. Isozaki’s model of extinction occurs in three stages, none particularly linked the Siberian Traps eruption but focusing on the chemical crisis in the ocean. First, the deep-sea anoxia coincides with a smaller Guadalupian stage extinction within the Permian period. Next, full ocean anoxia happens at the P-Tr boundary. Finally, the ocean resolves itself. The process is symmetrical, beginning and ending with deep-sea anoxia. A problem with this hypothesis is that it does not fit current ocean processes, but this could reflect the very different ocean that Panthalassa was compared to today’s oceans. However, this
evidence that may potentially fit into some of the models previously discussed, such as the mantle plume explanation (Cowen, 2000).

The Hooper Virtual Paleontological Museum also posits some possible causes for the Permian extinction, including the formation of Pangea, glaciation, and volcanic eruptions. While volcanic eruptions has been previously discussed, and glaciation could be connected to some of the global climate change that has been discussed, the formation of Pangea was a new possible cause of the Permian extinction. As the continents came together, shallow continental shelves would have been destroyed, destroying a viable habitat for many marine species. This could have caused a mass extinction. However, the formation of Pangea happens mid-Permian time period, while the extinction obviously occurred at the end of the Permian era, and this is problematic for this to be a viable theory (Hooper, 1996).

**Summary and Conclusions**

While it is clear that it would be foolish to declare one hypothesis the true cause of the Permian extinction, the current evidence seems to point toward a mantle plume being the primary cause of the massive and devastating Permian extinction. The contradicting evidence steers us away from an extraterrestrial event, and a mantle plume has a more comprehensive explanation than the sole Siberian Traps explanation. While “Murder of the Orient Express” certainly has its de facto value, it is not very satisfying in our pursuit of truth and knowledge. Finally, the creation of Pangea has the potential to be viable if not for its faulty timetable.
References


