THE GREAT PERMIAN EXTINCTION DEBATE. James A. Marusek, *Impact*, (RR 6, Box 442, Bloomfield, IN 47424 e-mail: tunga@custom.net or marusek_j@crane.navy.mil).

Abstract: The cataclysm that brought the Permian Period to an end was caused by a cluster of comet/asteroid impacts over a short geological timeframe, 5-8 million years. Several impacts were of sufficient size to rupture through the Earth's crust, producing deep impact effects. The impacts focused shock destruction on the opposite side of the Earth creating fractures at continent/ocean seams. The resulting Emeishan & Siberian Traps generated prolonged periods of surface flood basalt eruptions inducing extensive acid rainfall. The shock waves also produced large fractures in the ocean floor along the tectonic plate joints. This undersea volcanic eruptions injected acidic gases into the ocean where natural gas scrubbing took place as the gases bubbled to the surface, contributing to ocean acidification. Acidification targeted evolutionary weaknesses within marine and terrestrial life forms, culminating in a massive die-off at the end of the Permian Period.

Impact Theory: Around 250 million years ago, a cataclysm of incomprehensible proportions struck a fatal deathblow. Ninety-six percent of all marine species along with seventy percent of all land vertebrates species became extinct [1, 2]. A rapid die-off of rooted plant life occurred [3]. Insect suffered their only mass extinction [2]. This event is referred to as the Permian Extinction. It is the greatest die-off of life on planet Earth, ever.

The Permian extinction was a cluster of mass extinctions tightly constrained in geological time [4]. The first mass extinction was at the Guadalupian-Lapingian Boundary (GLB). The next was at the Wuchiapingian-Changshingian Boundary (WCB). The third and largest was at the Permian-Triassic Boundary (PTB). These three major mass extinction events were clustered within a period of 5-8 million years [5]. Figure 1 shows extinction rates across these three boundaries.

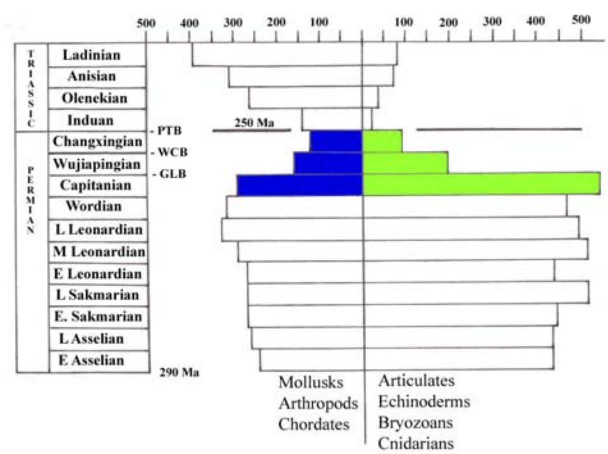

Figure 1. Number of Genera
Source: Knoll, A.H. et al. (1996) *Science*, **273**, 452-457.

This paper presents the hypothesis that:

* *The cluster of extinction events were caused by a cluster of impact events.*

* *That several of these impactors had sufficient kinetic energy to break through the Earth's crust.*

* *That these deep impactors produced massive flood basalt eruptions.*

* *Acidic gases released from magma was leading cause of the ocean and terrestrial extinctions*.

After completing a study of mortality effects triggered by large asteroid/comet impacts, the analysis showed these effects are too localized to adequately explain the global nature of the extinctions that occurred at the end of the Cretaceous and Permian Periods. Several postulated effects, such as global firestorm, ejecta debris-induced impact winter, and mega-tsunami with deep landmass penetration are not supported [6].

The effects of an asteroid or comet impact have been compared to that of a large nuclear weapon. Although the comparison may be a good approximation, there is one significant difference. In a nuclear weapons blast, the kinetic energy is released spherically in all directions. In an impact, the kinetic energy is focused along the line of the impact vector. This paper makes the hypothesis that a large impactor can tear through the Earth's crust and release most of its energy deep within the mantle. This is especially true for an impact where the crust is thin, such as an ocean impact. The process is called acoustic fluidization [7]. The impact energy turns the solid crust into liquid. The impactor in a fraction of a second cuts its way through the atmosphere, the ocean and the Earth's crust in a manner similar to a shaped-charge projectile penetrating tank armor. Unlike a surface impact that leaves behind a large crater and throws up a worldwide debris field, these deep impactors generate large scars or crustal uplifts burying much of the impact debris.

The impact energy can be thought of as the sum of the energy released at the surface and the energy released deep within the Earth. The surface component can be approximated to the blast and thermal radiation effects from a comparable size thermonuclear weapon. The effects of the impact energy released in the mantle are obscure and are only observable in massive flood basalt eruptions, the creation of a deep magma hot spot and interior structures anomalies, such as magnetic pole reversals. This paper also theorizes that the energy released deep within the earth may be an order of magnitude greater than the surface component. [As an example, a 20-mile diameter Long Period Comet (LPC) traveling at 110,000 mph (50 kps) with a density of 0.75 gm/cc would release the kinetic energy equivalent to 38 x 10^8 megatons of TNT (1.6 x 10^{25} joules). Of this, approximately 6 x 10^8 megatons of TNT might be released at the surface, producing an impact structure 200 miles across. The scar left from a deep impactor might appear to be from a much smaller impactor because all that is visible is the surface component. A deep impactor will break through the Earth's crust and release most of its impact energy (in this example 32 x 10^8 megatons of TNT) as heat and momentum transfer deep within the Earth's shell.]

The interior shock wave from a deep impactor will flex the tectonic plate joints, producing large fractures in the ocean floor and massive undersea flood volcanic eruptions at these seams worldwide. But the shock wave will focus most of its destructive energy at the exit vector, traveling through the Earth at speeds exceeding those of a primary earthquake (~20,000 mph), devastating a large area of crust on the opposite side of the globe. Generally damage is greater if the exit vector is close to a continental/oceanic crust seam because a hinged joint is a weak flex joint. The tectonic plates function similar to a slow moving engine. Impact force can upset its delicate balance and cause plate fracturing and derailment, which will produce extensive long-term crustal damage.

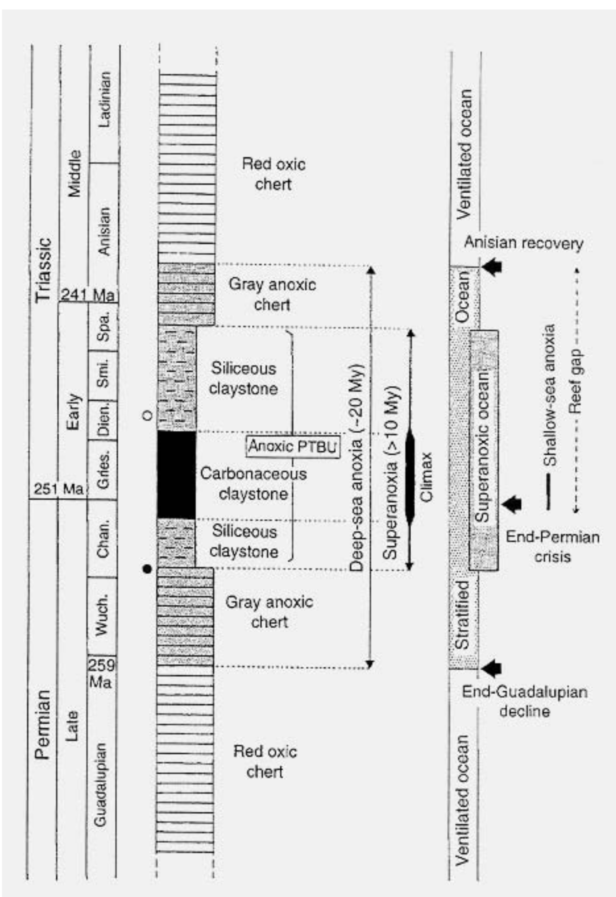

Figure 2. Permian Stratified Layers
Source: Isozaki, Y. (1977) *Science*, **276**, 235-238.

In the GLB impact, the focused shock wave ruptured the crustal surface producing the Emeishan Traps. The GLB impact produced an acidic tuff bed (approximately 2 meters thick) with extensive distribution of air-borne ash over thousands of kilometers [8]. The GLB impact also drove the oceans into a state of anoxia.

The WCB was caused by another deep impactor that produced a magnetic pole reversal [9]. The WCB threw the oceans into a superanoxic state, which lasted for more than 10 million years [10].

In the PTB impact, the focused shock wave damaged the Earth's crust near Eastern Russia, producing terrestrial flood volcanic basalt eruptions referred to as the Siberian Traps. This surface wound generated 3-5 million cubic kilometers of lava [11]. The PTB impact also produced a magnetic pole reversal [9].

The flood volcanic eruptions from the Emeishan and Siberian Traps lasted over 10 million years. The undersea volcanic eruptions produced a marine ecological disaster. The terrestrial flood volcanic basalt eruptions produced a terrestrial ecological disaster and contributed to the marine disaster. The primary cause of the extinctions was the release of acidic gases in the magma. The actual die-offs took place very rapidly. In the PTB, the collapse of the marine and terrestrial ecosystems occurred in just a few tens of thousands of years [12].

Flood Basalt Eruptions: In general, volcanoes release minute quantities of magma. For example the Mount St. Helen eruption of May 18, 1980 produced only 0.5 cubic kilometers of magma. Massive flood volcanic eruptions, on the other hand, can produce a significant uptick of magma levels. The Lakagigar Eruption in Iceland of June 8, 1783, for example, produced 14.7 cubic kilometers of basalt. Large-scale flood volcanic eruptions such as the one that produced the Siberian Traps released 3,000,000-5,000,000 cubic kilometers of lava. Volcanic eruptions produce several gases: water vapor, carbon dioxide, sulfur dioxide, hydrogen sulfide, hydrogen, hydrogen chloride, carbon monoxide, hydrogen fluoride and helium.

Volcanic Gases

Volcano	**Kilauea Summit**
Tectonic Style	**Hot Spot**
Temperature	**1170° C**
Carbon Dioxide	**48.9%**
Water Vapor	**37.1%**
Sulfur Dioxide	**11.8%**
Carbon Monoxide	**1.51%**
Hydrogen	**0.49%**
Hydrogen Chloride	**0.08%**
Hydrogen Sulfide	**0.04%**
Hydrogen Fluoride	**Trace**
Helium	**Trace**

Source: Symonds, R.B. et al, (1994) Mineralogical Society of America, 30, 1-66.

The "Russian-Ukrainian Theory of Deep Abiotic Petroleum Origin" is an integral part of this "Permian Extinction Hypothesis". This theory explains why the atmosphere suffered a dramatic decline in oxygen levels and why the oceans became anoxic/superanoxic. According to the Russian-Ukrainian Theory, petroleum is not a fossil fuel. Petroleum comes from hydrocarbons that were basic components in planet creation. These hydrocarbons exist in a stable form under extreme pressures and temperatures on the underbelly of the Earth's crust. If the Russian-Ukrainian Theory is applied to volcanic eruptions, it produces an interesting observation. Small amounts of these hydrocarbons bleed into the magma during volcanic eruptions. The hydrocarbons in the magma burn when they are exposed to the oxygen in the atmosphere. Several gases released during volcanic eruptions, such as carbon dioxide and monoxide, rather than originating as compressed gases from deep within the Earth, are in reality, a product of a combustion process at the Earth's surface. The combustion process, not only injects acidic gases into the atmosphere, but bleeds oxygen from the atmosphere, which in turn removes oxygen from the oceans.

Ocean Extinction Mechanism: The acidification of the oceans were directly responsible for the massive marine kills that produced the oceanic extinction. Acidic gases were released at three general locations: point-of-impact, exit vector, and tectonic plate seams. The thermal radiation from the impact induced creation of nitric oxide and nitrogen dioxide. The impact fireball also produced a local firestorm that injected combustion gases into the atmosphere. The crustal damage at the exit vector produced massive flood basalt eruptions (Emeishan & Siberian Traps) that generated the bulk of acidic gases. Carbon dioxide because of its higher density migrated towards the lowest point, in this case into the oceans. The acidic gases also combined with atmospheric moisture and fell back to Earth as acid rain. The shock waves from the impact produced massive earthquakes that flexed and fractured the oceanic crust throughout the globe. The ocean crust took the biggest hit simply because the oceanic crust is almost ten times thinner than the continental crust. Cracks developed at the ocean floor allowing large-scale volcanic basalt eruptions, mostly at the tectonic plate seams. Gases, such as hydrogen sulfide, released at the ocean floor bubbled to the surface and underwent natural gas scrubbing along the way.

* *Carbon dioxide reacts with water to produce carbonic acid, which dissolves calcium carbonate.*

* *The sulfur gases (hydrogen sulfide and sulfur dioxide) react with water and oxygen to produce sulfuric and sulfurous acid. These acids further react with calcium carbonate to form calcium sulfate (gypsum).*

Marine invertebrates were the hardest hit during the Permian extinction. Marine invertebrates do not have backbones; rather, they have hard exoskeletons. Acidity in the oceans can dissolve these exoskeletons.

- The extinction wiped out all trilobites. Trilobites were one of the oldest species on the planet, existing all the way back in the early Cambrian Period. They were also the most diverse group of organisms, making up 9 orders, over 150 families, 5000 genera and over 15,000 species. Trilobites have exoskeletons made out of calcium carbonate.
- The extinction wiped out all of the fusulinids. Fusulinids were single-celled organisms. They ranged in size from sesame seeds to soybeans. There were 3,600 species of fusulinids. They had an outer shell made out of calcium carbonate.
- The extinction wiped out all of the blastoids. Blastoids were high-level stalked suspension feeders that filter food particles out of water. They are protected by a set of interlocking plates forming the theca made of calcium carbonate.
- The extinction wiped out all the rugose and tabulate corals. Corals are part of a group of soft, jelly-like animals called Cnidaria polyps. Coral polyps secrete a rock-like skeleton of calcium carbonate in which they live.
- Brachiopods are filter-feeding coelomates enclosed in a bi-valved shell. They were a dominant species in the Permian Period. Their dominance came to an abrupt end, when 90 percent of the families and 95 percent of the genera became extinct. The shells of brachiopods are made of calcium carbonate.
- The extinction wiped out 98 percent of the crinozoa species. Crinozoa, referred to as sea lilies and feather stars, have endoskeleton of separate calcium carbonate plates.
- The extinction wiped out 96 percent of the anthozoans. Anthozoans look like miniature sea anemones; they live by day in stony cups of secreted calcium carbonate, which they use as a detachable exoskeleton. At night they leave their exoskeleton to feed.
- The extinction wiped out 97 percent of the ammonoids. Ammonoids are cephalopods similar to the modern nautilus. They have spiral shaped shells made of calcium carbonate.
- The extinction wiped out 59% of bivalves. Bivalves are marine animals that secrete a two-valve shell for protection. The shell is composed of calcium carbonate.
- The extinction wiped out 8 families of ostracods. Ostrocods are micro crustacean with a soft body covered by a thin bean shaped bivalve shell know as the carapace. The carapace is made of calcium carbonate.
- The extinction wiped out 85% of the gastropods. Gastropods (snails) are mollusca with a single unchambered shell composed of calcium carbonate.
- The extinction wiped out 79% of the bryozoans. Bryozoans (moss like animals) are colonial suspension feeders. They secrete hard skeletons of calcium carbonate, minerals, calcite and aragonite. Thousands of these animals live individual in their own tubes the size of a sewing needle within the colony.

Organisms that produce calcium carbonate exoskeletons are very sensitive to hypercapnia because carbonate biomineralization requires very delicate control of the acid-base balance [4].

Marine animals are sensitive to increased carbon dioxide levels. An increase of even a few torr above ambient can cause hypercapnic acidosis. But marine animals with active circulation and gills are better able to compensate for elevated carbon dioxide levels than animals with passive gas exchange [4]. Ocean acidity can retard the growth and reproduction of marine life. It can cause loss of consciousness and death to marine life due to disruption of oxygen-transport mechanisms [13].

The evidence of ocean acidification is visible in the PTB strata by the abundance of gypsum and framboidal pyrite [4, 10, 14, 15]. As stated earlier, gypsum is the product of sulfur based acids and calcium carbonate. Iron pyrites are formed when hydrogen sulfide reacts with dissolved iron.

Two other major contributors to the oceanic extinction were the radical decline in ocean oxygen and the production of hydrocarbon chains at the deep sea/magma interface. Hydrocarbons under intense magma temperature, that contacts seawater undergo a natural cracking process that produced aromatics and terpenes, which will rise to the surface and poisoned marine life.

Terrestrial Extinction Mechanism: Several gases released by flood basalt eruptions severely damaged the terrestrial ecosystem. These gases include sulfur dioxide, hydrogen fluoride and carbon dioxide.

During the phase of active volcanic eruptions, sulfur dioxide was ejected high into the atmosphere. Sulfate aerosol particles are highly reflective of incoming solar radiation and have the capacity to significantly cool and darken the surface of the planet. At the same time, magma pumped vast quantities of heat to the planet's surface where it was trapped by the insulation properties of the carbon dioxide layer. Water acted as a safety relief valve. Evaporation provided a heat transport mechanism for moving this trapped magmatic heat through the carbon dioxide layer. Massive flood volcanic episodes produced long dark (but not necessarily cold) spells, which lasted for several years or decades. The reduction of sunlight radically diminished the photosynthesis process in plant life, shutting down food production, bringing death to animals up the food chain.

Sulfur dioxide would bleed from the atmosphere in the form of acid rainfall, which damaged the internal structure of plants. Henk Visscher analyzed the global bio-mass storage [16]. He studied saprophytic fungi that feed on woody tissues under aerobic conditions. A large fungal spike at the PTB boundary showed there was an excessive dieback of dominant gymnosperm vegetation. He theorized this was caused by prolonged acid rain. The size of the plant growth played into the survival. The trees and shrubs were the first to die off followed by short shrubs and herbs. The cataclysm selectively removed the dominant large plants and left only small weedy survivors. This plant die-off rippled through the ecosystem.

At the time of the Permian extinction, the Earth was composed of one massive landmass called Pangaea and one vast ocean called Panthalassa.

It is generally believed that animal life began in the oceans and transitioned over time onto land. Amphibians played a critical role in this process. They developed the ability to live on land or in the sea. But their habitat was restricted because they had to lay their eggs in water. If the eggs were removed from water and placed on land, they would simply dry out, killing their offspring. Amniotes were the first species that evolve the ability to lay amniotic eggs. These eggs featured a tough outer layer that prevented the eggs from drying out. The amniotic egg has a shell hardened by calcium carbonate, which is impermeable to water but allows gases to be transpired. As a result, the amniotes were not restricted to wet regions. The amniotic egg opened up all of the supercontinent Pangaea for colonization. Synapsids, a member of the Amniotes, were the dominant terrestrial group of land vertebrate. They took a savage hit at the end of the Permian. One cause was the reaction of acid rain on the calcium carbonate shell of the amniotic eggs. The eggshells became thin and brittle resulting in a disruption of their reproduction process.

Hydrogen fluoride is another gas released by massive flood volcanic eruptions. Fluorine is a pale yellow gas that in relatively low concentrations is very toxic. Fluorine attached itself to fine volcanic ash particles. This ash flung high into the atmosphere and spread by the prevailing winds eventually fell back to Earth and coated the skin of edible plants. Animals that ate these plants died. Even in areas that received as little as a millimeter of this ash (a fluorine content exceeding 250 parts-per-million (ppm)), poisoning occurred. Fluorine is very reactive and generally forms soluble fluorine salts. Rainfall dissolved and flushed these salts into rivers, streams and lakes, poisoning surface water supplies.

The Lakagigar Eruption in Iceland occurred on June 8, 1783 and lasted eight months. The sulfur gases released from the Lakagigar Eruption produced a 1 degree Centigrade temperature drop in the Northern Hemisphere. Most of the livestock in Iceland were killed because they ate grass contaminated with fluorine. The acid rain caused a massive crop failure that lead to starvation and the death of 9,000 individuals, one-quarter of the island's population. Approximately 14.7 cubic kilometers of basalt was erupted. This is equivalent to 0.0005% of the magma released by the Siberian Traps.

The third gas that played a role in the terrestrial extinctions was carbon dioxide. In high concentrations, carbon dioxide can be lethal to plants and animals. Carbon dioxide is heavier than air and can flow into low-lying areas. The supercontinent of Pangaea was flatter than present topography. Because carbon dioxide is a colorless, odorless gas, animals that came in contact with high concentrations of this gas may have been unable to detect the threat until it was too late.

Plant growth rates can be severely impacted by elevated carbon dioxide levels above 2,000 ppm.

In general, animals are more tolerant to elevated levels of carbon dioxide because they can compensate for hypercapnia with increased respiration. But very high levels of carbon dioxide can disrupt the acid-base balance of internal fluids producing narcotizing acidosis and can cause hemoglobin to lose its affinity for oxygen. In animals, carbon dioxide concentrations above 200,000 ppm can cause loss of consciousness and convulsions and concentrations above 300,000 ppm can produce death [4].

One of the unusual characteristics to the Permian extinction is the prolonged recovery period. A diverse ecosystem did not reappear for at least 5 million years [11]. Plant life did not fully recover from the extinction until the mid-Triassic when a new plant group appeared that was tolerant of oxygen stressed, acidic environments.

Evidence of Impact Events: Evidence of an extraterrestrial impact at the PTB has been accumulating for the past few years. The study of the other boundary events, GLB & WCB, is only in its infancy. Large ocean impacts that penetrate the Earth's crust would generate less ejecta debris than surface impactors. Analysis that relies heavily on quantitative comparisons (size of craters, abundance of impact markers) will underestimate and discount the severity of these impacts.

One of the arguments used against the impact theory is "Where is the crater?" The answer is that deep impactors do not always create craters. They produce **impact scar morphology** in the form of domes or uplifted core, volcanic filled basins, and crumpled, folded landforms. Deep impact morphology may produce a visible absence of an elevated crater rim. The morphology may includes gravitational and magnetic anomalies.

The Bedout Structure is impact morphology located 200 miles off the coast of Broome, northwest Australia. It is 220 km across and dated to 253 +/- 5 Ma [17]. The North Falklands Basin is a volcanic filled basin dated roughly to the PTB. The basin is over 200 km in diameter. Michael R. Rampino (NASA) suggested an impact origin. The basin is one of four huge basins surrounding the Falkland Islands. The Araguainha Impact Dome is located in central Brazil and is the largest impact structure in South America. It is 40 km across and dated to 247-251 Ma. The site is a cluster impact site with 3 to 4 secondary craters ranging in size from 25-35 km across. [18, 19].

The candidate ocean impact sites are located in the Southern Hemisphere with Northern Hemisphere exit vectors, Emeishan & Siberian Traps. This impact pattern has the signature of Oort Cloud comets rather than asteroids or Kipper Belt comets which generally strike along the planetary plane.

One of the markers of an extraterrestrial impact is an abundance of **rare earth elements**. Beginning in 1992, Shukla et al [20], began reporting a europium spike at the PTB layer in the Himalayas in India. Europium, a rare earth element, is present in the Earth's crust in only minute quantities. The element is produced in the furnace of an exploding supernova. Fragments of the nebula explosion are flung through deep space. Oort Cloud comets have been collecting material ejected from supernovas for the past 4.6 billion years. When a comet impacts Earth, a portion of the material is ejected into the upper atmosphere. Over time the material falls back to Earth and becomes part of the sediment layer.

Iridium is another rare earth element. Iridium spikes were found in the PTB in China, Soviet Armenia, Carnic Alps of Austria, and the Dolomite Alps. Reported concentrations were 10 to 100 times lower than observed in the KTB [21]. The intensity or abundance of the iridium marker is not directly proportional to the size of the impactor. The presence of an iridium spike is strong positive evidence that an impact occurred.

Quartz is a very stable mineral that can withstand extremely high temperatures and pressures. Only a very violent event, such as an impact, has the power to disfigure quartz. Finding traces of **shocked quartz** is a good indicator of a close proximity to an impact site. Shock quartz were found at Graphite Peak and Mount Crean, Antarctica and Wybung Head Australia [22]. The small size and lower abundance of the shocked quartz at these sites indicate that they were still a significant distance from the actual point-of-impact.

Buckminsterfullerenes (abbreviated as fullerenes) is the third natural form of elemental carbon. Certain kinds of stars are surrounded by dusty envelopes. Spectroscopic analysis reveals that this stardust is composed of interstellar diamonds. Scientist trying to replicate stardust discovered this new form of closed-caged carbon structure, called fullerenes. The shape of fullerenes allows the material to trap and permanently seal gases within a stable carbon shell. Fullerenes (C_{60} to C_{400}) is rare on Earth but occurs abundantly in space. Fullerenes with trapped noble gases were discovered in the PTB layers in Meishan, South China, Sasayama in southwest Japan and Graphite Peak, Antarctica. Fullerenes is generally considered a marker for comet/asteroid impacts. It is theorized that the fullerenes was delivered "intact' to the Earth during the impact. The analysis of noble gases (helium and argon) extracted from the fullerenes samples matched the signature of an extraterrestrial origin [23, 24].

Microspherules are microscopic droplets of glass formed when melted rock rapidly cools in the atmosphere or in deep space. Studies found microspherules at the PTB in Sasayama, Tanba Belt (Japan), South China, Guizhou province (China), Bukk Mountains (Hungary) and the Carnic Alps (Austria). Samples showed strong concentrations of Fe, Ni, and Zn; with some Al, Si, Cu, Sn and Pb. The concentration of nickel (>2.25%) was significant, indicating these microspherules were extraterrestrial in origin. The aluminum and trace element composition showed that the microspherules were interstellar in origin [25, 26, 27].

Both the PTB and the KTB sediment contain magnetic microspherules with very unusual magnetic properties. Boundary samples contain nano-size iron particles exhibiting quenching of magnetic moment due to superparamagnetic relaxation. Samples analyzed from the Spiti Valley in the Himalayas, India displayed paramagnetic iron phases that are not normally found in terrestrial sediments but could be created in the extreme pressures and temperatures of an impact vapor plume [28].

Contributing Factors: A strong surge of acidity in the ocean was the primary cause of the marine extinctions and acidification of the atmosphere was the primary cause of terrestrial extinctions. There were several other factors that contributed to the severity of the death and destruction. Other than those previously discussed, these effects included:

- Impact blast wave.
- Impact ground shock.
- Impact thermal radiation and mass fires.
- Impact induced tsunami.
- Impact induced severe magnetic storms.
- Massive up tick in earthquake activity.
- Impact induced undersea landslides that produced secondary tsunamis.
- Impact ejecta.
    - Dust blocking of solar radiation.
    - Debris fall.
    - Black rain and ground contamination (heavy metals).
- Unusual hydrocarbon fires (release of frozen methane hydrate, impactor hydrocarbons).
- Enhanced ultraviolet radiation due to destruction of ozone layer.
- Enhanced cosmic/solar radiation due to loss of Earth's magnetic shield during pole reversal & multipole realignment.
- Chemically binding free oxygen, thereby starving the oceans and atmosphere of oxygen.
- Leaching of aluminum from soil and the runoff contaminating groundwater, lakes and rivers.
- Undersea volcanic eruptions induced hydrochloric acid and laze.
- Earthquake induced landscape realignment.
- Enhanced erosion due to plant die-off.
- A weakening of the health & vitality of the population of living organisms resulting in lowering the population's resistance to disease. This weakening was caused by low sunlight and environmental stressors (i.e. acid rain, contaminated soil, abnormal temperatures and degraded atmospheric gases) in plants, and starvation and environmental stressors in animals.
- The mass kills caused a breakdown in the carbon cycle. The loss of plant life and phytoplankton destroyed the mechanism for converting carbon dioxide into organic carbon. The loss of animal life destroyed the conversion of organic carbon into calcium carbonate (bones, exoskeletons) for long-term carbon sequencing.

Prologue: One area of interest for Eugene Shoemaker was the study of impact cratering through geological time. His analysis suggests that the larger impacts (i.e. larger extinction events) were predominantly caused by comets [29]. In general, Oort Cloud comets are larger and faster thereby releasing far greater kinetic impact energy than asteroids. The flux rate of comets injected into the inner solar system is not constant but controlled by external factors. The passage of the solar system through a galactic spiral arm can perturb the Oort Cloud releasing a cascade of inward falling comets. The Permian extinctions may correlate to the last passage through the Scutum-Crux spiral arm [30]. Refer to Figure 3.

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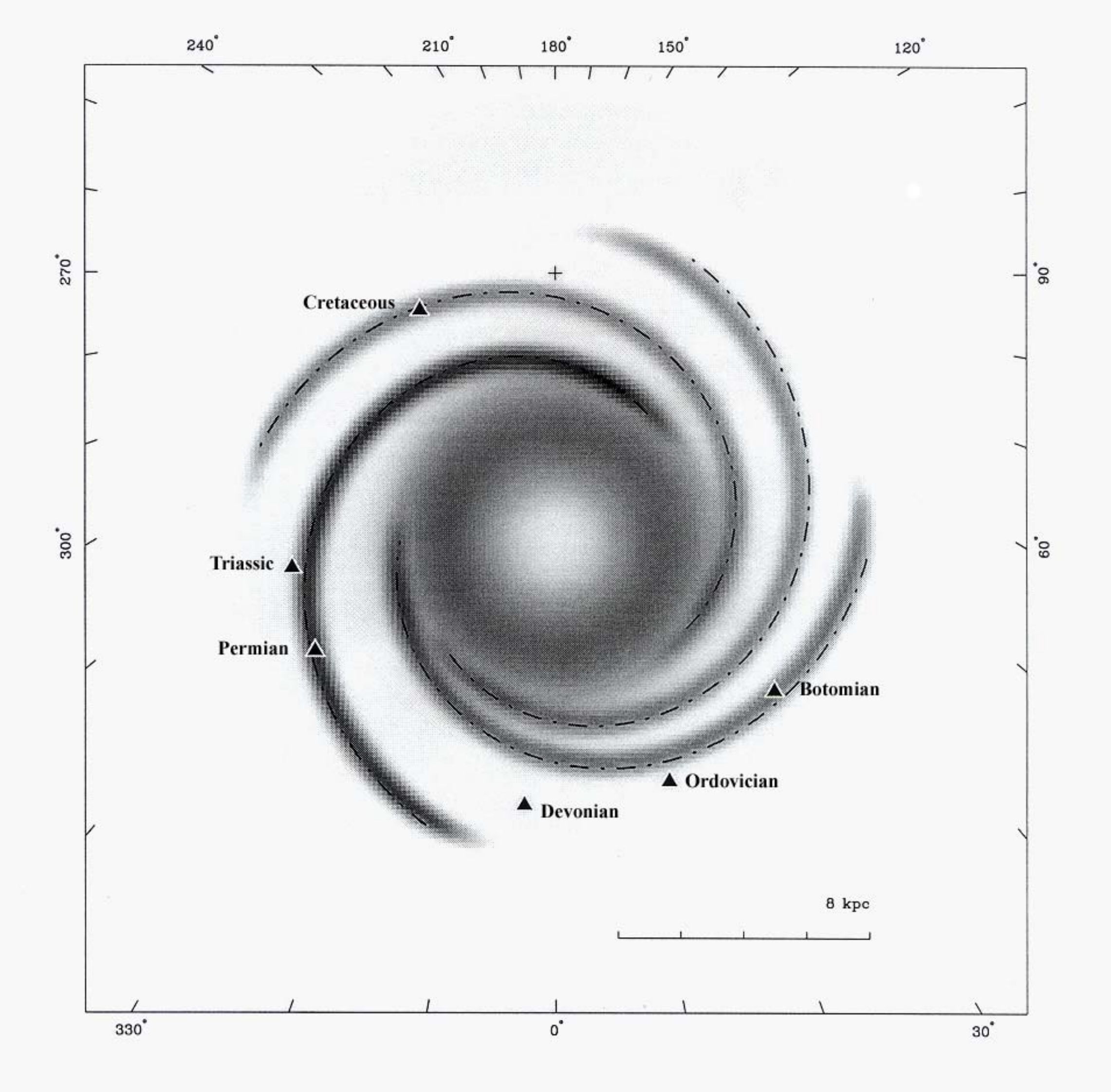

Figure 3. Earths Passage Through Galactic Spiral Arms.
Plus sign (+) denotes present location of Earth. Solid triangle denotes Major Extinction Events.
Source: Leitch, E.M. and Vasisht, G. (1998) *New Astronomy*, **3**, 51-56.