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"A Whole Lotta Shakin' Goin' On"

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By Eric J. Sorenson, Sr.

Dr. Sorenson is a retired physician and the President of the Sphex Club of Lynchburg for the year 2007-2008.

About 200,000 years ago, give or take a few thousand years, the island that comprises England, Scotland, and Wales, was actually a peninsula of the continent of Europe, much like Denmark is today. It was connected to the mainland by a narrow isthmus of land, and at that time, early humans could, and probably did, walk across that land bridge to what we now call England. Northeast of this isthmus was a giant lake in what is now the North Sea, and the isthmus itself was a gently unfolding chalk ridge that was perhaps some 30 meters higher than the current sea level in the English Channel.

And then, and nobody knows precisely when, there was a cataclysmic event that caused a massive flood. Although nobody can know for sure, this flood was probably triggered by a massive earthquake which broke up the land of the isthmus and created not only the English Channel, but also the white cliffs of Dover. At its peak, this mega flooding probably lasted several months, and it helped reorganize river drainage in northwest Europe, re-routing both the Thames and the Rhine.

This event and the subsequent development of the English Channel have played a crucial role in British history. The Channel has acted as a filter through time, letting some animals, including humans in from mainland Europe, but keeping others out. More recently, in the period of recorded history, the fact that England was an island nation was key to her development as the prominent maritime nation and colonial power in the world. One can only shudder to contemplate how the course of World War II would have been altered if Hitler's triumphant army had been able to march into England in 1940, rather than be halted by the English Channel.

The formation of the English Channel and the events that led up to it are interesting, but, there have been other innumerable catastrophic events on the surface of the earth throughout time. These events have most commonly been volcanic eruptions or earthquakes, but they have also included tsunamis and even the formation of new islands.

On November 15, 1963, only 44 years ago, the island of Surtsey was literally born. Its birth was a dramatic fire and brimstone event caused by a volcanic eruption from beneath the sea off of Iceland's southern coast, and the island continued to evolve and enlarge until all volcanic activity ceased in 1967, at which time the highest point on the island was 560 feet above sea level. Today, Surtsey, although still off limits to all humans except research scientists, is inhabited by a remarkably diverse array of life. About 60 different plants are growing on the island, ten different kinds of birds are nesting there, and insects and smaller creatures can be found by the thousands.

The formation of Surtsey is recent, interesting, and unusual, but volcanic eruptions are certainly <u>not</u> unusual. We are all familiar with the eruption of Mt. Vesuvius in the year 79 AD. This event was first brought into popular modern consciousness by the novel, published in 1834, by Edgar

Bulwar-Lytton. This book, “The Last Days of Pompeii”, captured the public imagination, and people began to ponder what had happened then. The discovery of the ruins of Pompeii and Herculaneum was very exciting, and even now, tourists flock to both of those places to examine what daily Roman life was like. Vesuvius had lain dormant for thousands of years, and nobody had really given it much thought. But, suddenly, and without warning, it erupted and laid waste to a large area. The whole event had attracted the attention of the Roman natural scientist and naval commander, Pliny the Elder. He saw, from across the bay, what was happening, and he sailed to the site, only to die, probably from a stroke or heart attack. He did take observation notes of the event, and these were saved for posterity by his nephew and adopted son, Pliny the Younger.

The eruption of Vesuvius is interesting and historically resonant, but it is hardly unique. Throughout history, there have been multiple volcanic eruptions, including Vesuvius (again) in 1631 with the loss of 3500 lives. These volcanic eruptions have occurred all over the world, including Japan, Indonesia, Iceland, the Philippines, Columbia, Ecuador, and Mexico. I’m sure we all remember the 1980 eruption of Mount St. Helens in Washington State. 57 people were killed, and there was great destruction of property.

Probably the most destructive volcanic explosion in history occurred on Krakatoa in 1883. Krakatoa, located in the Sundra Strait between Java and Sumatra in Indonesia, literally exploded on August 27, 1883, after rumbling, shaking, and smoking for the preceding 99 days. This natural disaster caused the island of Krakatoa to completely disappear, and in the aftermath of its eruption, 165 villages were devastated, 36,417 people died, and uncountable thousands of others were injured. Most of the deaths, injuries, and destruction were caused, not by the explosion itself, but by the immense sea-waves, or tsunamis that followed. The long-term aftermath of the explosion was truly incredible. Dust and ash particles circled the globe for the better part of 3 years, causing, among other things, incredibly vibrant sunsets and much colder than normal temperatures. In November, 1883, (now 3 months after the eruption), firemen in Poughkeepsie, New York, noticed bright lights which they interpreted as being a fire. They raced down to the river with their equipment, only to realize that it was not fire, but a brilliant sunset which was caused by the dust particles of Krakatoa that they were observing. Immense tonnage of pumice stone was released by the explosion, and floating rafts of pumice went all the way to the southeastern coast of Africa, where many were observed to have transported skeletons of victims to the shores of Africa. Finally, it should be observed that the sea bed where Krakatoa was located has continued to smoke, bubble, and explode (although with much less force), so that in 1930, at that same site, there developed the new island of Anak Krakatoa (the daughter of Krakatoa).

As we have seen,Volcanic eruptions have not only been common in Earth's history, but they have had great historical importance. But, volcanoes are not the only natural cataclysmic force on the planet. Earthquakes have played a similar role. On November 1, 1755, a great quake struck Lisbon, Portugal, and 60,000 people were killed. On August 31, 1886, there was a huge earthquake in Charleston, SC, in which almost 100 people died, thousands, out of a population of 49,000 were injured, and it was said that seven out of every eight houses were damaged, some a total ruin.

Years before the Charleston event, in 1811 in the town of New Madrid, MO, there was a large earthquake which was felt over an area of one million square miles – in places as far away as New York, Toronto, Montreal, Boston, Chicago, Milwaukee New Orleans, and Charleston. The number of aftershocks was truly prodigious – no fewer than 1,874 separate earthshaking episodes in and around New Madrid over the next few weeks.

In the twentieth century alone, there have been numerous large earthquakes with significant loss of life, and they have occurred literally around the world – China, Japan, California, Mexico, Morocco, Armenia, Turkey, Iran, Alaska and under the oceans. When an earthquake occurs on the ocean floor, the result is often a tsunami, or large sea wave which hits costal areas with terrifying force. In 1964, there was a tsunami in the California coastal town of Crescent City. This town of 7500 people was completely devastated, and 11 people were killed. We all remember the incredible Indian Ocean tsunami of 2004 which killed 225,000 people.

The strongest recorded earthquake in history occurred in Chile in 1960. It measured 9.5 on the Richter scale. The epicenter of the quake was 60 meters down below the ocean floor about 100 miles off the coast of Chile. Although the physical damage was devastating, the loss of life was not as bad as it could have been because there were large foreshocks that sent people out of buildings and onto the streets. Enormous tsunamis traveled for thousands of miles across the vast expanse of the Pacific Ocean, reaching the shores of Hawaii, the Philippines, and even Japan, destroying everything in their path.

Even the earth itself was changed by the enormous energy of the earthquake. Huge landslides, massive flows of earthen debris and rock were sent tumbling down mountain slopes. Some landslides were so enormous that they changed the course of major rivers or dammed them up, thus creating new lakes. The land along the coast of Chile, particularly in the port city of Puerto Montt sank as a result of the movement of the ground during the quake, and the city was flooded with ocean water.

Another great Chilean earthquake occurred in the 1820's, and this one caused the elevation of the nearby Chilean coastline to change. This change was substantiated by the captain of the HMS Beagle, Robert Fitzroy. This voyage was also notable because of the presence of Charles Darwin, whose observations led to his famous theory of evolution.

And then there was 1906, a year which the author Simon Winchester has dubbed "the year of living dangerously". 1906 was a particularly active year, seismically speaking. On January 31st of that year, a huge earthquake occurred under the seabed of the Pacific Ocean. 2000 people were killed, many more thousands were injured, and countless villages and one major port city in Ecuador were destroyed. The effects of the tsunamis were felt as far away as San Diego and Honolulu.

Sixteen days later there was another very large earthquake in the Caribbean, which caused destruction to a wide area, although there was no loss of life. Five days after that event, there was another major earthquake in Shemakha, an ancient town of mosques and temples in the Caucasus Mountains.

Four weeks later, on March 17, an enormous quake ripped through the island of Formosa. Thousands of homes were destroyed, 2000 people were injured and at least 1228 people were killed.

And then Vesuvius erupted on April 6th. This eruption, Vesuvius's first in 300 years, lasted for 10 terrifying days. Although just 150 people are thought to have died, many Italian villages were covered in ash, much as Pompeii and

Herculaneum had been 1900 years earlier. Finally, the eruption stopped on April 16, and all was at last quiet.

But, only two days later, on April 18th, 1906, there occurred the great San Francisco earthquake, which was the first major natural disaster to be photographed. 700 people were killed and countless structures simply vanished into jagged piles of crushed masonry and contorted iron. The city seemed to have shrunk, and one witness reported that all of a sudden it seemed "no distance, between points formerly too far to walk. Squares thought commodious … dwindled to insignificant enclosures." Gas lines and water mains broke, then massive fires broke out and added to the destruction.

Before the year was done, a further 20,000 Chileans would die when an enormous quake struck the port city of Valparaiso in mid August, essentially wiping it out.

Another interesting, though not destructive, phenomenon involves the so-called Wallace Line, first discovered and described by a man named Philip Sclater. It was later extensively studied by Alfred Russel Wallace, and he is therefore honored by having the line named after him. To be brief, this line is in Southeast Asia in the islands around New Guinea. One would expect to see, and in fact does see, great biological variation in areas separated by great distances. For example, the Arctic has polar bears, seals and humans, while the Antarctic has penguins and albatrosses. There are great differences between African birds and Brazilian birds. But here, at the Wallace Line, there is an abrupt transition in life types. To the east of this line are Australian fauna such as cockatoos and kangaroos, while to the west are Indo-European thrushes, monkeys, and deer. This transition is sudden and dramatic, and there is no intermingling between the two types of life.

Well – what in the name of Terra Firma is happening here' Why does the seemingly rock solid and immoveable land beneath our feet shake, rumble, smoke and explode – not only so devastatingly but also so frequently? The rest of my paper will address these questions and give us an understanding of the processes at work.

Aristotle was one of the first Europeans to create a theory of the origin of earthquakes. He believed that they were the result of heavy winds, although how he arrived at that conclusion is unknown to me. For centuries after that, not much serious scientific thought was given to the subject. Indeed, many, if not most, people thought that earthquakes and volcanoes were simply acts of God, usually manifesting the wrath of God. How else could one explain such horrible and seemingly random events?

To answer that question, we need to turn our attention to the science of geology. Modern geology was begun by an Englishman named William Smith, who was a surveyor and canal digger. Over a period of 20 to 30 years beginning in 1793, in the course of practicing his profession, he made countless observations of the earth's strata and the fossils they contained. Among other things, he observed that each of the earth's strata contained fossils that were unique to that stratum. He also noted that in some areas the strata were well organized in predictable layers, and in other areas they seemed jumbled and out of order. His work culminated in the creation of the world's first geologic map, it's being a beautiful multicolored map of the British Isles.

For the next century and a half, geology was mired in the study of rocks, fossils, crystals, and strata. Geologists never looked at the earth as a unit, as a whole structure. But all of that began to change in the early 20th century.

Scientists had been aware of fault lines for some time, and during the latter part of the 19th century, European scientists had begun to wonder if faults were somehow related to earthquakes. Then along came a geologist named Harry Fielding Reid, who was a member of a commission that had been named to study the San Francisco earthquake of 1906. By studying US Geologic Service data, he was able to determine that the earthquake was a result of forces which he identified as "elastic strain", which had built up slowly but unequally at points along the San Andreas Fault, and it took a massive tremor to release the strain at that point along the fault where the greatest energy had accumulated. Reid thus established tha there was a clear and dynamic relationship between faults, which had previously been observed but not understood, and earthquakes. He called his new theory "Elastic Rebound", and even into the 21st century, it remains at the foundation of modern tectonic studies. But there was still no understanding as to what exactly a fault is.

"Utter, damned rot!"said the president of the prestigious Philosophical Society. Another American scientist, whom my source unfortunately neglected to name, remarked: "If we are to believe this hypothesis, we must forget everything we have learned in the last 70 years and start all over again." A (also unnamed) British geologist added to the chorus by stating that anyone who "valued his reputation for scientific sanity" would never dare support such a theory.

The target of these blistering critiques was the new theory proposed by Alfred Wegener, a German climatologist and geophysicist. This theory, which he called "Continental Drift", was first proposed in his 1912 book entitled *The Origin of Continents and Oceans*. He published an expanded version of the book in 1915, but it was little noticed at the time because of World War I. However, it was translated into English in 1924, and at that time it aroused the previously noted hostile criticism.

With even a cursory glance at a globe or world map, one is struck by the fact that the east coast of South America appears that it would fit snugly into the west coast of Africa. Wegener noted this phenomenon, and in 1910 he wrote his future wife that it appeared that South America and Africa had been joined and: "This is an idea I'll have to pursue."

Well, pursue it he did, and he amassed a large amount of geologic data to support his theory. Among other things, he noted that when you fit Africa and South America together, mountain ranges and coal deposits run uninterrupted across both continents. He also extensively studied fossils.

Because of the importance of Wegener's work, it is worth looking at it in some detail. He began by demolishing the theory that large land bridges had once connected the continents and had since sunk into the sea as part of a general cooling and contraction of the Earth. He pointed out that the continents are made of a different, less dense rock than the volcanic basalt that makes up the deep sea floor. Wegener proposed the astonishing idea that continents are floating, somewhat like icebergs in water. He also noted that the continents move up and down to maintain equilibrium in a process he called isostasy. As an example, he cited the sinking of Northern Hemisphere lands under the weight of continental ice sheets in the last ice age, and their rise since the ice melted some 10,000 years ago.

Wegener further reasoned that given the difference in density between continents and sea floor, plus the process of isostasy, if continent-sized land bridges had in fact existed and somehow been forced to the ocean bottom, they would have "bobbed-up" again when the force was released. Therefore since fossil and geological evidence clearly showed the continents were once connected, the only logical conclusion was that the continents themselves had been joined and had since drifted apart.

By his third edition, published in 1922, Wegener was citing geologic evidence that some 300 million years ago all the continents had been joined in a super continent that stretched from pole to pole. He called it Pangaea, and he said that it began to break up about 200 million years ago.

Wegener's theory was best summarized by his countryman Hans Cloos, who was one of the few scientists who believed what Wegener had written. Cloos said of the theory: "It placed an easily comprehensible, tremendously exciting structure of ideas upon a solid foundation. It released the continents from the Earth's core and transformed them into icebergs of granite on a sea of basalt. It let them float and drift, break apart and converge. Where they broke away, cracks, rifts, trenches remain; where they collided, ranges of folded mountains appear."

As we have already noted, the vast majority of the international geologic community greeted Wegener's ideas with militant hostility. And Wegener himself realized that his theory was incomplete. His major problem was finding a force or forces that could make the continents "plow around in the mantle", as one critic put it. He finally somewhat ruefully concluded in 1929 that: "It is probable the complete solution of the problem of the forces will be a long time coming."

Wegener died the following year at age 50 on an expedition to the interior of Greenland, so he did not live to see his work vindicated.

In fact, the underlying mechanism behind Continental Drift was not discovered until the 1960's, and even today the process is not completely understood. Expeditions to Greenland in 1965 were conducted to, among other things, study the rocks and to see if there might be any evidence in these rocks to support Wegener's hypothesis, which at this point was still very much a theory. As these Greenland rocks were collected, the plan was to study the magnetic alignment of crystals in the rocks laid down in the distant past and to see if they might be substantially different from the alignment of the rocks themselves today. In fact, that is exactly what was found, and, although I won't go into the technical details, this finding proved conclusively that Continental Drift had in fact occurred

But, the mechanism of the moving of the continents was still unknown. Then along came a Canadian geologist by the name of J. Tuzo Wilson. He was familiar with the writings of geologist Harold Hess, who noted that the ocean floors were being continuously created and changed. Hess attributed this activity to two physical structures: mid-ocean ridges, where the ocean floor is created, and ocean trenches, where the sea floor is destroyed.

Wilson recognized the immense implications of Hess's idea, and using Hess's theory, he postulated the existence of a third category of physical structure on the ocean floor which he called "transform faults", which are faults that are separating rather than rubbing together. He suggested that transform faults could not exist unless the earth's crust was moving, and that the physical confirmation of these faults would prove the scientific validity of the continental drift theory.

In 1967, the US Navy, which had developed very sensitive underwater seismic equipment as part of its effort to listen for Chinese and Soviet nuclear tests, performed a series of tests which confirmed conclusively that the faults in the ocean floor were indeed transform faults. Transform faults were eventually incorporated into the larger concept of plate tectonics, which today is accepted by all serious geologists.

Plate tectonics is the concept by which we are able to explain the occurrence of earthquakes and volcanic eruptions, and so we need to look at it in some detail. It has been said that plate tectonic theory is so robust in its ability to explain and predict geological processes that it is equivalent in many ways to Darwin's theory of evolution in biology and Einstein's theory of relativity in physics. Plate tectonics offered for the first time an intellectual mechanism for taking the earth and looking at it as an entity unto itself. Fortuitously, the evolution of plate tectonic theory coincided with the advent of the space age and the development of satellites that could look at the planet as a whole. And what a vision it is! The oceans are coming apart at the seams. The crust and the upper mantle beneath them are spreading out across the deep ocean floors, moving in opposite directions on each flank of the mid ocean ridges. Then when the mobile material reaches the edge of the plate, it plunges down below whatever it meets, to be recycled in the deepest recesses of the planet before being thrust upward to begin the whole cycle again.

In essence, plate tectonics is the way by which the world deals with its steady loss of heat. When the earth was formed about 4.5 billion years ago, a vast amount of heat accumulated. But that heat is now ebbing away, and it is doing so by means of convection currents that rise to the surface at fault lines, which are areas where tectonic plates collide.

To really understand plate tectonics, we need to look at the basic structure of the earth, which is made up of several layers. The outermost layer is called the earth's crust. The thickness of the crust varies. Under the oceans, the crust is only about 3-5 miles thick, while under the continents, the crust is about 22 miles thick and reaches depths of up to 37 miles under some mountain ranges. Underneath the crust is a layer of rock material that is also solid, rigid, and relatively cool. This layer varies in depth from about 31-62 miles. These two layers together are called the lithosphere.

Beneath the lithosphere is an extremely hot (1,832 degrees F) layer of unstable, molten material called the asthenosphere. The lithosphere floats on top of the asthenosphere, which seems to be in continual motion. This motion creates stress in the rigid rock layers above it, forcing the plates of the lithosphere to jostle against each other, much like ice cubes floating in a bowl of swirling water. This motion of the lithosphere on the asthenosphere is plate tectonics, and it is responsible for all the earthquakes, volcanoes, and tsunamis I mentioned earlier, as well as the geysers and bubbling hot pools of Yellowstone and Iceland and the geothermal springs of Iceland from which steam escapes from the ground.

Depending on how they are classified, there are between six and thirty-six major plates recognized as wrapping themselves around the entirety of our planet. The edges of these plates are where the geologic activity of the world most dramatically occurs. Where plates of the same kind collide with each other head-on, their edges hitting each other, mountain ranges rise up. This phenomenon is most dramatically illustrated where the Indian Plate collides with the Asian Plate to form the Himalayan Mountains, which are geologically quite young and which are continuing to rise. Where plates pull away from each other in mid-ocean, volcanic islands ooze slowly moving lava streams onto the sea floor. Where plates of different kinds smash into each other, and one plate rides up over the other, violently explosive volcanoes develop. And where plates slide alongside each other, like ships passing too closely in the night, violent earthquakes occur, of the kind most frequently experienced in California. Mid plate earthquakes, such as the powerful New Madrid, MO, quake, are explained by inter plate pressures that bend plates much like a piece of sheet metal pressed from opposite sides. There is, however, some evidence to suggest that the North American Plate may be trying to break into two separate plates somewhere in the middle of the continent.

The biggest of the plates have suitably big names: the African Plate, the Eurasian Plate (by far the biggest), the Pacific Plate, the Antarctic Plate, and the North American Plate. These plates do not precisely coincide in location with their names. For example, the North American Plate's eastern edge is located in Iceland, at a place called Thingvellir. Thingvellir is an Icelandic shrine, for it was there that the Icelandic parliament first met in the year 930. It met there for three centuries before Iceland lost its independence because of a treaty with Norway. It is at Thingvellir that one can truly appreciate tectonic plates, because it is here that the Eurasian and North American Plates are slowly separating at a rate of about 3 millimeters a year. Between these two plates is a deep canyon whose walls are now 25 yards apart and continuing to separate. It is truly an awe inspiring sight. The other end of the North American Plate is at the California coast, where the Pacific and North American Plates collide. This area, including the famous San Andreas Fault, is particularly dangerous, because the western side of the fault is sliding to the north, while the eastern side is expanding toward the Pacific Plate. These conditions are suitable for violent earthquakes of the type seen in San Francisco in 1906.

By specifically mentioning by name only the largest plates and only a few faults, I by no means am implying that the story ends there. There are innumerable smaller plates within the larger ones, and there are faults seemingly everywhere, even where one would least expect to find them. For example, there have been numerous earthquakes in New England, and the local seismic observatories say that they record an average of 40 earthquakes a year in New England, of which five are strong enough to be felt by any reasonably aware person.

Even more unlikely is the recent discovery of a very distinct fault line under the small Oklahoma town of Meers. Meers is very near Fort Sill, in the southwestern Oklahoma Arbuckle Mountains, and study of the fault line there indicates that this fault is alarmingly large and unpredictable. Seismologists agree that the fault is primed for a rupture and a large earthquake, but nobody knows when it will happen. The problem at Meers simply underlines the difficulty that seismologists have in predicting earthquakes. At the present time, at best, earthquake prediction is an inexact science.

Tonight, we have seen that catastrophic seismic events such as earthquakes and volcanic eruptions are really quite common, and that they are caused by movements of the Earth's surface on a sea of very hot material and by the escape of heat from the Earth's core. It is now known that the Wallace Line with its sharp demarcation of different types of life follows the tracks of the extremely violent tectonic plate activities that have created so much seismic mayhem in Indonesia. So, although the two sides of the Wallace Line are geographically close, tectonically speaking they are literally a world apart.

Finally, why were there so many volcanic eruptions and earthquakes in 1906? No one knows for sure. It may have just been a huge coincidence. On the other hand, other forces may have been at work. Until spacecraft began to send us images of the entire earth as seen from afar, humanity did not really appreciate that the earth is alive. In 1974, the American biologist and philosopher Lewis Thomas wrote of the earth as seen from the moon: "...the astonishing thing about the earth...is that it is alive....It has the organized, self-contained look of a live creature, full of information, marvelously skilled in handling the sun." Five years later, a British chemist and environmentalist named James Lovelock advanced the idea that is now known as the Gaia theory. This theory, which is still only a theory, holds that the earth in its totality is very much a living entity – alive, fragile, and living in a delicate equilibrium.

Some geologists, expanding on the Gaia theory, but also using objective scientific data, have felt that the events of 1906 were all interrelated – a sort of cruel butterfly effect. As the plates shifting against one another are all interconnected, jostlings on one part of the planet's surface might well create sympathetic movements elsewhere. Thus far there is no firm evidence – only the numbers and the anecdotes.

It should be readily apparent that humanity can do nothing to stop earthquakes and volcanoes. It is hoped that as our knowledge of plate tectonics and seismology increases, we will be able to predict these occurrences in an accurate and timely fashion in order to minimize casualties. Someday, we may in fact be able to predict earthquakes and save lives. However, because of our knowledge of plate tectonics we can be absolutely certain that mountains will continue to move, cracks will appear on the earth's surface, volcanoes will erupt, earthquakes will happen, coastlines will sink and rise, continents will drift, and landscapes will change. In short, there will continue to be “a whole lotta shakin goin on!”

Bishop James Ussher 17th
Anglican Bishop of Armagh (North Ireland)
began at nightfall
4004 B.C. preceding Sunday, Oct 23

Whole Lotta Shakin Goin On"
in 2005 was selected for permanent
preservation in the
National Recording Registry at the
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