Volcanoes of Ecuador: Understanding volcanoes and how they compare across the small country of Ecuador

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Summary:

Ecuador is a small country located along the equator and pacific coast of South America, seated between Peru to the south and west, with Columbia to the north. Ecuador is home to the northern reaches of the Andean mountain range that, in its entirety, stretches from the very southern reaches of South America up through Venezuela. The country is home to numerous large volcanoes that sit in the high altitudes of the Andes, as well as the low-lying and island-forming volcanoes of the Galapagos Islands. These two differing types of volcanoes behave in very different ways, from how they form to how they perform when active. Although different in type and geography, they both have similar human health concerns in both Ecuador and nations worldwide.

Volcanism Overview:

Volcanoes are geologic structures that protrude from the earth's surface from a combination of build ups in gas, movement of tectonic plates, and cyclic movements of the earth's mantle. They are most commonly found along contours where tectonic plates meet. It is these seams in the crust that create a perforation in the crust for magma and gases to well up from below.

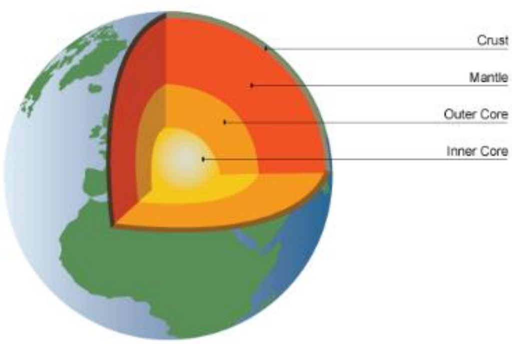

Figure 1: BBC

Volcanoes appear along subduction zones where one plate converges, or collides into, and underneath another plate. This action of sliding underneath another tectonic plate causes the earth to push up and create mountain ranges and steep terrain. For example, the Nazca plate, west of South America, is colliding with the South American Plate. This creates a convergent boundary on the west coast of South America. The resulting subduction zone of the Nazca Plate makes a deep trench that runs up the western coast of the continent. This action is also what creates the towering Andes mountains that run down the length of the continent like a spine. Ecuador sits right in the middle of this subduction zone.

Volcanoes will also form when the opposite occurs. Divergent boundaries, or boundaries where the tectonic plates are ripping apart from each other, will rip open the crust and cause magma to pour out and a volcanic slope that is not very steep. This can be seen on the mid-

Atlantic ridge in the Atlantic Ocean on the sea floor. The mid-Atlantic ridge is a divergent zone that runs up the middle of the Atlantic Ocean and can be seen clearly with sonar imaging maps as a “spine” that travels up the center of the ocean. When two continental plates diverge, it is called a continental rift. The rifting is the pulling apart of plates from one another and often creates volcanoes that do not exhibit very much explosiveness, but rather “ooze” lava.

Another type of volcano formation that is seen in the Galapagos Islands of Ecuador are ones created by Mantle Plumes. These plumes are also referred to as “Hotspots”. This is because they do not move along with the tectonic plate lying above it like other volcanic activity. This action is what causes the formation of island archipelagos like Hawaii or the Galapagos. In a Mantle Plume, the magma is rising up from down deep within the mantle and coming up through the ocean floor. As the magma piles on top of itself and cools over millions of years it creates a rocky island. Over millions of years the island shifts with the movement of the earth’s crust and another island is formed in the same place where the “Hotspot” is. This is repeated over time and creates chains of islands in the middle of the ocean.

Figure 2: The Galapagos Archipelago can be seen to drift eastwards with the Nazca plate Galapagosisland.net

Furthermore, on top of there being many different ways of volcano formation, and where they form, there exists several different types of volcanoes. Each of them are caused by something different and function in their own way. First, is the cinder cone volcano or scoria cone (Bagley, 2018). These volcanoes are what most of us think of when we imagine a volcano. They are very steep, symmetrical and launch lava and debris into the sky with considerable amounts of lava and often form on the flanks of both shield and stratovolcanoes. They are one of the most simple volcanoes with a single large vent at the top, which forms a crater that is surrounded by layers upon layers of tephra (lava and ash and other volcanic debris) that has formed as it falls back down after an eruption where it cools to form a mountain of rock that slowly grows over millions of years. This debris that collects often forms into a loose substance and is not solid rock like a pyroclastic or lava flow. The basic function of a cinder cone volcano is to erupt and throw ash and lava into the sky with great force and then create a crater or cone at the top of the volcano.

Although cinder volcanoes are destructive in their nature; for example, Paricutin in Mexico destroyed the original city of San Juan in 1943 (Principle Types of Volcanoes), they are not typically as destructive as others such as the stratovolcano. Stratovolcanoes, also called composite volcanoes, are also associated with the classic tall and cone shaped structure that we think of when we imagine a volcano. These volcanoes are the most common on earth, and with the exception of mars, have not been found anywhere else in our solar system. Although, common on our planet, our planet is one of the only with them in existence. But, these types of volcanoes are different in how they perform from a cinder volcano.

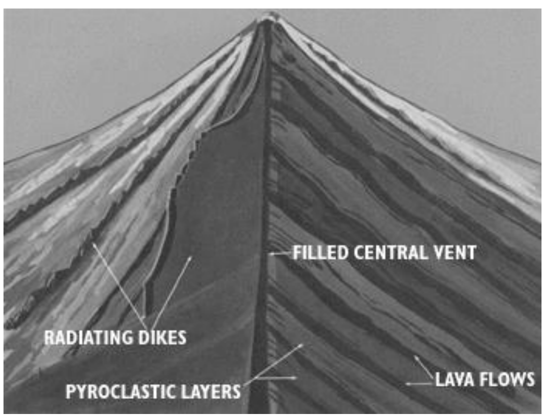

Figure 3: Stratovolcano courtesy USGS

Stratovolcanoes typically form at subduction zones, like many volcanoes. For example, where the Nazca plate subducts underneath the South American plate. The Andes make up the eastern edge of the “Ring of Fire”. The oceanic waterlogged crust subducts beneath the continental crust and is therefore pushed into the mantle of the earth. This creates immense pressure on the rock, and through a series of geochemical processes becomes so heated and pressurized that it turns into liquid, or magma. Because substances in their fluid state are always lighter than in their solid state, the magma begins to rise. As the magma rises, gases and volatiles become released from the magma. This creates even more immense pressure within the crust. The magma and gasses find their way to the surface forming a stratovolcano. The pressure of gasses and volcanic substances become released with an extremely explosive and violent eruption. This eruption rains down ash, lava (magma that has breached the surface of the earth), and tephra often resulting in some kind of impact on society.

Finally, the third type of volcano that exists are shield volcanoes. Shield volcanoes are gently sloping and often associated with island archipelago volcanoes. For example, both the Galapagos Islands and the Hawaiian Islands are derived from shield volcanoes. These mountains are formed through the process of usually non-violent eruptions where very fluid basaltic lava effusively flows up, out, and down the sides of the mountain. The lava will not always flow out of the central vent located at the summit of the volcano but will often seep out through cracks or rifts in the surface on the flanks of the volcano and silently flood the surrounding countryside with molten rock. The name “shield” originated due to the fact that the lava flows and cools in thin layers on top of one another forming a gentle slope of roughly five to eight degrees; resembling a shape that of a roman warriors shield (Principle Types of Volcanoes). Due to the low viscosity of the lava and its ability to release volatiles faster, it flows very quickly down the slopes and often quite far. Though not the most destructive, these can become an issue when the lava flows down into populated areas.

Volcanoes in Ecuador:

Now with a basic understanding of different types of volcanoes around the globe we can begin to discuss the commonalities and differences between the volcanoes that exist in Ecuador. Although Ecuador is a small country only taking up less than 300,000 square kilometers (the

United States being just under 10,000,000 square kilometers); it has a wide variety of ecosystems and biodiversity. On its western coast, Ecuador can go from 90 degree weather at sea level to the towering Andes reaching over 4,000 meters and drop into the 40s in just 80 kilometers. Travelling through the country in a car, one can see a dry desert-rlike scenery on one side of the mountains and an hour later be in the midst of a sweltering, cloud engulfed, and thickly vegetated rainforest.

One can also board an airliner in Guayaquil and fly just an hour west to the famed Galapagos Islands, most well known as the catalyst for Charles Darwin's concept of evolution, which changed science forever. These islands would not exist without the presence of volcanoes. The islands situated about 1,000 kilometers west of Ecuador's mainland in the Pacific Ocean straddling the equator are comprised of shield volcanoes that have grown over millions and millions of years as a result of a mantle plume hot-spot that sits underneath the ocean there.

What is a hot-spot and how do they work? A hotspot, or better referred to as a mantle plume, is a column of "hot rock" that originates deep within the lower part of the mantle. This is caused by portions of the mantle close to the molten liquid outer-core being heated up via extreme temperature and pressure.

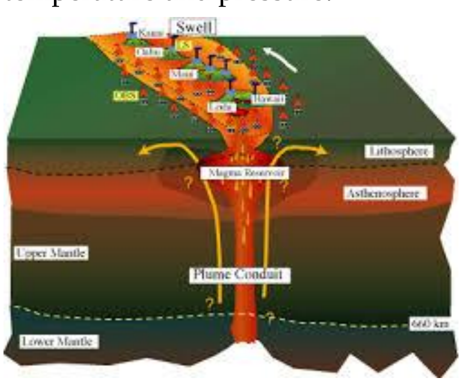

Figure 4: mantle plume; igppweb.usgs.edu

This superheated rock then begins to rise at a rate of roughly 10 centimeters per year (White, 1997). As the rock makes its way up through the mantle through channels and by finding weaknesses within the rock layers, it eventually arrives in the asthenosphere. This layer lies just below the lithosphere and the crust. The asthenosphere of the earth is thought of as "plastic" although it is a solid. Here the magma will begin to dissipate and continue to rise. Then, the hot rock begins to melt. The melting occurs at roughly 150 kilometers beneath the surface and is caused by the decrease in pressure. Once melted, the rocks and minerals group together and rise to punch through into the lithosphere where the magma pools into "magma chambers" just below the surface and builds up pressure. The overlying crust is thick and holds the magma back from pouring out of the seafloor.

Once enough pressure has built up, the magma explodes through the thick and sturdy surface to form a volcano. Along with the magma cooling and thickening the crust more, the force of the volcano also pushes up the lithosphere and therefore moves the crust toward the surface. This process happens over and over again for hundreds of millions of years until finally, the volcanic rock breaks the surface of the ocean (White, 1997). The first island to do so in the Galapagos was Española, dated to about 3.3 million years old using potassium/argon radiometric dating (Leonard, 200). Radiometric dating is a technique used to date rocks that are older than any carbon dating can achieve. It functions on the basis of known decay rates of certain isotopes; potassium and argon in this case.

Once an island is formed through the mantle plume action, the island will begin to drift away with the movement of the crust. 3.3 million years ago Espanola was moving to the east along with the Nazca plate toward the South American plate. The crust moves continuously while the mantle, and therefore the mantle plume, stays stationary in its same position on the globe. Over time another island forms and drifts away. This process repeats, resulting in what is seen as a chain of islands like the Galapagos.

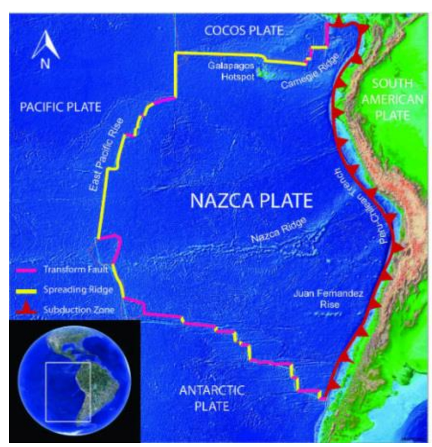

Figure 5: Nazca moving toward S. American plate carribeantectonics.weebly.com

One example of a volcano on the Galapagos is one named Sierra Negra. The largest volcano in the Galapagos sits proudly in the center of the lower portion of Isla Isabela. Reaching 1,500 meters from sea level, this gently sloping shield volcano can be seen as soon as one steps foot onto Isabela Island in Puerto Villamil. At first, it is not immediately apparent that the slope in the distance is in fact a volcano because the summit is shrouded in clouds and not often devoid of precipitation.

Sierra Negra's last eruption was the sixth since 1948 and occurred June 26, 2018 and lasted until August 2018 (Sierra Negra, n.d.). The graph shown (figure 6) shows an increase in both the seismic activity and inflation of the caldera floor leading up the 2018 eruption.

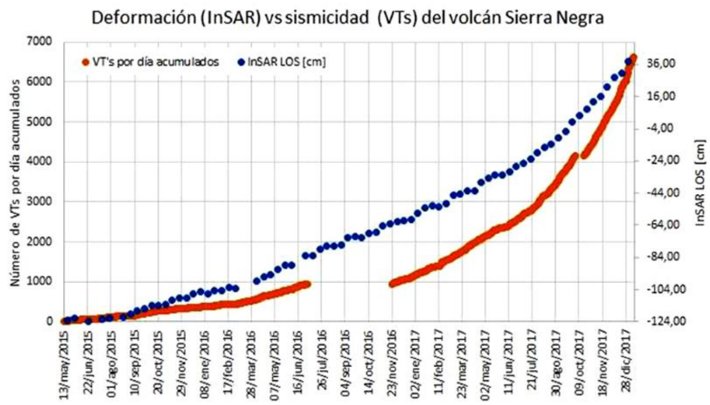

Figure 6: Figure 16. Seismicity and deformation at Sierra Negra between 13 May 2015 and 28 December 2017. The orange line represents the cumulative VT earthquakes, and the blue points record the inflation in cm of the floor accumulated since the beginning of 2015. A change in slope of both curves is evident at the end of 2017 indicating the rate of increase of inflation and seismicity. Courtesy of IG (Informe Especial Nº 2, Volcán Sierra Negra- Islas Galápagos: Descripción del estado de agitación interna y posibles escenarios eruptivos, 12 January 2018). (Sierra Negra, n.d.)

Analyzation of past historical eruptions showed that lava would typically flow out of fissures on the north/northeast edge of the caldera.

Finally, after significant increases of seismic activity and earthquakes around the edges of the caldera, Sierra Negra erupted out of the northern flank of the mountain, and fortunately away from the populated areas. One fissure located on the rim of the caldera opened and began to flow lava down the mountain side. The three remaining fissures opened down the slope on the northern side and began to spill lava up to 150 meters long and 130 meters wide. Flows averaged one half to one meter thick and are estimated to have totaled 150 million cubic meters of lava. Satellite imagery was able to pick up ash plumes reaching upwards of 10 kilometers into the atmosphere although not a particularly explosive volcano. This eruption allowed a great opportunity for scientists to safely observe and collect data on volcanism. All the while no one was injured in what is an often times hazardous event.

If one were to board another plane and fly back to Guayaquil and the mainland of Ecuador, there can be found many volcanoes but of a different type. In mainland Ecuador, situated high up in the Andes mountains there exists mostly stratovolcanoes. These are by far the most common of the hundreds of volcanoes that exist in Ecuador. The Andes mountains are the longest continuous mountain range in the world, stretching 7,000 kilometers from the southern tip of South America all the way up to the top of the continent. The mountains hug the western side of South America as a result of the subduction of the Nazca plate underneath the South American plate, which pushes up material of the crust towards the sky. This subduction action created the Andes and a prime environment for volcanoes to emerge from the depths of the earth.

The reason that the area is mostly stratovolcanoes is because they are typically very explosive, which is caused by the water that is present in the crust of the earth there. The water becomes trapped there because of the subducting, waterlogged, tectonic plate and essentially boils to build pressure within the mountain. An example of a volcano that acts in this way is the popular stratovolcano Cotopaxi that sits just south of Ecuador’s capital: Quito. As the second highest mountain in the country, this volcano stretches over 5,000 meters into the air capped by a glaring white glacier. This historically violent volcano is the epitome of a classic volcano description. Its steep sides lead upwards to a summit with a crater that is known to spew ash and pumice high into the atmosphere and send lahars (volcanic flash floods) down the mountainside spreading more than 90 km out. This looming and dangerous beauty has stood to become something to be conquered in the eyes of humans for a long time and was finally done so in

November of 1872 by a German scientist by the name of Wilhelm Reiss. It has also become the name of a very popular outdoor gear brand.

This volcano has become quite popular for a reason. Its most violent eruptions on record occurred in the years 1768, 1877, and 1904 (Britannica, n.d.). The 1768 eruption was very large and caused widespread fatalities. The eruption was explosive, launching ash high into the atmosphere and bombs (large chunks of volcanic rock greater than 64cm) as far as 24km from the crater. Pyroclastic flows flew down the mountainside at great speeds, destroying everything in its path.

These flows become quite dangerous as pyroclastic flows are not liquid flows of lava but are gaseous clouds of ash and debris that flow like a liquid down the sides of the mountain, typically following valleys or riverbeds. Heated up to 1,000 degrees Celsius, these flows cause extreme damage and can be very large in size, spreading for tens of kilometers in every direction. A pyroclastic flow will typically start out as a column of ash and rise into the air from the crater of the volcano. Sometimes the air column will become disrupted, often by a change in air densities like a cold front and will collapse and rush down the sides of the mountain like a wave of liquid. Other times the flow will shoot out as a result of the side the mountain "blowing out" and flowing down in that direction. This was seen at Mount St. Helens in 1980 when one half of the mountainside exploded out laterally and resulted in pyroclastic flows that decimated everything in its path.

Pyroclastic flows can cause other issues as well, such as Lahars like that in the 1877 eruption of Cotopaxi. A lahar is the result of a volcanic eruption melting a glacier at the top of the volcano. This sudden melt releases millions of gallons of water that have no where to go but down. Naturally, the lahar will follow streams and rivers on their way down. Unfortunately, many towns and cities are built in low flat plains where the lahars would flow directly toward. The 1877 eruption was so large that the pyroclastic flows that descended 360 degrees around the volcano triggered lahars that eventually flowed north 225 km into the Pacific Ocean in Esmeraldas (Cotopaxi, n.d.) and south east into the Amazon Basin. This pure size of an eruption is hard to comprehend due to its scale, and one would only be able to begin to understand it by being there in person, which would likely be like experiencing a "hell on earth".

Figure 7 Boulder carried by 1877 Lahars (Tom Pierson 1992 U.S. Geological Survey)

Human Health Impacts:

In 2005, a study reported that 91,000 people have died as a result of volcanoes in the 20th century. Considering that the flu has killed up to 61,000 people annually in the U.S. alone since 2010 (Disease Burden of Influenza , n.d.) and for earthquakes, upwards of 2 million people worldwide since 1900 (Karlsruhe Institute of Technology (2016, April 18). This goes to show that volcanoes are not all that dangerous in comparison to other events that occur all over the globe, at least not in our everyday lives. That is

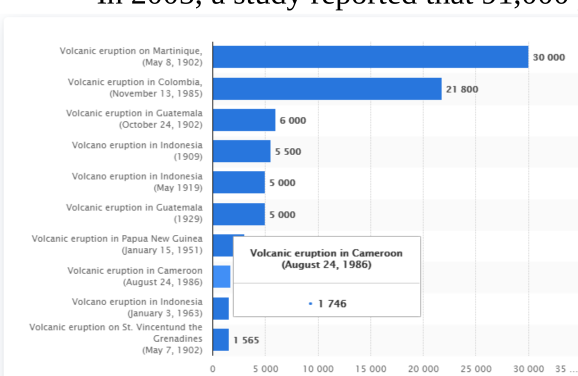

Figure 8 Death Tolls from volcanoes in the 20th century (statista.com)

not to say that volcanoes are not dangerous at all. That would be a grossly misinformed statement.

When volcanoes do erupt, and happen to be particularly large and explosive, they wreak havoc for potentially hundreds of miles or even worldwide. It is usually those who live closest to the mountain that are affected the most. Considering that 10 percent of the world's population live in active volcano areas, this comes out to 780,000,000 people that reside in areas potentially affected by an eruption.

It is not only the explosive volcanoes that have killed many and caused mass destruction. Some volcanoes have even been known to kill many people silently and invisibly and with great swiftness. This particular type of danger with volcanoes has been most commonly caused by Carbon Dioxide gas (CO2). CO2 is more dense than the air that we breath. Therefore, when the gas is released it will fall and stay close to the ground. This happened in 1797 when crater lake volcano Quilotoa in Ecuador had a limnic eruption (Gunkel, 2008). The limnic eruption is when the lake "overturns" all at once, releasing vast amounts of CO2 at the same time. The CO2 initially becomes trapped at the bottom of the lake by the pressure of the water above it. Lakes typically overturn seasonally as a result of water temperature changes and therefore causing more dense water to shift and sink and allow water from below to rise. When this change happens, the CO2 that has collected at the bottom of the crater lake rises to the top and is released into the air like a huge bubble called "degassing". Luckily, Quilotoa has not had an eruption since the 1797 limnic eruption. There is, however, worry that the crater will exhibit another massive limnic eruption that will "spill" CO2 gas over its 250 meter brim and wipe out any living being for tens of kilometers around.

Among the many dangers that volcanoes pose, such as pyroclastic flows, lahars, and CO2, there is another gas that has been known to cause damage and pose a threat to the wellbeing of humans. Sulfur Dioxide (SO2). This gas can create what is referred to as “vog” or “volcanic fog”. It is released into the air when an explosive eruption launches gasses and ash into the atmosphere. There it forms a cloud and when inhaled can exacerbate preexisting conditions such as asthma or other respiratory related illnesses. Although potentially deadly, vog is not considered one of the main causes for death during volcanic eruptions. The previously mentioned occurrences are typically far more dangerous than vog.

However, ash clouds released from volcanoes impact humans around the globe on several different levels. On a lower level, ash plumes that are released into the atmosphere from explosive or Plinian eruptions can then spread for hundreds of kilometers around. Due to gravity, at some point the ash will begin to fall and cover the ground beneath it. In larger eruptions in our times, areas closer to the eruption have been known to be covered by several inches of ash and even several centimeters as much as over 200 km away. The settling ash will not only pose an issue for those who suffer from asthma or other respiratory illnesses but will keep airplanes grounded, and generally disrupt everyday function of society. This, however, is often only for the short term. With larger eruptions, like that of Mount Pinatubo in the Philippines in 1991 which dropped the global temperature by nearly one degree Celsius due to the ash clouds increased our planet’s albedo effect. The ash clouds act much like regular clouds in the fact that when they are present, they block out the sunlight and reflect it off our planet. If there is a vast amount of ash present in the atmosphere, it lasts for quite a long time, blocking the suns energy from warming the globe.

Also, the eruption of Mount Tambora in Indonesia is what is responsible for the "year without a summer" when it erupted in 1815. The drop in global temperatures due to the ash clouds caused a summer with low temperatures and hardly any sunlight. This promptly led to crop failures and widespread famine. One of the most well-known being the Irish potato famine.

On much larger scales, there have been eruptions in the history of the earth that are thought to have sparked the existence of modern man on our planet. The eruption of Mount Toba (now Lake Toba) 75,000 years ago is thought to have released so much ash into the sky that the temperature of the planet plummeted and had long lasting effects for many years, possibly causing an ice age. This massive explosion is thought to have killed many hominoid species and after eons they began to adapt and evolve into what is now the modern human. This is known as the Toba Catastrophe Theory. Others, on the opposite side of this theory, believe that humans were not greatly affected by the Toba eruption by analyzing volcanic glass shards that were thrown from the volcano and deposited in South Africa. Anthropologists and Archeologists were able to line up the years that humans lived in that region and when the Toba eruption occurred, showing that the humans lived from 90,000 years ago to 50,000 years ago in that place. This theory then claims that humans were not affected by this massive eruption due to the fact that humans were present on that site in a span of time that began well before and lasted long after the eruption (Modern humans flourished through ancient supervolcano eruption 74,000 years ago, 2018).

Conclusion:

Ultimately, there are many different types of volcanoes worldwide, and all them function differently from one another. There are many different combinations of species of volcanos, but the most common that exist are Stratovolcanoes, Shield, and Cinder Cone volcanoes. The most common in Ecuador differ from where in the country one may go. For being such a small country there is a vast array of biodiversity and geological diversity. In the Galapagos, the islands themselves are formed from volcanoes and result in gently sloping Shield volcanoes like that of Sierra Negra on Isabella Island. In the mainland high up in the Andes, the vast majority of volcanoes are Stratovolcanoes. These “movie-like” volcanoes are the ones we mostly think of, with great explosiveness and ash plumes reaching high into the atmosphere. Volcanoes pose many different threats to humanity and in different ways throughout history. Some may be immediate and affect those who live closest to the eruption, while others may have worldwide effects that potentially could change the course of humanity forever. For now, they are simply geologic wonders from which we have much to learn for both our past and our future.

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