The Amazon Basin is a multi-ring impact basin.

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Abstract:
The Amazon Basin forms a 3500 km diameter circle in northern South America. It is hypothesized that the Amazon Basin is a multiring impact basin, due to a comet of 350 to 400 km diameter impacting Earth in the Mesozoic era, causing the basin to be in its present shape. If it is an impact basin, then it should have features similar to other large impact basins such as the Lunar basin, Orientale. Such an impact should form a large melt zone in the center of the Amazon Basin, and cause gravity and magnetic anomalies. The Amazon does fit these criteria. Topographic maps show a series of concentric circles in the basin that match the patterns of Orientale Basin. The geological cross section fits an impact profile with a central basalt sea and over 1500 km diameter area of older sediments mixed with melted basalt. Gravity and magnetic anomalies are associated with the basin. There is no satisfactory Plate Tectonic explanation for the central basalt sea, vast areas of melted rock, or the areas of uplift such as the Tepui table top mountains in the north, but an impact would explain them. It has a best fit to an impact that would have been formed by a 370 km diameter comet traveling at 72 km/sec. Such an impact would have caused an extinction event, but the age dating of the central Amazon is not precise, so which extinction event is not determined. There is no present shock metamorphic evidence, but that is not surprising since the basin is filled with over 1 km of sediments, and high speed low density comet impacts are expected to have different shock metamorphic signatures.

Introduction:
The Amazon Basin is a unique feature on Earth. It is 3500 km in diameter, almost flat, and a vast jungle of life. Plate Tectonics does not explain how it formed, or why it is round or flat. Paleo reconstructions show that the basin has existed as a circular body for at least 2 billion years (*Blakey,* 2014). It is a craton that has had little change in billions of years. It has no fault lines, no rifting, no extension or compression features from plate interactions other than the recent Andean related events and some Paleozoic extension, and is extremely stable (*Torsvik et al.,* 2009; *Barros et al.,* 2009). Yet the basin is full of melted rock, basalts, and apparent intrusions (*Milani and Zalán,* 1999; *Gonzaga et al.,* 2000). In the center, the bedrock is shattered like a fall-back breccia (*Marchi et al.,* 1999). Without any Plate Tectonic related events, and no volcanism, it has been impossible to explain these features. Geological cross sections show massive upheaval during the Triassic, and only horizontal layers of sediments since then. Its features fit an impact origin instead of a Plate Tectonic origin. The Amazon Basin topographic cross section has elevation changes in the same relative spacing intervals as the Lunar multi-ring basin, Orientale (*Potter et al.* 2012). It is proposed that a 370 km diameter comet, of density 800 kg/m3, traveling at 72 km/sec hit the center of the Amazon Basin, shaping the northern part of South America into its present circular shape, causing an extinction event.

The Amazon Basin and Orientale Basin have matching topographic cross sections.
The Amazon Basin is a vast flat area, with the Andes Mountains on the west and the Atlantic Ocean to the east. Generally the topography is

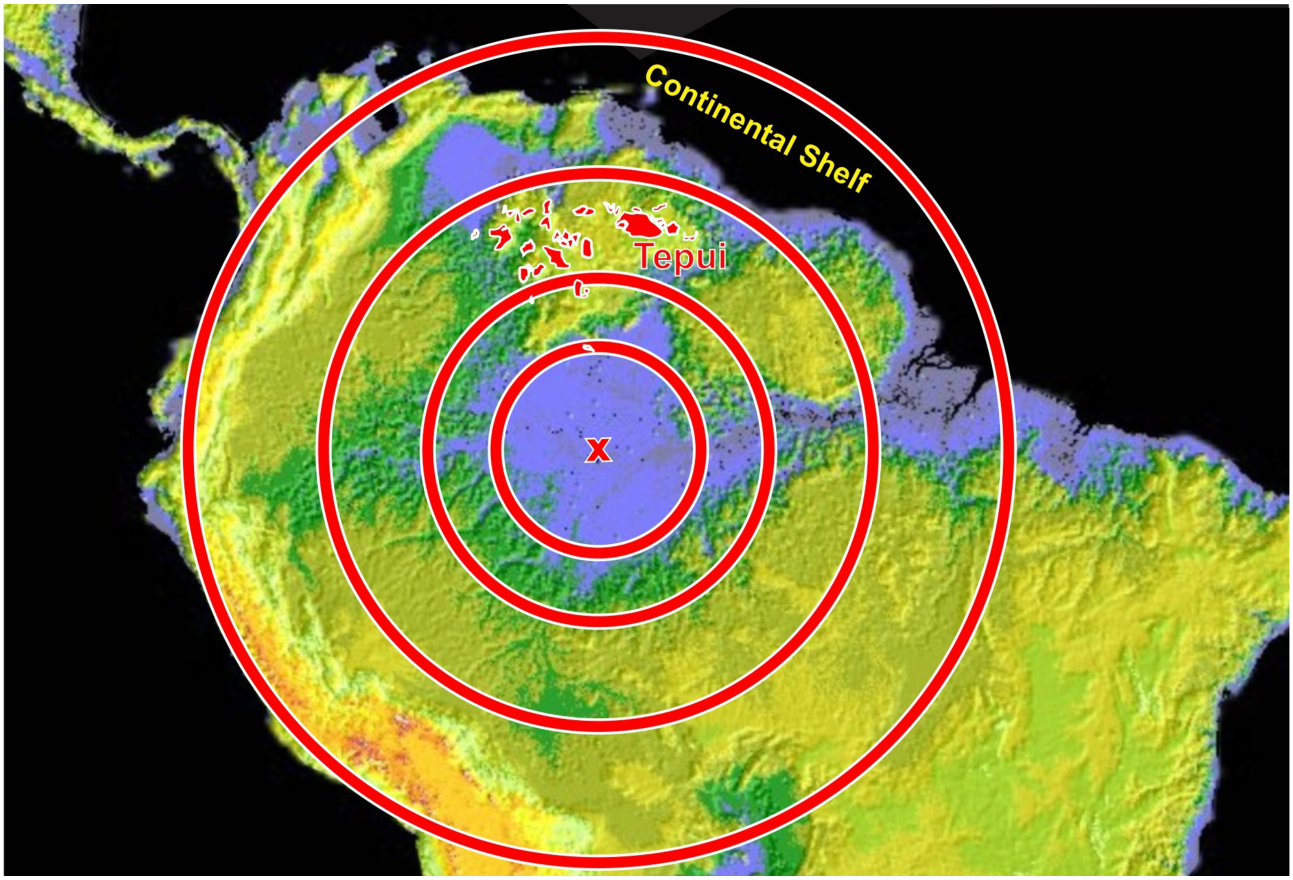

Figure 1: NASA GDEM elevation map of South America with the proposed Amazon multi-ring basin outlined in red rings and the Tepui and highlands shown in red irregular shapes.

noted to be simply flat, but new maps based on satellite imagery, such as the Global Digital Elevation Model (*NASA,* 2009), show a distinct circular pattern that extends around the basin. There are other noticeable concentric circles in the middle of the basin. Figure 1 shows the map with circles outlining the patterns visible in the basin. It is comparable to Orientale crater on the Moon.

Orientale Crater is the type sample for multi-ring basins. It has 4 sets of rings with the innermost outlining a basalt sea. The basalt sea (Orientale Mare) is believed to be indirectly formed by the impact causing the mantle to heat up and the basalt to be extruded as a flood basalt later, possibly up to 100 Ma after the impact (*Whitten and Head,* 2011). Orientale is only 930 km in diameter compared to the Amazon Basin's 3500 km diameter. However the pattern is the same for both. Both have a central flat area of basalt, and have ring spacing in the same ratios, as shown in Figure 2. It is worth noting that the areas of uplift between the second and third rings are irregular in Orientale with the eastern part essentially flat. The corresponding uplift in the Amazon is represented by the severely weathered Tepui and highlands in Venezuela, Brazil and Guyana outlined in Figure 1. The uplifted areas do not extend all the way around the center of the Amazon, similar to the uplifted areas in Orientale. The curvature of the Tepui and highlands fitting the third ring is only apparent with the circles drawn on the elevation map. Some smaller Tepui are present close to the center, which also matches raised areas in Orientale.

Figure 3 shows topographic cross sections of the two basins. Cross section data for Orientale is from *Potter et al.* (2012) and from *NASA JPL* (2010). Data for the Amazon is from Google Earth. Both have elevation changes at the same respective distances out from the center. Several

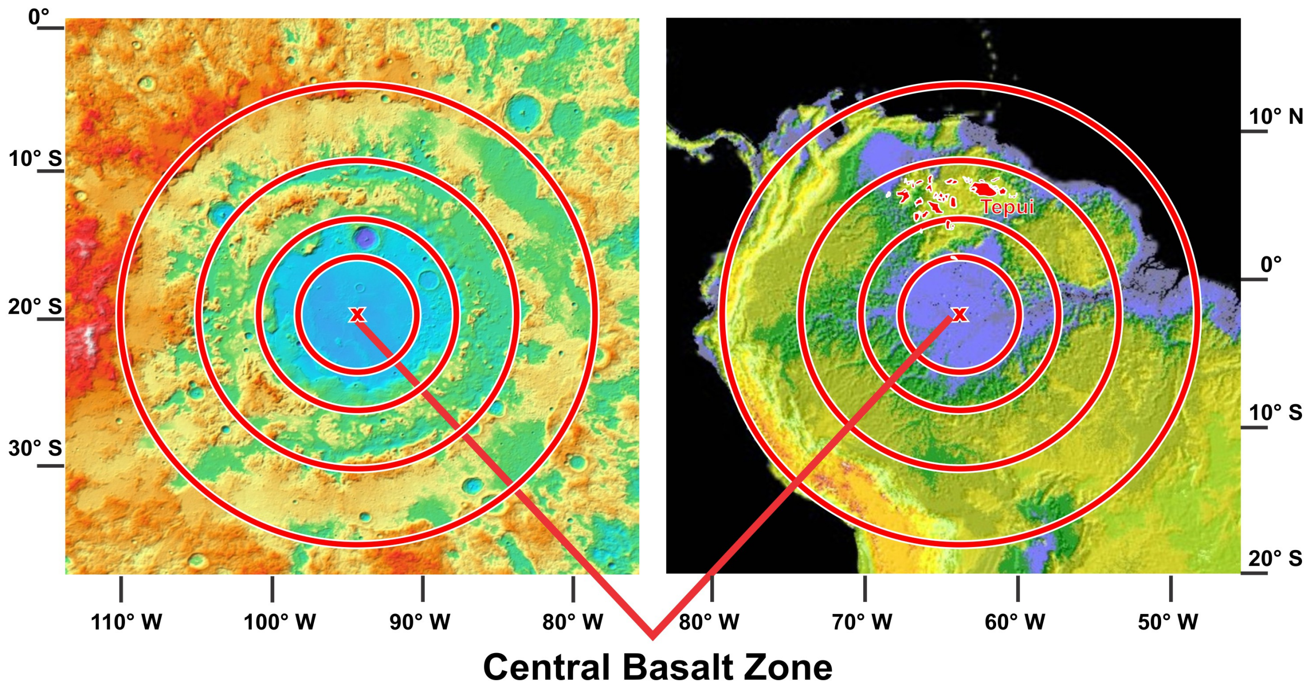

Figure 2: Comparison of Orientale Basin and Amazon Basin. Note that the rings are in the same ratios. The inner rings in each are basalt seas, but the Amazon has over 1 km of sediments covering the basalt.

topographic cross sections of the Amazon are presented here to show that the similarities are not a matter of chance – they all show the same patterns. The Amazon has a layer of sediments over 1 km thick from millions of years of deposition, and the high areas have been eroded extensively, diminishing their heights. Orientale has not had any erosion or deposition. This is one factor leading to the topographic sections having significantly lower elevations in the Amazon than in Orientale.

In addition to the erosion and sediment infill, lower topography in the Amazon is to be expected since the Amazon Basin is larger, and was formed by a high speed and low density impactor which are factors that lead to relatively lower elevation features in craters (*Schenk,* 1989; *Melosh,* 1989; *Svetsov,* 2005). Many of the large craters on Mars are of similar depth/diameter as the Amazon (*Howenstine,* 2006). At present, the Amazon is 3500 km in diameter, but the west coast has been shortened approximately 300 km from the mountain building of the Andes. This means that a better estimate of the original diameter would be 3800 km. Larger craters tend to be impacts by higher speed comets which form lower depth craters (*Shoemaker,* 1990). A study by *O'Keefe and Ahrens* (1982) showed that porous and low density bodies react significantly differently than rocky or metallic bodies when they collide, producing a much smaller crater depth for a given diameter, and reducing the height of the rings and crater walls. The “Earth Impacts Effects Calculator” (*Marcus et al.,* 2010) uses the formula $0.4\ D^{0.3}$ to calculate the depth expected for a given crater diameter D. For a 3800 km crater, the $0.4D^{03}$ formula calculates a depth of 4.7 km. With the Tepui at 3 km height, and the central area having 1 km depth of sediments as shown on the geological cross section of Figure 4, the original depth of the Amazon should be estimated as 4 km, which is appropriate for the size of the Amazon Basin if caused by a porous low density comet impact.

Figure 3 shows the alignment of the various rises that fit similar patterns to Orientale. The Tepui and highlands are well matched to the rings of Orientale. The outer ring for the Amazon on the east is the coast of the continent instead of a crater wall. Plate Tectonics has effected the crater wall.

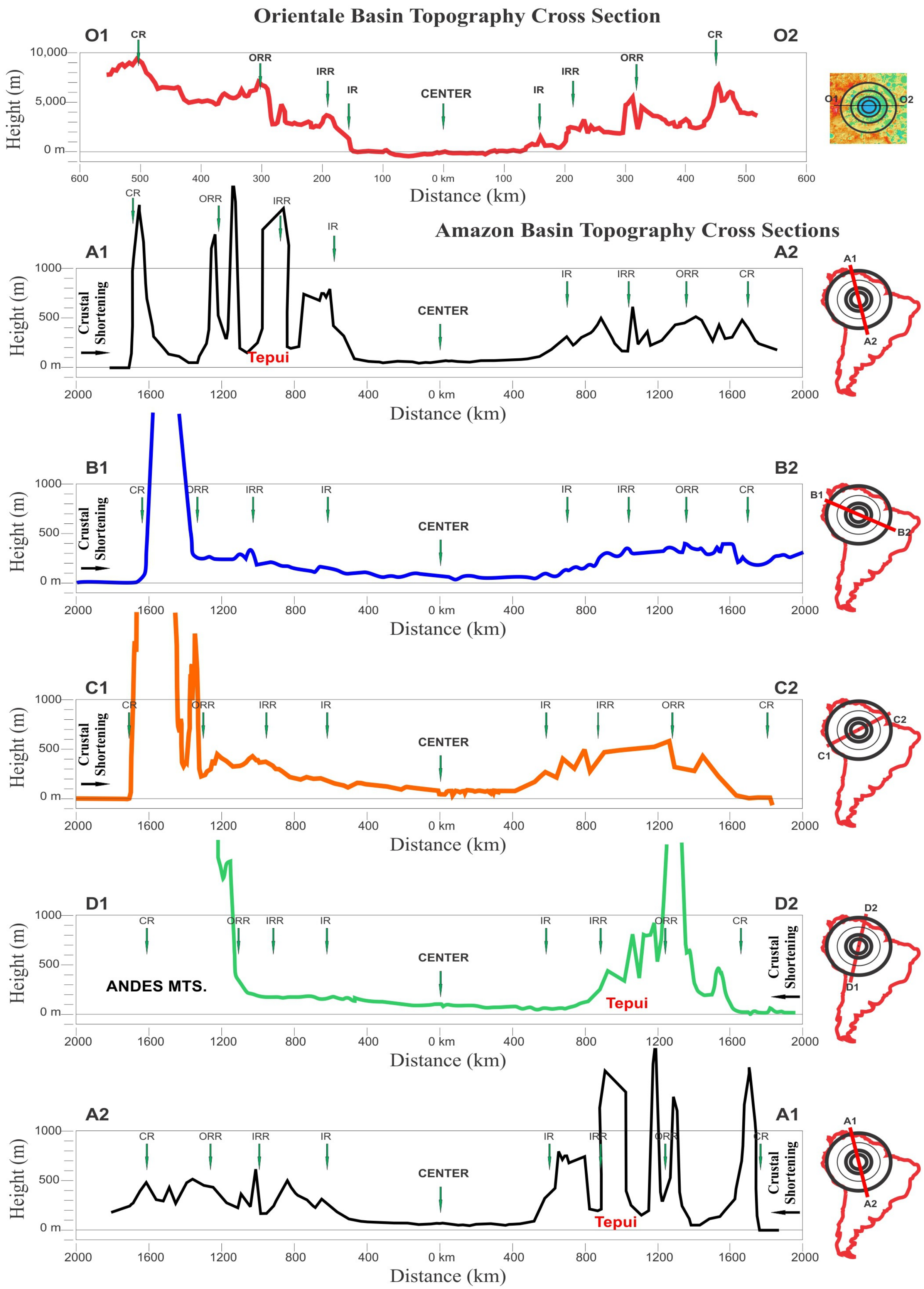

Figure 3: Topographic cross sections of Orientale and Amazon basins. The rings are not as clear in the Amazon due to millions of years erosion, 1 km layer of sediments on top of the original rings, and crustal shortening as the Andes formed.

The east coast was probably still attached to Africa at the time of the impact. An impact this large would have influenced the breaking apart of the two continents. The edge of the crater would produce a weak point that would influence the location of separation. As the continents separated, there would be stretching and breaking which could change a crater wall into a coastal edge.

Section A1-A2 in Figure 3 is repeated, with both north to south and south to north orientations shown. It shows more clearly how well the two sides of the topology match.

As previously mentioned, along the west and north coasts the crust has been shortened by the collision of the Amazon with other plates, forming the Andes mountain range. This has pushed the ancient crater edge in towards the center and dramatically elevated the edge, merging it with the Andes. The cross sections show this clearly as the outer crater edges are closer to the center on the coastal sides then in the southern areas. One could estimate the shortening from the cross sections as 200 to 300 km, which matches the general expectations on the evolution of the Andes (*Sobolev and Babeyko,* 2005).

Paleo-reconstructions of Amazonia show it as a circular craton since at least 2.0 Ga. There was a brief contact on the east coast about 1.1 Ga, but the west coast is believed to have always been a circle (*Pesonen et al.,* 2003). While there are many variations on reconstructions suggested by different authors, most agree that Amazonia was essentially the same circular shape for at least 2 Ga. No one has discussed why the west coast is a circle or how tectonic activity could produce a circle. As an impact feature, it would be expected to be circular.

The Tepui are unusual table top mountains found mainly in the southern part of Venezuela. They are formed of Precambrian sandstones, about 1.5 to 2 billion years old. The Tepui are remnants of a vast area of uplift that are estimated to have risen in the late Cretaceous (*Gibbs and Barron,* 1983) and have remained in place ever since. Most of the sandstone has eroded away, leaving the few areas still standing as the steep walled, 1 to 3 km high Tepui. The razor sharp walls are due to fracture planes that cause the erosion to take off sections rather than wearing down the edges slowly. The fracture patterns extend over many kilometers in distance, implying that they may have been formed by an extensive shock wave, such as an impact event. The Tepui lie mainly in an arc around the center of the Amazon where the third ring would be expected. When they first formed, they would have made a clear ring feature matching the Orientale Crater's third set of rings. Where the cross sections show the Tepui, the weathering produces irregular patterns in the cross sections. The original uplift would probably not have had spaces between the Tepui.

The Amazon's geological cross section matches what is expected for an impact crater.

The Solimões Basin is the center 480,000 sq km of the Amazon Basin. It is shown in cross section in Figure 4. The area remains essentially unexplored, having only 147 drill holes as of 2009 (*Neves et al.,* 2009). The 1500 km cross section is based on seismics with correlating information from only 17 oil wells (*Marchi et al.,* 1999). The eastern part of the cross section is based on two drill logs from *Milani and Zalán* (1999) and *Gonzaga et al*. (2000). Most of the wells are in the central area of the cross section, so the majority of the cross section is an extrapolation from seismics. Seismic exploration is unreliable here due to the complex and extensive layers of diabase/basalt blocking the seismic signals (*Neves et al.,* 2009). Extensive sills of basalt are shown in the cross section. Three main ones in the Solimões Basin are 168, 500 and 449 meters thick (*Garcia et al.*, 2013), and are probably all the same age (*Wanderley Filho et al.,* 2007). The geological cross section is usually labeled as having continuous layers of "intrusive sills". This is convenient for the purpose of indicating that oil is likely to be found under the sills. They are not meant to be an accurate portrayal of what is actually present. There is so little concern about the cross section's accuracy that several authors have used the same cross section in their articles with ages and rock types misnamed (*Clark,* 2002; *Avila and Nascimento,* 2009). If the sills are melt

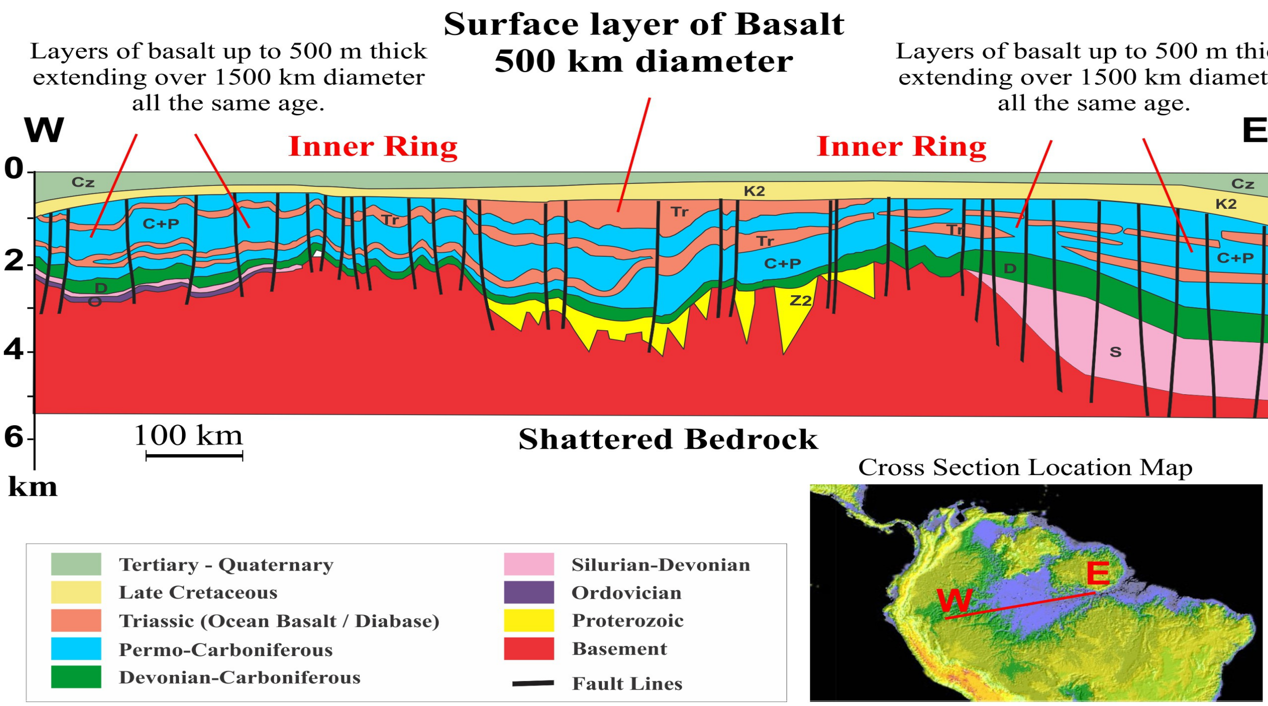

Figure 4: Geological Cross Section of the center of the Amazon Basin. The labels have been changed from the original reported cross sections to show the impact related features. Modified from Marchi et al. (1999) with additions based on Milani and Zalán (1999); Gonzaga et al. (2000).

zones from an impact, then the cross section would remain essentially the same, but with the intrusions shown as discontinuous areas. This is further supported by a more recent cross section of the eastern part of Solimões which does show the intrusions as discontinuous areas (*Munis,* 2013). The basalt layer is described as "mid oceanic ridge basalt type quartz diabase" by *Gonzaga et al*. (2000). This would be the most likely type of melt expected from an impact that primarily ejected rock from the mantle rather than from the crust, or from later intrusions caused by the impact heating the mantle under the basin.

It is important to note that the sills are defined as intrusions primarily since there is no other explanation at present. An impact would form melt and apparent intrusion layers in the center area of the crater. Actual sill intrusions are typically of thin layers extending several kilometers. Here there are three sills of thicknesses up to 500 m extending over 1,500 km. They are all essentially the same age, so they occurred at the same time. They are connected to a central layer that did extrude onto the surface, so the fast moving magma should have just risen to the surface. Instead, the entire central 1500 km diameter area of the Amazon Basin was lifted a total of 1100 meters to allow the sills to run freely without solidifying until they extended 750 km away from the central source zone. The forces required to lift the overlying kilometers thick layers of sediments to such heights to allow the magma to flow freely without solidifying is vastly greater than the force required for the magma to simply rise to the surface and flow over the land. There should be only the surface flow, but the sills exist. For an impact event, this is expected. For Plate Tectonic events, this is impossible. Also note that for rock described as basalt or diabase the melt must have cooled rapidly or the grains would have grown and the intrusions would be described as granites. The scale of this much magma moving so far and cooling rapidly while the upper kilometers of sediments were lifted over 1 km to allow it to happen is essentially a description of an impact, not of a slow gradual plate tectonic process.

Multi-ring impact craters typically have the central area filled with molten rock forming a basalt sea. Orientale has a central basalt sea of 320 km diameter (*Whitten and Head,* 2011; *Potter et al.,* 2012). The Amazon's central basalt layer is 500 km in diameter and can be seen in the cross section of Figure 4, along with wide areas of melted rock extending over 1500 km in diameter. They are presently classed as Triassic intrusions. Most of the northern part of South America and the Amazon Basin was formed in the Archean and Paleoproterozoic, with over 80% of the present crust in place by the end of the Paleoproterozoic (*Schobbenhaus and Bley de Brito Neves,* 2003). Accretion on the west occurred in the Mesoproterozoic, and on the East during the formation of Pangea. The Andes are more recent formations, starting in the late Mesozoic. In most paleo-reconstructions, the Amazon Basin is shown to have been in its present shape for over 2 billion years (*Torsvik et al.,* 2009; *Barros et al.,* 2009). There is no present Plate Tectonic explanation of what would cause intrusions. However, the basalt sea in Orientale is estimated to be 100 Ma younger than the impact event that caused Orientale (*Whitten and Head,* 2011), with the basalt filling the crater from yet unexplained factors related to the impact. *Whitten and Head* (2011) discuss the possibility of the impact heating the mantle and leading to the formation of a large melt zone that eventually rises to the surface. The exact process is not determined yet, but the point remains that the basalt sea in Orientale when viewed in a geological cross section would look like an intrusive event that broke out onto the surface rather than appearing to be obviously part of the impact event itself.

Multi-ring basins typically have layers of original rocks remaining after the impact. The center of the basin will rebound and then settle, leaving a shattered but recognizable layering of the original rock (*Grieve,* 1980). The shattered basement and severely faulted rock layers in the cross section match *Grieve's* (1980) drawings of what is expected for a multi-ring crater.

It has been proposed that the basin was extensively faulted and vast areas were overturned due to horizontal compression related to the break up of Africa and South America forming the South Atlantic (*Barata and Caputo,* 2007; *Caputo,* 2014). However, no details are proposed on how a rifting event in the Atlantic would effect the entire Amazon Basin as far west as the Andes, or how this would lead to intrusions extending over much of the Basin, with the main intrusions centered 1000 km southwest of the rifting. Today, there are no earthquakes in the Basin other than very deep ones associated with the Pacific Ocean's Nazca Plate subducting under the west coast. A lack of earthquakes as seen in Figure 5 is a strong correlation with the stability of the area, and is a clear indication that there is no Plate Tectonic activity in the Amazon that could have caused the massive intrusions present.

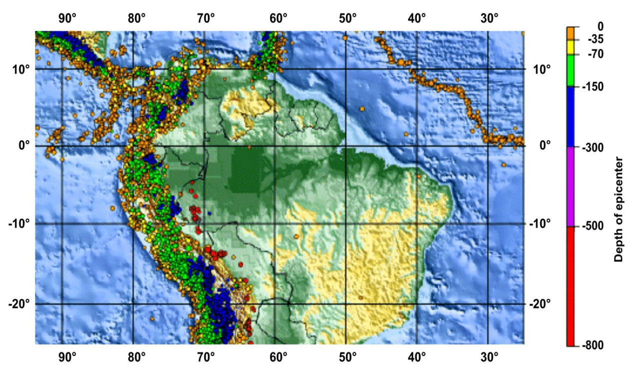

Figure 5: USGS Earthquake map of South America 1990 -2000 - note there are no earthquakes in the Amazon Basin except very deep ones from subduction of the Nazca plate.

If the central basalt sea was an intrusive event occurring in and under the surface sediments, then the topography would be considerably different. Most such intrusions form dome structures as seen in many areas in the Canadian Shield. Surface flows such as the Traps form high mountains with clearly defined edges and lava flow patterns formed while flowing and cooling. But the central basalt sea in the Amazon basin lies perfectly level with the surrounding land. The present explanation of the flat center of the Solimões basin is that it has lost 900 meters of basalt due to erosion between the intrusive event and the late Cretaceous (*Wanderley Filho et al.,* 2007). To erode to a flat surface in less than 100 Ma is not likely since the Siberian Traps of Triassic age (over 200 Ma) and similar rock type remain as mountains today. Even the sandstone Tepui in the Amazon Basin are still standing up to 3 km high after at least 65 Ma of erosion. Erosion is proposed when no other solution exists, but it does not provide a satisfactory explanation here. Once again, this phenomena can be best explained by an impact. As an impact related melt layer, it would have filled the crater as a single melt event, forming a flat surface at the level of the land around it, which is what is seen in the cross section.

Dating the impact.

The reported age of the basalt in Figure 4 is listed as being Triassic (*Marchi et al.,* 1999; *Milani and Zalán,* 1999; *Gonzaga et al.,* 2000; *Barata and Caputo,* 2007; *Caputo,* 2014). The oldest sediments above the central basalt sea are listed as Cretaceous. The dating of the sediments is based on little available information. The original determination of Cretaceous age was based on the finding of a dinosaur tooth (*Price,* 1960) and later on the basis of pollen analysis (*Mendes et al.,* 2012; *Hoorn et al.,* 2010). In general, there are no fossils in these sediments (*Mendes et al.,* 2012). A kilometer thick layer of sediments with virtually no fossils indicates a long period with minimal life in the area as would be expected after such a massive impact. The Amazon Basin is now the most densely populated area in the world with more plants and animals than anywhere else on Earth. For sediments to have been deposited without fossils is unimaginable now. For millions of years, the Amazon Basin had minimal or no life in it or fossils would be abundant in the sediments. Only an impact would explain this.

Radiometric dating is rare and attempts to properly date events are still ongoing. *Wanderley Filho et al.* (2005) have used $^{40}Ar/^{39}Ar$ dating to determine the Triassic intrusions to be 204 Ma instead of various reported ages of 150 – 210 Ma. *Caputo* (2014) proposes that the age of the most recent orogeny is a late Jurassic event, not Triassic. So the Triassic age of the basalt layers is a rough estimate of age. Without proper dating of the melt zones, the assigned ages do not carry any significance. More accurate dating of the melted rocks and associated sediments should be done to determine the timing of the impact.

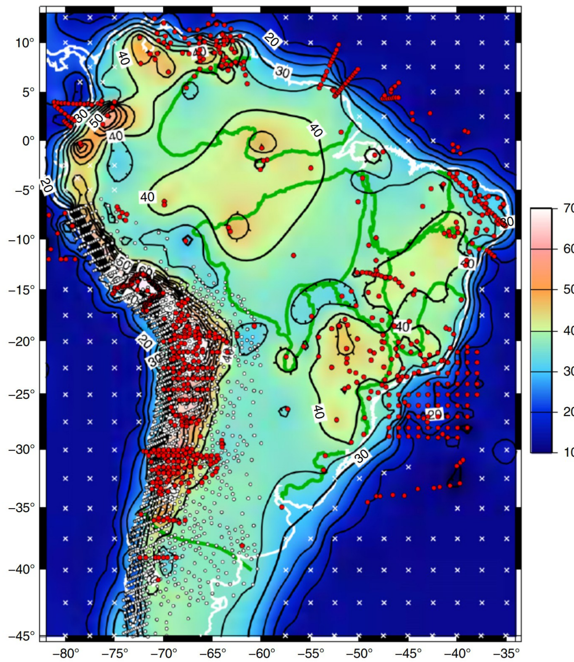

Figure 6: Crustal thickness of South America from seismics. Note that the ancient cratons outlined in green show no relationship to the crustal depths. The dots are seismic receiver locations.

Seismic, gravity and magnetic maps of South America.

The geological cross section of the Amazon only shows the top layers down to the bedrock as determined by local seismic maps and oil wells. Data for deeper features have been scarce. However, recent seismic work using many locations has been produced by *Assumpção et al.* (2013), and is shown in Figure 6. The crustal thickness pattern shows a distinct circle centered on the Amazon Basin with the thickest crust in the center. The crustal thickness is unrelated to the oldest cratons making up northern South America. They are outlined in green in Figure 6. It would normally be expected that the oldest cratons would be the thickest part of the continent, but they are not in the Amazon.

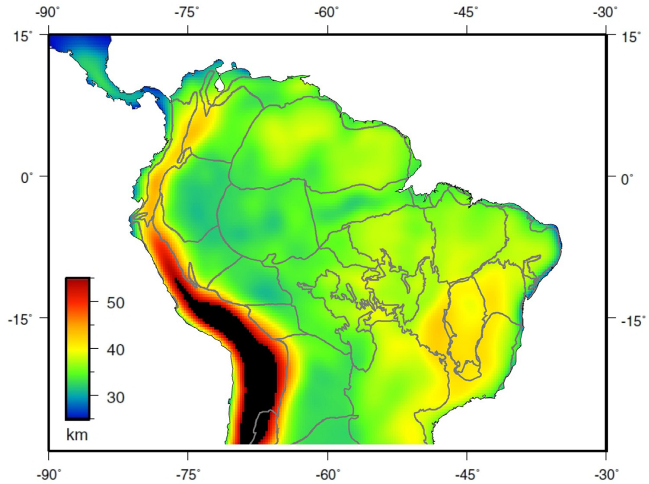

Figure 7: Crustal Thickness of South America based on gravity measurements. Note that the depths calculated by gravity have little relationship to the calculations from seismics for the Amazon Basin. Gravity calculated crustal depths do match seismic calculated crustal depths in areas outside of the Amazon Basin.

Figure 7 (*Van der Meijde et al.,* 2013) shows crustal thickness / Moho depths calculated from gravity data. This map is dramatically different than the seismic based crustal thickness map of Figure 6. Here the old cratons show up as thicker areas. The ring shape of the Amazon still shows. It is possible that this map relates to the density variations in the crust more than to the thickness of the crust or lithosphere. In Figure 7 the crust is thin in the center and to the west, and the Moho is higher under the center of the Amazon than around it.

Tassara et al. (2007) show the effective elastic thickness in Figure 8. There is a significantly thicker area in the central part of the Amazon Basin, but the thickest area is south-eastward of the center of the Amazon Basin. A massive impact forming the Amazon Basin would effect the entire lithosphere, not just the crust. If the thicker area relates to an impact, it ideally would be in the center of the basin, but in this case, the continent has moved westward for millions of years since the impact. The shift to the southeast may relate to the motion of the continent, but this needs to be studied further.

Larger craters usually have gravity anomalies outlining the crater (*Batista-Rodrıguez et al.,* 2013). The Amazon has moved 5000 km west since the impact occurred due to Plate Tectonic drift, and the lithosphere is expected to have changed significantly. Yet a circular gravity pattern shows in detailed gravity maps. Figure 9 shows the bouguer gravity map of Brazil

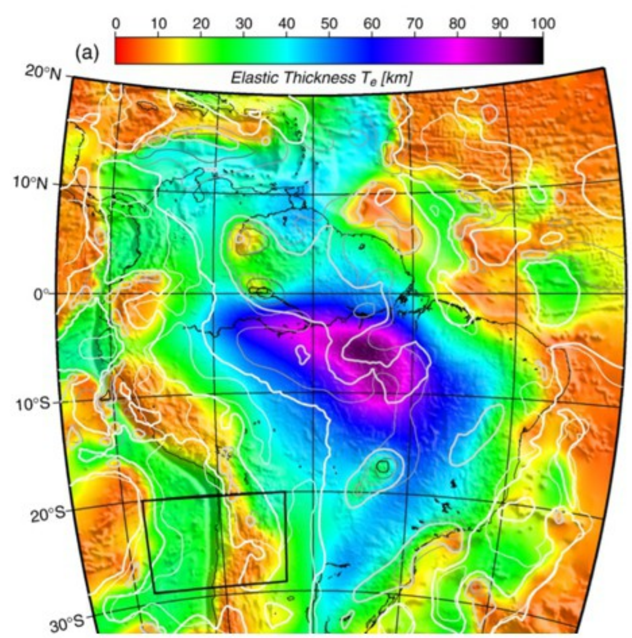

Figure 8: Bouguer anomaly coherence map of effective elastic thickness.

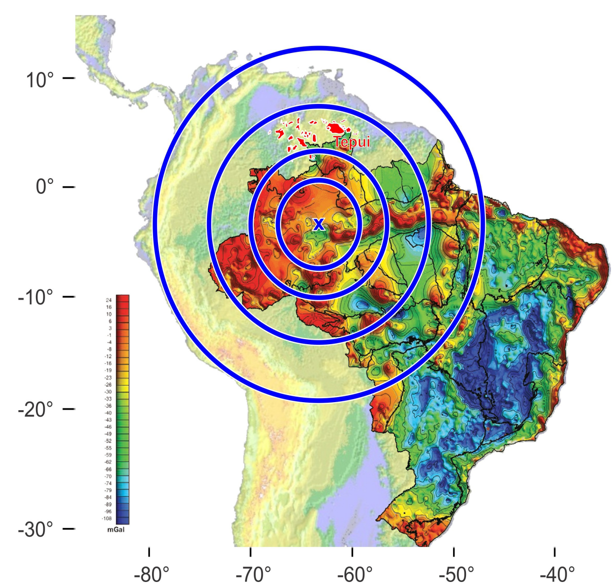

Figure 9: Bouguer gravity anomaly map of Brazil with the outline of the impact overlain. Note that outside of the impact, the pattern is dramatically different than the central area and that the outer ring shows clearly.

superimposed on South America, with the proposed multiring basin rings superimposed. This is much more detailed than other gravity maps of South America. It shows clear rings on the south east side, matching the proposed rings. It also shows a significant difference in patterns outside of the proposed impact area's rings compared to inside the rings.

Figure 10 shows the northern portion of South America in the Magnetic Anomaly Map of the World with the proposed rings of the impact superimposed. The pattern is circular, but it is not a series of concentric circles, which would allow for a simple interpretation. However, it does show a significantly different pattern in the area covered by the rings compared to the area outside of the rings. The outermost ring zone has more negative nano-Tesla values than the rest of South America. The pattern extends into the Atlantic Ocean on the north-eastern part of the proposed ring area, fully completing the circle.

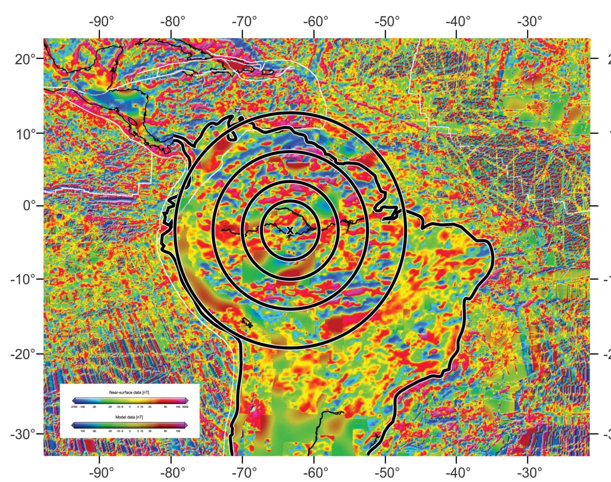

Figure 10: Magnetic Anomaly Map with impact rings shown. There is a clear circular pattern in the anomaly - the zone covered by the rings is significantly different than the rest of South America.

Shock metamorphic evidence in the Amazon.

The majority of accepted craters on Earth have been identified with shock metamorphic evidence. *French and Koeberl's* (2010) work on identifying craters is a good reference on what is desired to prove a feature is a crater. However, their work focuses on asteroid and meteorite impact structures which relates to much smaller impacts than the Amazon Basin. Most impacts on Earth are from asteroids, which hit at speeds from 11.2 to 25 km/sec. All presently accepted craters are from asteroids and meteorites (*Spray,* 2014), with no evidence of comet impact events found at all until 2013 (*Kramersa et al,* 2013). Asteroids are rarely more than 10 km in diameter, and the vast majority are much smaller. The majority of short period (less than 200 years) comets are from the Kuiper Belt, and there are over 130,000 comets in the Kuiper Belt that are greater than 100 km in diameter (*Petit et al.,* 2011). Larger craters will generally be caused by comets (*Shoemaker et al.,* 1990), which are much faster and less dense objects than asteroids. This means that the identifying features of such craters will be different. A massive comet impactor provides a good explanation of the Amazon's features as listed above, but it may not be possible to find standard shock metamorphic evidence.

If the impact caused the formation of any standard shock metamorphic evidence, there would be significant challenges in finding such features: The majority of the Amazon is buried under one kilometer of sediments, and there are no outcrops of the layers of basalt or rock below the 1 km thick layer of more recent sediments. The west coast is compressed and distorted by the Andes Mountains formation. The north and east edges are under the Atlantic Ocean. The south is largely jungle and difficult to access.

However, it is probable that there is no standard shock metamorphic evidence to find. An impact at 72 km/sec is a dramatically different event than a much slower one. Such impacts may lead to penetration impacts in which all of the shocked material is driven deep in front of the comet, or possibly rebound effects in which case most of the shocked material will be tossed back into space. A significant part of the ejecta will have escape velocity and not remain in the crater to be examined.

Calculating the size of the impactor and the expected fireball of such an impact.

Using the "Earth Impacts Effects Calculator" (*Marcus et al.,* 2010), one can easily calculate the

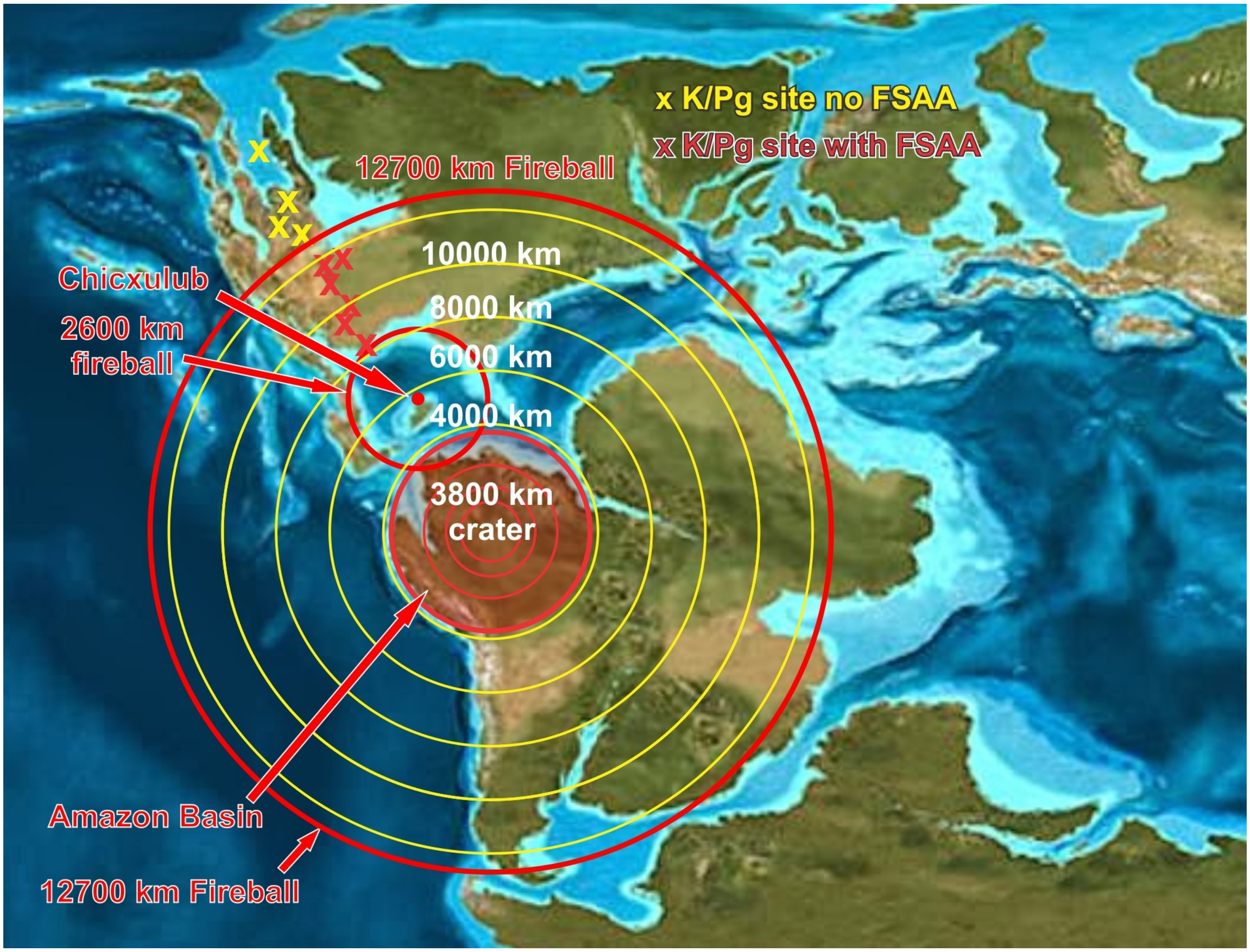

Figure 11: A 12,700 km diameter fireball (half of the planet) can be expected for a 370 km comet impact. Extent of expected fireball is superimposed on a Jurassic (about 150 Ma) paleo-reconstruction of Earth. The size of the fireball is shown compared to Chicxulub's 2,600 km diameter fireball as a reference of scale, and the Fern Spore anomaly for the K/T boundary layer is shown to help indicate how vast the fire damage would have been for the impact.

best fit of an object impacting the Earth required to fit the features of the Amazon. The Amazon crater is estimated to have been originally be 3800 km diameter, with a depth of 4 km.

For an asteroid, the "Earth Impacts Effects Calculator" calculates that to form the Amazon crater would require an object 515 km in diameter of density 2000 kg/m^3 hitting the Earth at 20 km/sec. At 3000 kg/m^3, at a speed of 22 km/sec (near the maximum possible impact speed of an asteroid), this would bring the asteroid size down to 430 km in diameter. For an asteroid to be the impactor, it needs to be over 400 km in diameter. At present, of the millions of known asteroids, only 4 are over 400 km in diameter. Therefore it is unlikely that such an asteroid impact occurred. Also, the Earth Impacts Effects Calculator predicts a melt zone more than 100 km thick for Asteroid impacts, and instead of a deep melt zone, it predicts a sea of melted basalt on the surface for a comet impact. On Earth, a 100 km melt zone is hard to interpret as such a melt zone would merge with the mantle. It would be difficult to predict how it would appear after millions of years of continental movement, but it would probably not look like layers of sediments. The Amazon Basin does not have an extensive, deep melt zone, which also indicates that it is not an asteroid impact.

Comets range greatly in size and as discussed previously, there is a significantly higher probability of a 400 km diameter size comet occurring than such a large asteroid. Due to orbital mechanics, comets from outside of Jupiter's orbit falling towards the Sun will pass Earth at speeds up to 75 km/sec. Using 72 km/sec as the proposed speed, with an impact angle of 70 – 90 degrees and a density of 800 kg/m^3, the comet impactor size works out to be 370 km diameter for the best fit. The Impacts Effects Calculator calculates a depth of 3.5 km for a crater diameter of 3800 km. And it calculates a fireball ignition radius of 11,200 km. The Earth Impacts Effects Calculator takes into account the height of the fireball and the curvature of Earth, but the 11,200 km radius / 22,400 km diameter it calculates is still too large as the diameter of Earth is only 12,700 km and a line of sight from the fireball can not wrap around the planet. This gives a maximum fireball diameter equal to the Earth's diameter or 12,700 km.

The calculated crater and fireball are shown in Figure 11, on a paleo-reconstruction of the world about 150 Ma. This time is presented as 200 Ma to 150 Ma is the most likely age of the Triassic Basalt layers, which should be the age of the impact.

Figure 11 gives a presentation of the extent of a firestorm expected for the event. In this prediction, all of South America, Africa and the southern half of North America are burned by the fireball directly. Asia, Antarctica and Australia are outside of the fireball radius, so some life would survive. A significant part of the Pacific Ocean would be vaporized, dramatically affecting all ocean life.

North America has a "Fern Spore Abundance Anomaly" (*Fleming and Nichols,* 1990) shown as red Xs in Figure 11. The anomaly is associated with the K/T boundary layer, related to widespread death and burning of forests from heat from the Chicxulub impact. It is apparent that everything burned within that range, so that no trees or flowers survived. A recent study by *Robertson et al.* (2013) re-confirms the wide extent of the firestorm. There is an absence of pollen and seeds in the K/T boundary layer, but there are fern spores. Ferns spread over burned territory and grow much faster than trees and other plants. There is also a presence of burnt material in the layer, confirming that either a firestorm from falling hot ejecta or radiation from the fire ball ignited all plant life in the area. Similar fern spore anomalies exist for the Triassic extinctions.

Two recent studies (*Goldin & Melosh,* 2009) and (*Adair,* 2010) rule out a firestorm from ejecta. If ejecta falling back does not create enough heat to burn forests, then the fern spore anomaly radius should be mainly from radiation in line of sight of the fireball and associated spreading of fires. The proposed Amazon impact would create a fireball similar in extent to what is seen in the K/T fern spore anomaly. With the Chicxulub impact causing firestorm damage well past its fireball radius, it is to be expected that most of the planet would have been burnt by the firestorms from an impact the size of the Amazon. Subsequent studies should seek evidence of such a world wide anomaly.

Extinction events and the Amazon Basin.

Zahnle and Sleep (1996) calculated that an impact by a body over 500 km diameter would vaporize the whole ocean and thereby wipe out life on Earth. By their calculations, a 370 km diameter comet impact would not vaporize the entire ocean, but it would vaporize a significant portion. Enough of the oceans should remain to allow some survivors, but most life would die. So between the fireball and firestorms, and the vaporizing of a significant part of the oceans, the proposed impact must be associated with a major extinction event.

The two most likely extinction events associated with the Amazon, based on the age of the basalt layers, would be the Permian–Triassic extinction event at 250 Ma, and the Triassic–Jurassic extinction event at 200 Ma.

The Permian-Triassic event was the most extreme, killing almost everything and taking millions of years to recover (*Chen,* 2012). At present there is not an impact event associated with it, although there are some reports that indicate that an impact may be the cause (*Kamo et al.* 2003). The Triassic-Jurassic extinction event is also a possible candidate since it too has indications of an impact associated with it, including a strong Iridium anomaly (*Olsen et al.,* 2002).

Chicxulub is well associated with the K/T boundary layer and extinction event (*Schulte et al.,* 2010). However, most agree that Chicxulub is considered to be too small to have caused the extinction in itself (*Kring,* 2007; *Keller,* 2014). *Keller* **(**2014) discusses how the K/T extinction event may have been due to many factors, of which Chicxulub would be part, but global warming or volcanic fumes or other factors were the main killers. For an impact the size of the Amazon, extenuating factors are not necessary - the impact itself would have been sufficient to cause the extinction. If the Basalt layer is younger than presently expected, then the extinction event for the Amazon may be the end of the Cretaceous. Many of the Amazon's factors seem to relate well to the K/T extinction event.

World wide boundary layer for the Amazon impact.

One of the reasons that Chicxulub is convincingly attributed with the K/T boundary layer is the calculation that the size of the impacting asteroid should have been about 10 km in diameter, based on the thickness of the boundary layer and the amount of iridium in the boundary layer (*Alvarez,* 1980). Therefore it seems reasonable to assume that a 370 km diameter comet should leave a much larger boundary layer. Alvarez used the factor from the Krakatoa eruption (0.22) as the amount of asteroid material that would stay in the atmosphere. When a comet hits at 72 km/sec, the vast majority of the comet material will either be buried deep into the Earth or ejected at speeds in excess of the escape velocity, and be lost to space. Instead of nearly ¼ of the comet remaining in the atmosphere after the impact, very little would remain.

Jeffers et al. (2001) showed that the Iridium deposited by a higher speed comet is dramatically less than from a low speed asteroid:

"In fact, provided that the body is in the multi-kilometre size range, the fraction of the mass of the impactor deposited is a sharply decreasing function of the impactor velocity. … above 25 km/sec essentially none of the impactor mass is retained. This means that the initial mass required to explain any given Iridium anomaly increases rapidly with increasing impact velocity above 20 km/sec."

The worldwide boundary layer thickness and the iridium concentration numbers due to the proposed Amazon impact may be similar to the K/T boundary layer, or smaller.

Discussion

Shoemaker has often stated that larger impacts will tend to be comet impacts since most asteroids are small (*Shoemaker et al.,* 1990; *Shoemaker,* 1998). At present we have less than 200 confirmed impact craters on Earth, and all of them are proposed to be from asteroids (*Spray,* 2014). No comet impacts have been recognized on Earth to date. The modern criteria for defining impact craters is based on impacts by low speed, high density asteroids. However, it is to be expected that high speed, low density comet impacts will have different defining features. There are many other massive features on Earth that are probably comet impact features (*Burgener,* 2013), so the Amazon Basin is not the only one of this order of magnitude size. The other potential impact features are typically difficult to explain with Plate Tectonics, are geologically stable as recognized by having minimal earthquakes, and have features in common that fit an impact origin. The Amazon Basin is the focus of this article because it is one of the largest potential impact areas that has enough evidence to show clearly,

As there are few studies of massive high speed impacts, there needs to be some guessing at what happens when such an impact occurs. They will be dramatically different in nature than asteroid impacts. When an asteroid hits the Earth, the interaction is of a small asteroid of rocky or metallic material hitting a very much larger rocky

Earth with a crust much thicker than the diameter of the asteroid. The usual result is an explosion, with the shock waves causing the cratering and most effects of the event. However, shock waves travel at speeds related to the material being impacted and to the incoming speed of the object. At 70 km/sec, a comet is traveling faster than the shock wave speed in the crust. This will lead to phenomenon not yet studied, such as the potential that the comet will penetrate the Earth rather than exploding on contact. This would leave a deep hole – essentially removing most of the impacted crust and driving it into the mantle, but little in the way of standard crater morphology. Alternatively, as the comet impacts, the leading edge will compress and slow and send shock waves back to the trailing edge, effectively causing a rebound or partial reflection of the incoming comet. If such happened, then a large comet could hit the Earth, cause it to bend and flex, send ripples out like a drop into water, and then be largely ejected back into space. The Earth would flex up and down, but the layers of sediments and rock would remain essentially in the same pattern as before. Such a shock wave event would likely loosen the layers of sediments allowing an easy path for intrusions between the layers, and heat the mantle leading to massive basalt intrusions and surface floods or Traps.

According to *Price* (2001) an impact this large would lead to momentum being passed into the crust, initiating plate movements. The Bouguer anomaly coherence map of Figure 8 shows a major anomaly in crustal elastic thickness centered to the south east of the center of the Amazon, but looking stretched more to the west than to the east. Over the center of the Bouguer anomaly the seismic crustal thickness is only 35 - 40 km thick as shown in Figure 6, but the elastic thickness of the lithosphere is about 100 km thick. If this anomaly is associated with a deep effect from an Amazon impact, then it would appear that the anomaly in the mantle has been moving more slowly than the crust. If the mantle is dragging the crust, then the mantle should be moving faster than the crust and the deep anomaly should be west of the center of the Amazon Basin. This implies that the crust is moving the mantle, not that the mantle is moving the crust, which fits the theory presented by *Price* (2001). It would be interesting to look at other possible comet impact sites to see if the crust is moving differently than the mantle at those sites. One such site is the western side of the Black Sea where the crust is moving westward against the flow of the African and European continents which are moving northeast (*Burgener* 2013).

The Amazon has similar topographic patterns to the topography of the Lunar Orientale impact Basin. The central basalt sea and vast area of intermixed melted rock and sediments seen in the geological cross section match what is expected for an impact basin (*Grieve,* 1980). The only Tectonic event that can be related to the Amazon basalt layers is the rifting in the Atlantic. It is unlikely that intrusions throughout the Amazon Basin far from the rifting can be caused by it. Without rifting in the Amazon itself, or uplifts, plate interactions, hot spots or any other activity in the Amazon leading to the intrusions, the present understanding of Plate Tectonic processes does not provide a useful explanation. As mentioned above, geologists have recognized that some significant event in the Amazon happened in the Triassic or Jurassic eras, but they have not been able to determine what caused it. There are significant anomalies in the crustal thickness, gravity and magnetic measurements, which indicates something unusual. The anomalies can be explained with an impact origin followed by millions of years of continental drift.

The greatest challenge in considering the Amazon Basin as an impact is that it is too large to fit the present understanding of frequency and size of impacts on Earth. One objection to *Keller et al.'s* (2003) theories that there was more than one impact at the end of the Cretaceous was the lack of a second crater (*Schulte et al.,* 2010). *Price* (2001) proposed that Plate Tectonics was driven by impact events, but his work was dismissed as unbelievable since his theory required craters over 1000 km in diameter, and such craters have not yet been found on Earth. The recent impacts on Jupiter of Comet Shoemaker–Levy 9 in 1994, and of an asteroid in 2009, imply that such events are more frequent than previously expected, leading to the conclusion that there should be some comet impacts on Earth. Considering the Amazon Basin as an impact will enable scientists to recognize many other comet impacts as well.

Conclusions

The Amazon Basin features can be calculated as the result of an impact by a comet of 370 km diameter, with an impact speed of 72 km/sec, a density of 800 kg/m3, and an impact angle of 70°-90°, impacting into sedimentary or crystalline surface rock.

The hypothesis that the Amazon Basin is an impact structure was based on the observed circular shapes seen in recent NASA topographic maps. This led to the prediction that the geology of the Amazon should match that of Orientale, including: a basalt sea in the center area, massive areas of shattered / fall back breccia equivalent in the central areas, uplifted areas in the rings matching the uplifted areas in Orientale, and gravity anomalies. In addition, on Earth there should be substantial fossil free, clean sediments lying on top of the basalt sea. All of these predicted features have been found to be present. Considerations of present Plate Tectonic explanations of these features does not explain them, but an impact event fits them all.

The aim of this paper is to suggest that the Amazon makes sense to study as an impact, with the consideration that it is probably the cause of one of the major extinction events. Obtaining proof is desirable, but may not be possible, as the defining features will be dramatically different than present criteria for asteroid impacts. Reviews of the drill cores and more drilling in the center of the basin are necessary. A reevaluation of the ages of the Amazon sediments and older formations in the Amazon with a impact considered as a factor in their formations is also needed.

More studies should be done on what happens when comets of low density hit the Earth. At present only a very few such studies exist and none have considered 300 – 400 km diameter, high speed, comet impacts on Earth.

A 3800 km diameter crater can not exist as the only large impact crater on Earth, with all others less than 300 km diameter. Other large features on Earth that do not fit Plate Tectonic explanations should also be considered as impact features. With the Amazon as an example of large impacts, it should be possible to recognize many more. Associated properties such as the stability of an area and the difficulty of explaining features with Plate Tectonics can be used to recognize features worth reviewing as impacts.

Considering the Amazon Basin as an impact crater dramatically changes the present understanding of how large impacts and craters can be and how significant their effect on the evolution of the continents can be. Massive impacts like the Amazon Basin are clearly able to reshape the continents. At present, Plate Tectonics is the defining theory of how all features were formed on Earth. When there is only one mechanism to explain all features on Earth, then everything must be interpreted through that theory's assumptions. Adding massive impacts to the Earth's history allows for new interpretations of many features and understanding of features that Plate Tectonics has not been able to explain. It may be determined that impact events are as significant in the formation of the continents as Plate Tectonics.

The impact craters presently recognized on Earth have been studied extensively to prove that they are craters. Similar work will be required to positively confirm comet impact craters. It is undesirable to limit the world view to the present criteria of proving craters with features only shown to apply to asteroid impacts. While the Amazon needs to be studied to see if present proofs apply, it also follows that the whole planet should be reviewed with the concept that massive impacts happen, that life survives them, that the features of Earth have changed because of them and the changes are significant, noticeable, and recognizable with different criteria than presently used to identify craters.

FIGURE CREDITS

Figure 1: NASA 2009 , GDEM image, http://www.nasa.gov/topics/earth/features/20090629.html . Accessed December 01, 2011.

Figure 2: NASA 2010. A lunar topographic map showing the Orientale basin from the Lunar Reconnaissance Orbiter compared to the GDEM image of the Amazon.

Figure 3: Topographic cross sections of Orientale and Amazon basins. Orientale data from *Potter et al.* (2012). and NASA JPL (2010). Amazon data from Google Earth.

Figure 4: Cross section of the center of the Amazon Basin. Adapted from *Marchi et al*. (1999) with additions based on *Milani and Zalán* (1999); *Gonzaga et al*. (2000)

Figure 5: USGS: Seismicty of South America, 1990 – 2000

Figure 6: Crustal thickness map based on seismic analysis. *Assumpção et al.* (2013)

Figure 7: Moho map of South America from *Van der Meijde et al.*, (2013).

Figure 8: Bouguer gravity anomaly and elastic thickness maps. *Tassara et al.*, (2007)

Figure 9: Bouguer Gravity Map, *Bizzi and Vidotti* (2003), Page 349.

Figure 10: Magnetic Anomaly Map of northern South America with proposed impact rings superimposed. *Korhonen et al.,* 2007.

Figure 11: Late Jurassic (150 My) PaleoMap by Ron Blakey, Colorado Plateau Geosystems, Inc., cpgeosystems.com

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