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Investigation of Potential Factors on South Atlantic Magnetic Anomaly

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Abstract

The first part of this investigation analyzes the deep earthquake occurrences in Nazca subducting under South America. The depth taken is to get information about possible influences from the unknown materials and formations under the crust. The results revealed the presence of malleable material, which is unbreakable and, therefore, unable to trigger earthquakes. The structure of those elements is diamagnetic, attracting ionized particles from the Van Allen belt region in the ionosphere. The charged particles travel towards Earth's surface, enhanced during the geomagnetic storms. The South Atlantic Magnetic Anomaly (SAMA) found that the deformation suffered by the anomaly moving from South Africa to South America is, possibly due to a bulge of unknown flexible material buried underneath the oceanic and continental crust. The continental part is strengthening in weakness because the background also has a high amount of diamagnetic material in this region, and it would not happen over the Atlantic Ocean, where part of the deformation is placed.

Keywords

Ultra-Deep Earthquakes (UDQ), Diamagnetism, South Atlantic Magnetic Anomaly (SAMA)

1. Introduction

Earth creates a dipolar, an almost spherical magnetic field, and the Sun sends electromagnetic radiation. These ionized particles affect the Earth's magnetosphere. Earth's magnetic shield protects from the sun's radiation; however, it allows the entrance and trapping of the ionized energized particles deposited in different atmospheric layers. The Earth's magnetized field varies from 30,000 nT at the Equator to 50,000 nT at the poles. The South Atlantic Magnetic Anomaly

(SAMA) is a region around the Earth located in the Southern Hemisphere centered in South America over Brazil with a low magnetic field. It is understood that this weak magnetic field expanded over time and moved westward; it is linked with the geomagnetic field of Earth's distribution. Our former paper [1] found that the earthquake activity enhanced in this area during the solar minima 2006-2010.

We also found that most swarm events happened in the fall, summer/fall, and fall/winter between 2003 and 2010. It means the swarm events tended to enhance during fall and the transitions from summer to winter. Those results agree with [2]; in 2006, events occurred in two distinct periods, Fall/Winter, and Winter, totaling 1118 events; it agrees with the author that there is maximum solar radiation during the solar minima years. The location had coordinates −20.20N, −39.89S, −69.43E, −74.70W on the entire Chile coast, and the earthquakes had a maximum depth of 213 km. The South Atlantic Anomaly (SAMA) is a low magnetic field area that spans from east of Africa over the Atlantic Ocean and is centered on South America. This weak magnetic field region has expanded over time and moved westward; it is linked with the geomagnetic field distribution. A lower magnetic intensity characterizes the SAMA, where the Van Allen inner radiation belts are closest to the Earth's surface. The movement of this anomaly over South America was found to be 0.06 N/yr. and 0.28 W/yr [3].

The energetic particles captured by the geomagnetic field can reach lower altitudes, forming a high radiation region. The SAMA, when compared to other locations, indicates a more considerable number of energetic particles. The eccentric dipole is currently offset from Earth's center by about 550 km in a path of approximately 22˚N, 140˚E. This distance is steadily increasing, and the location of the eccentric dipole center is drifting westward and slightly northward. In the antipodal route, which corresponds to the location of the SAMA, the drift shells get closer to the Earth's surface and move mainly westward and slightly southward. The SAMA is almost centered over Sao Paulo (Brazil) [4].

Thermospheric density directly correlates with the Sun's activity due to heating driven by solar radiation [5]. It shows the exact time evolution of the solar cycle. The thickness of particles increases at high altitudes as the atmosphere expands during solar maxima, which leads to more frequent collisions between the trapped energetic protons and atmospheric atoms. The trapped protons are depleted during the higher activity of the solar cycles.

Shaeffer *et al.* [6] showed that the particle hit intensity in the region was anti-correlated with the solar activity. Suppose there are years of high solar activity. In that case, the radiation intensity is lower, while the radiation's power is more potent during quiet solar years. Their data implied that the strong solar wind from the Sun sweeps out more low-energy galactic cosmic rays while the Sun's smooth winds let more in. The peak of SAMA intensity occurs later than the last year of the solar minimum. Their data connected the sunspot number minimum occurring in 2009 with the rise of SAMA intensity. According to them, geomagnetic storms charge particles precipitated along the magnetic field lines in the auroral zone and induce photometer counters. The SAMA does not remain in a fixed geographic location; instead, it tends to drift mostly west-northeast [7]. McCracken *et al.* studied the effects of solar activity on Earth from 2004 to 2016, which showed that particle hit intensity was anti-correlated with solar events. The authors compared three former minimums named the three Grand Minima, the Spoerer, Maunder, and Dalton Minima, the long sunspot minimum of 2006-2009. The heliospheric magnetic field strength (3.9 nT) observed in 2009 was much more significant than the peak values of 2.0 - 2.9 nT found for the three Grand Minima. Former authors attributed the SAMA evolution particle flux to two main effects: 1) the secular variation of Earth's core magnetic field and 2) the modulation of the density of the inner radiation belts during the solar cycle, as a function of the value which characterizes the drift shell where charged particles are trapped [8] [9]. The unusual spatial characteristics of the area indicate that it is essential to understanding disturbances caused by the earthquake's evolution [10].

2. Behavior of Deep-Depth Earthquakes under South Atlantic Magnetic Anomaly

This paper's preliminary aim is to investigate a subduction zone in South America caused by the subduction of the Nazca plate in the area. Our former documents in the subject [11] [12] [13] [14] [15] found some facts in the area as few tremors at depths 300 - 500 km into the coordinates chosen as below the South Atlantic Magnetic Anomaly (SAMA). **Figure 1** shows the Andean orogen, with three volcanos active in distinct zones. There are also four basins; basins are depressions in the Earth's surface. Their shapes are like bowls with sides higher than the bottom. Some are filled with water; others are empty. The basins in the area are Solimoes Basin, Parnaiba Basin, Parana Basin, and Chao-Parana Basin. Shallower earthquakes are rare in this area, and anthropogenic actions trigger some observed ones. The picture also displays the Patagonia domain. It shows two other tectonics features, the transform fault in northern Guiana and the Chile—Peru trench. The Nazca plate is an oceanic tectonic plate in the Eastern Pacific Ocean basin off the west coast of South America. The ongoing subduction along the Peru-Chile under the South American plate is mainly responsible for the Andean orogeny. The movement of the Nazca plate over several hot spots has created some volcanic islands and east-west running seamount chains that subduct under South America with a speed of 6.7 cm/year. South America moves in the opposite direction with 3 cm/year.

The data used in this paper are the following coordinates: 11.86N, −39.89S, −37.79E, −74.70W; the period for the maps is 1993-2023, and the catalog used is usgs.gov; with those data, we constructed the maps and different depths. For "shallow" earthquakes (40 - 300 km), the magnitudes were 4.5 M or higher. The

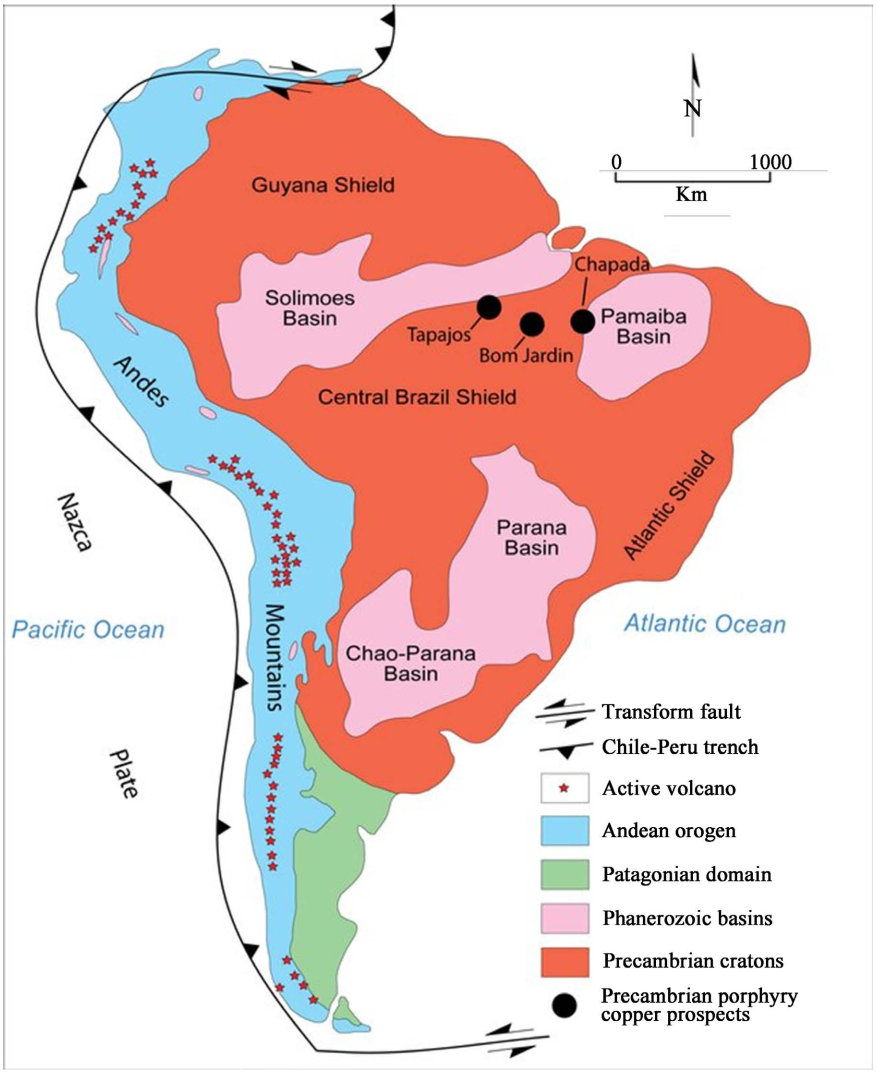

Figure 1. The map shows the tectonics of South America, the Nazca position subduction, and the location of active volcanoes (Map by Donald A. Singer).

temporal range is larger since plotting all the small magnitudes in the figure would be impossible. Next, in deeper depths (300 - 700 km), earthquake magnitudes taken are 2.5 M. Our definition of "shallow" quakes here is relative.

Figure 2 shows how earthquakes vary below the area of the South Atlantic anomaly in 40 - 150 km depths with magnitudes ≥ 4.5 M. The depths chosen are to avoid any anthropogenic interference that triggers earthquakes with shallower depths. The time interval is 1993-2023 to get as many occurrences updated as possible, to be precise, in some places. The figure displays a path (pink) where there are no quake occurrences in the entire period. Observe in **Figure 2** a path coming from the North to the South where no quakes happen at any time. If a slab underground sinks, the superior slab reaches the shallow depths in green (40 - 150 km), and then a slip slab hits the continent much deeper in blue (150 - 300 km). A second slab sinking into the platform will encounter breakable material only below ≥500 km into the continent. There is a possibility that several

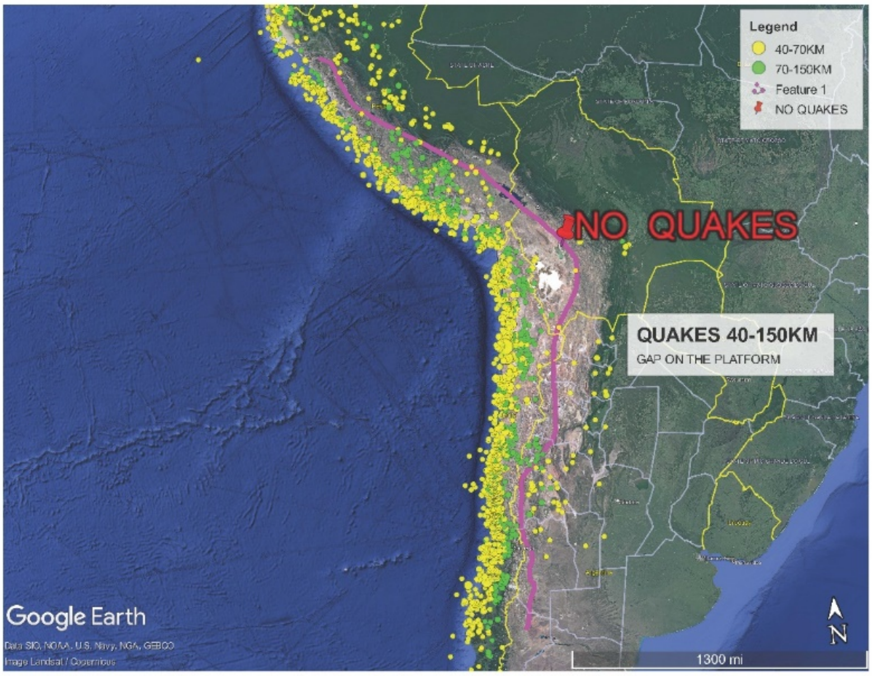

Figure 2. Showing the area with quake depth occurrences of 40 - 70 km (yellow). Observe several gaps in the map with no earthquake occurrences in the entire period. It also shows the 70 - 150 (green) km quakes on the platform; below this depth, there are no quakes inside the continent.

other regions are built of malleable material between 300 - 500 km into the platform. This figure shows a path where shallower quakes are happening near the boundary, and the ones 40 - 150 km are disposed in a stripe after the shallower ones. There is also a long stripe without tremors; after the shallow quakes, they will occur again. The pink path works as a wall for deeper events.

Figure 3 shows a scenario when the depths are 70 - 150 km and 150 - 300 km, the pink line showing a pattern free of earthquakes deeper and with rare occasions that the shallow depths (until 150 km) triggered. Observe the South American elbow, displaying the intense activity for the deeper depths and fewer below or above this area.

The movement of the Nazca plate being drowned below the continent indicates that Nazca collisions are pushing hard against the South American plate, creating more friction between the two plates until a depth of 300 km. At this point, we will discuss that deep earthquakes are observed in the exact location; some places have no occurrences. There are gaps in the map, indicating that the structure in the region is made of unbreakable elements.

Figure 4 shows the earthquake events with depths of 300 - 500 km, which only happened in a specific area in Bolivia, a location defined for a high occurrence of earthquakes in most depths analyzed in this paper. The 300 - 500 km earthquakes are scarce even in the South American elbow region. The Nazca plate collision with the Southern platform may be divided into two slabs; a superior slab hit the South American continent. They will trigger the observed quakes in

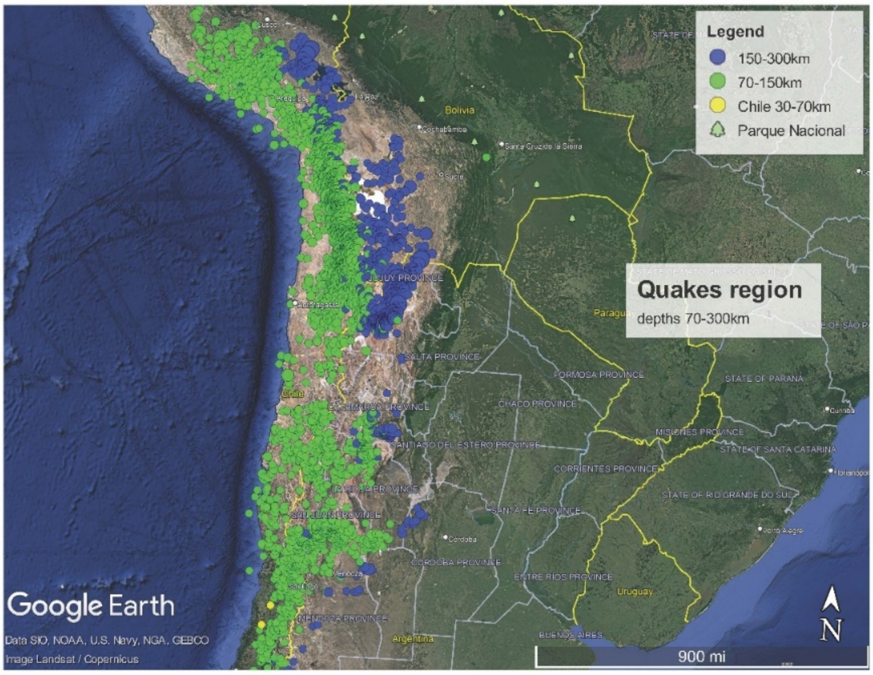

Figure 3. Earthquakes in three deep-depth locations occur in parallel regions with exceptions marked on the map; the magnitude adopted is 4.5 M and shallower earthquakes with lower magnitudes are too many on the map. Shallower are green, and deeper (150 - 300 km) are blue.

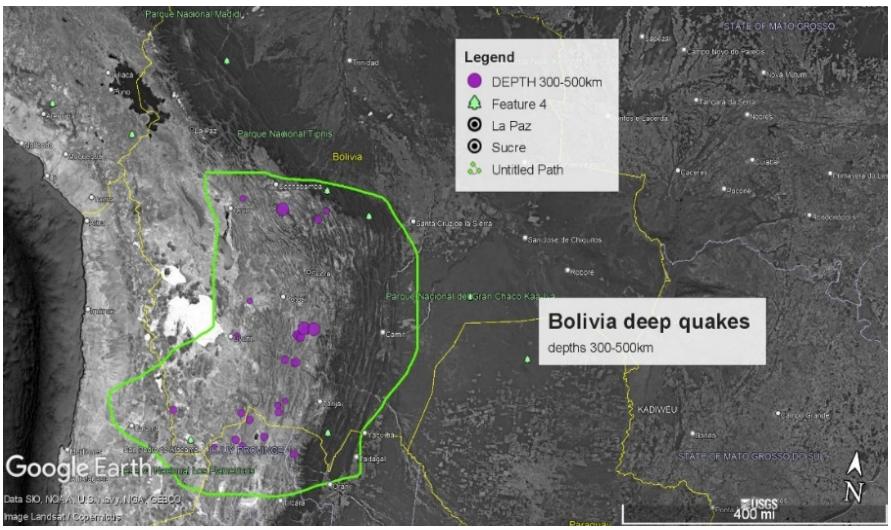

Figure 4. Showing the only area where the earthquakes happen, with a depth range of 300 - 500 km in South America magnitude ≥ 2.5 M.

the Nazca-South America border with 100 - 300 km depths. This slab does not meet any resistance against the subduction intrusion unless, in limited points with breakable material, all of them situated in Bolivia coinciding with the South American elbow.

The rare tremors have depths of 300 - 500 km in a narrow place, explaining that the movements that triggered earthquakes found a location in Bolivia with a reasonable amount of breakable material, which is the primary cause of events.

Finally, we searched for the events that took place in the South Atlantic Nazca plate for depths above ≥500 km, and surprisingly, they all happened deep inside the continent, as seen in **Figure 5**. In **Figure 5**, we see the paths of earthquakes ultra-deep earthquakes inside the continent. It indicates that shallower earthquakes mainly occur on the edges and inside the South American continent. Those ultra-deep quakes showed chaotic behavior and evidence of other internal mechanisms besides the Nazca-South America collision to consider.

Therefore, the description for the phenomena observed is that the Nazca plate is constructed by two different slabs, which we named a superior slab (SS) and an inferior slab (IS); the Nazca collided with the continental area, the superior part is stuck in the continent edge. The inferior part is still sinking and crashing with South America much deeper, with a gap between them not well understood; the evidence is that the earthquakes in deeper depths are inside the American Platform. Still, there are locations on the platform with no earthquakes, meaning that the material deposited has a different composition in those depths (**Figure 5**).

Those gaps on the almost straight trajectory from Amazon State to Patagonia region showed 2 points of accumulated occurrences as extreme Northern and Southern locations.

Figure 5 shows the ultra-deep earthquake variation far from the boundary of the South American plate. There are places with a high concentration of tremors and gaps in the path with no occurrences, as shown. Those regions are filled with

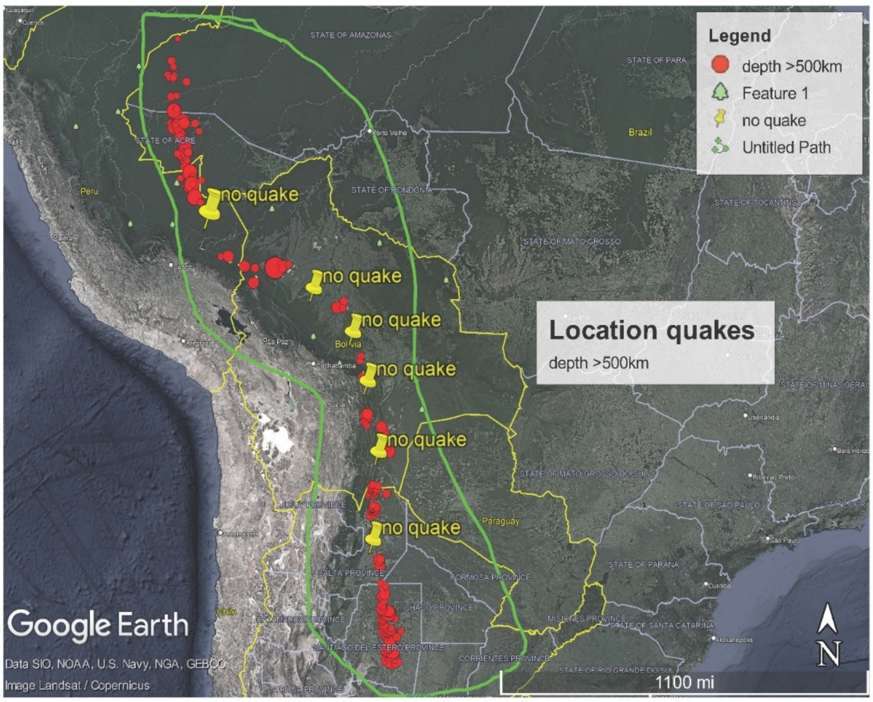

Figure 5. Path of ultra-deep earthquakes in the South American continent (The northern place is Peru—the southern location is Argentina) magnitudes ≥ 2.5 M.

non-brittle material, making it impossible to cause tremors; it is also noticed there are no shallower earthquakes in this region, even though we tried to find out tremors more superficial.

The known material buried in the South American plate is copper, silver, gold, or molybdenum; all are not brittle but malleable and ductile; however, they are excellent materials for electric currents. We hypothesize that the depression in the middle of the continent platform is diamagnetic material unable to break or cause tremors, which also would mean a bulge of water between 100 km depth and 500 km into the cratons.

Two "shallower" strips, 40 - 100 km and 100 - 300 km deep, follow the coast. Below such depths, the events concentrated in a small region around Bolivia in the South America elbow. The deepest-depth earthquakes on the South America platform flow from Northern Peru to Patagonia. Those earthquakes happen below ≥ 500 km and present some regions lacking tremors; those gaps are indicated in different rock structures in such areas as malleable material. Several metals are malleable, and a possibility of a bulge of water all have the requirements to stop tremors. Therefore, we found an earthquake anomaly in this region's South America subduction zone, defined as the deepest depth reached by the Nazca second slab.

3. Evidence of Highly Diamagnetic Area upon Amazon Craton

In the first part of this study, it was found that deep and ultra-deep earthquakes are in specific tiers on the South American platform, as displayed in **Figures 2-5**. **Figure 2** shows earthquakes in the two shallower depths on the entire coast of South America where the Nazca is subducting. The events 170 - 300 km follow the same path; however, they presented some gaps in the trajectory, signifying different formations of rock and material in the region at the same depths. Gaps in the path of earthquakes mean the structure inside the lithosphere found something unable to break or trigger quakes.

The events at 300 - 500 km depths rarely happen (**Figure 5**), with most strikes on Bolivia-Argentina (west). Brittle material is present, and not all rocks are ductile [13].

Examining the stratigraphy in the Nazca-South America region, we find that Chile's coastal places have vast amounts of copper (**Figure 6**) [13]. Zinc is a bluish-white metal with a shiny surface. It is neither ductile nor malleable at room temperature; it is plastic capable of being hammered into thin sheets. However, zinc becomes somewhat malleable at temperatures above 100˚C (212˚F). Since no unpaired electrons are present in zinc's outermost orbital, it is diamagnetic. Compounds containing zinc are typically diamagnetic, except in cases where the ligand is radical. Therefore, the edge of the South American coast and the location of the Nazca collision are highly diamagnetic metals. There are indications that the entire Amazon craton hides enormous amounts of Copper (Cu), molybdenum (Mo), Gold (Au), and Silver (Ag), and vast quantities of copper and zinc

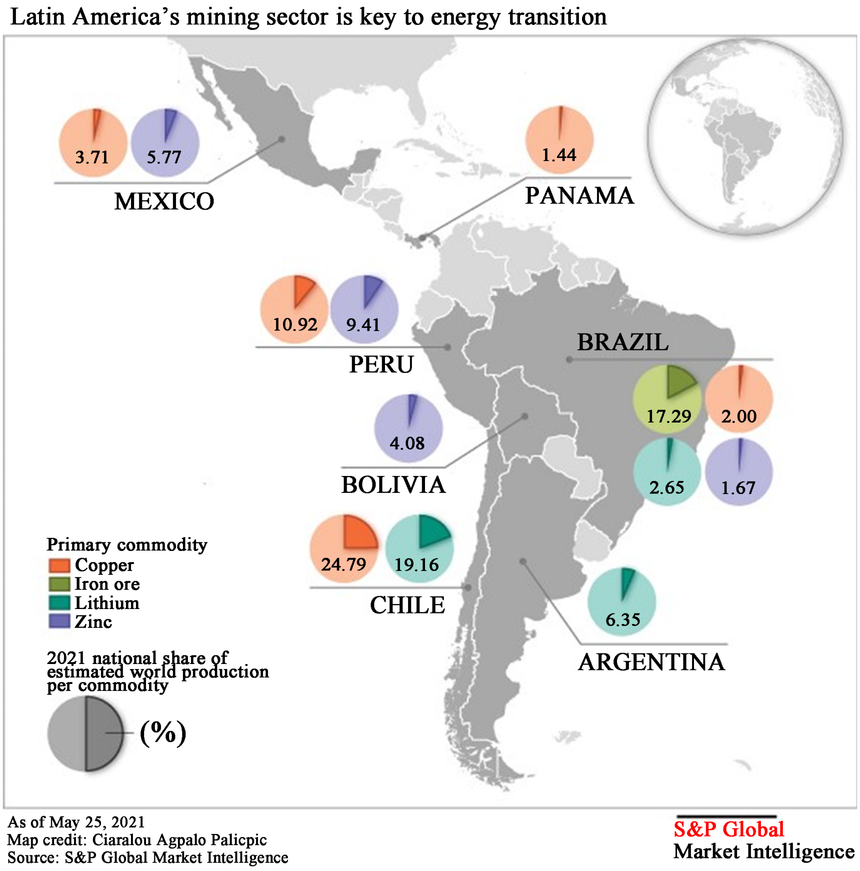

Figure 6. Copper and other minerals on the South American coast. Observe the enormous amounts of material that are non-breakable and diamagnetic [13].

have been discovered in the Andes Mountains located in South America. Such elements are ductile, which means the region rarely will trigger earthquakes [16]. All those materials have strong diamagnetism, which is the property of constituents repelled by a magnetic field; an applied magnetic field creates an induced magnetic field in them in the opposite direction, causing a repulsive force. We observed that earthquakes with depths 300 - 500 km occur only in the place known as South America Elbow in Bolivia. Below this depth, they only trigger a path into the continent in a long trajectory between Colombia and South Argentina. It would be paramount to the presence of magnetometers on the ground known as the Amazon craton. Unfortunately, it demands that each country fund some stations, which does not happen in Brazil, and many science programs and projects suffer a lack of money. People can get the information and analyze data sharing with partners worldwide. Therefore, we have compelling evidence that this path needs more investigation. The presence of those metals below the crust does not contribute to the tremors and yielding anomalies in a large zone. The deepest earthquakes observed in the region are defined by a long pattern from Colombia—over Brazil-Argentina for depths ≥ 500 km. Compared with other worldwide subduction zones, their behavior is abnormal. The standard subduction zone theories cannot explain it. They occur inside the plate, indicating an anomaly in South America in the lithosphere that remains of unknown source. It can be attributed to a bulge of fresh water trapped in deeper depths, probably located at the lower part of the craton but above the 500 km level. The mechanism in the area is that earthquakes are only possible in places with breakable rocks. Those elastic rock locations in this area are all below 500 km. Some factors may help in the circumstances, such as the Nazca slab position, the presence of non-breakable material, and the bulge of water into the craton.

4. Lightning and Electrical Phenomena Were Observed over the South American Region

In this section, we will connect the discovery in Figure 7; the connections between the buried water locations and the absence of tremors are coincident. Besides, the areas with no earthquakes are those with malleable material, as described in the last two paragraphs. Those places attract ionized and charged particles from the clouds and the Van Allen belts. Later, we are going to discuss this point. Figure 7 shows the global distribution of modern groundwater, with the highest cumulation worldwide observed in North Brazil. Our other paper found a location marked with an underground river in the Amazon craton. They concluded that this movement had to be from West to East, mimicking the mighty Amazon.

Cumulus nimbus clouds are composed of ice crystals, water droplets, supercooled water, and a mixture of them. It also contains large raindrops and, often, snow crystals, snowflakes, snow pellets, ice pellets, or hailstones. The dimensions of the base cumulus nimbus are found below 2 km. The top reaches higher than 10 km and sometimes gets 15 km. The middle portion is dark, with vertical currents exceeding 15 m/s. Turbulence is severe. It is most frequent for temperatures 0˚C and −2˚C.

Lightning is formed by electrostatic discharges through the atmosphere between two electrically charged regions, either in the atmosphere or the atmosphere and ground. Several mechanisms occur in clouds, the friction of wind and ice crystals becoming positive charges. The water is a diamagnetic material that can attract atmospheric ionized particles into the cloud in South America. Ionized particles will charge the clouds until maximum ionization and lightning occur; it can happen internally, between clouds, or from cloud to ground. Lightning is positive when attracted to the earth and negative when attracted to a positive cloud. It has been proved that 80% of discharges happen internally to clouds. The vertical winds and the different polarities in clouds made the discharge release. When a cloud is positively charged, it will be discharged to the ground. A vast, deep region in South America is covered by non-breakable material. Solid evidence indicates that the platform is filled with diamagnetic elements, creating an anomaly in the earthquake occurrences; it also performs magnetic anomalies on the ground. The water into cumulus nimbus clouds pushes ionized particles, charging the clouds and causing potent discharges in the region delivered to the ground or inter clouds during thunderstorms. Charged ions from the Van Allen belts are driven to the earth's surface in the region with the most diamagnetic elements. Therefore, these combinations linked the regions to become one of the worldwide places with higher intensity of electric atmospheric phenomena, as over Sao Paulo (Brazil). This electrical phenomenon comes from thunderstorms formed in the area. Figure 7 shows where the underground water is localized; observe places such as Venezuela, where Lake Maracaibo is one of the most lightning spots in the world; the same happens in the dark blue zone in Africa, one with more lightning bolts (Figure 8).

Compared to [7] and [8] figures, the locations match where groundwater is shown and with the considerable amounts of lightning.

Figure 8 shows how water is distributed worldwide; there are three colors: yellow, purple, and green. In this study, the groundwater (yellow) is vital since it is crucial in the lightning frequency in those places. The buried fresh water is a diamagnetic material and attracts charged particles. There are other kinds of charging the cloud; those regions have high altitudes and attract many ionized particles from the high atmosphere, and the droplets of water into the cloud will attract the charged particles. Those particles are added to the others created by

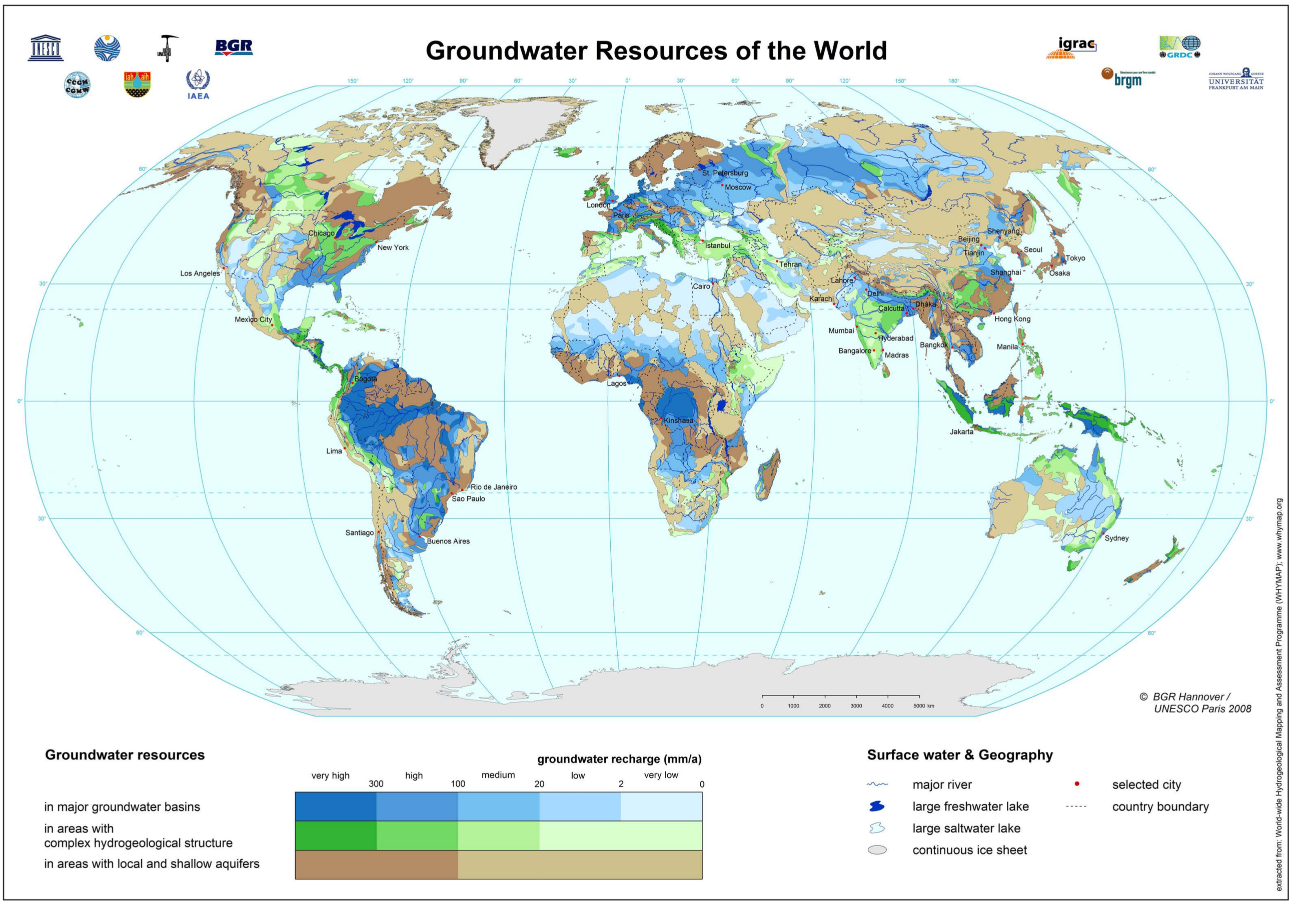

Figure 7. Global distribution of modern groundwater, with an extremely high amount in Brazil (Amazon) and Africa. Groundwater recharge is in mm/a.

the vertical winds' friction inside the clouds. When the clouds maximize the number of ionized particles from external and internal friction, it creates a lightning cloud to cloud when one of the clouds has less charge. There lightning discharges all the ionized particles to the ground, which is intensified if it is occurring in a area with high amount of diamagnetic material. Just compare Figure 7 with the places with groundwater worldwide and Figure 7 and Figure 8 with a global lightning strike; there is a high frequency of lightning in the locations with grounded water.

Comparing Figure 8 and Figure 9, we observed that the places with the most groundwater basins have more occasional ties between underground water and lightning. Observe there is also a connection with the high amount of diamagnetic (besides the underground water) materials in North Brazil.

Several places have vast underground water; one was recently found in the Amazon. Figure 10 shows a schematic representation of a recent discovery of subsurface water in the Amazon craton. It is supposed to flow as a river in the direction of the South Atlantic Ocean, moving towards the Earth's rotation direction. The inner river's movement flows in the same direction as Earth's rotation and does not create external pressure into the Amazon craton. It is an important observation since, as we will see later, it would be necessary to a huge force against the Earth's rotation and the tectonic in the subduction area since the Nazca plate is moving, also in the Earth's rotation direction. If any malleable material underneath the Earth, such as water, moves against the rotation, it would

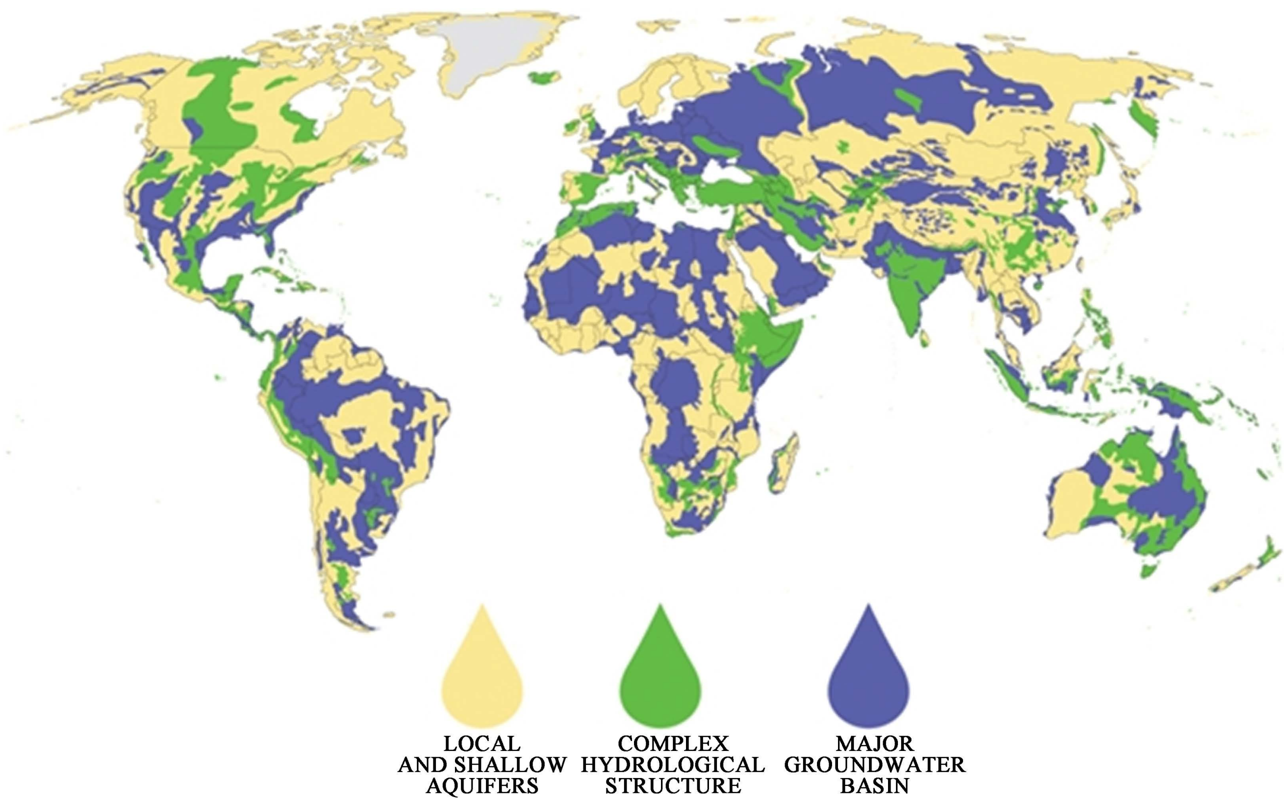

Figure 8. This picture shows how groundwater is distributed worldwide. The places with more groundwater coincident with lightning are North Brazil, South Africa, and Australia. There is a considerable amount of lightning in these regions.

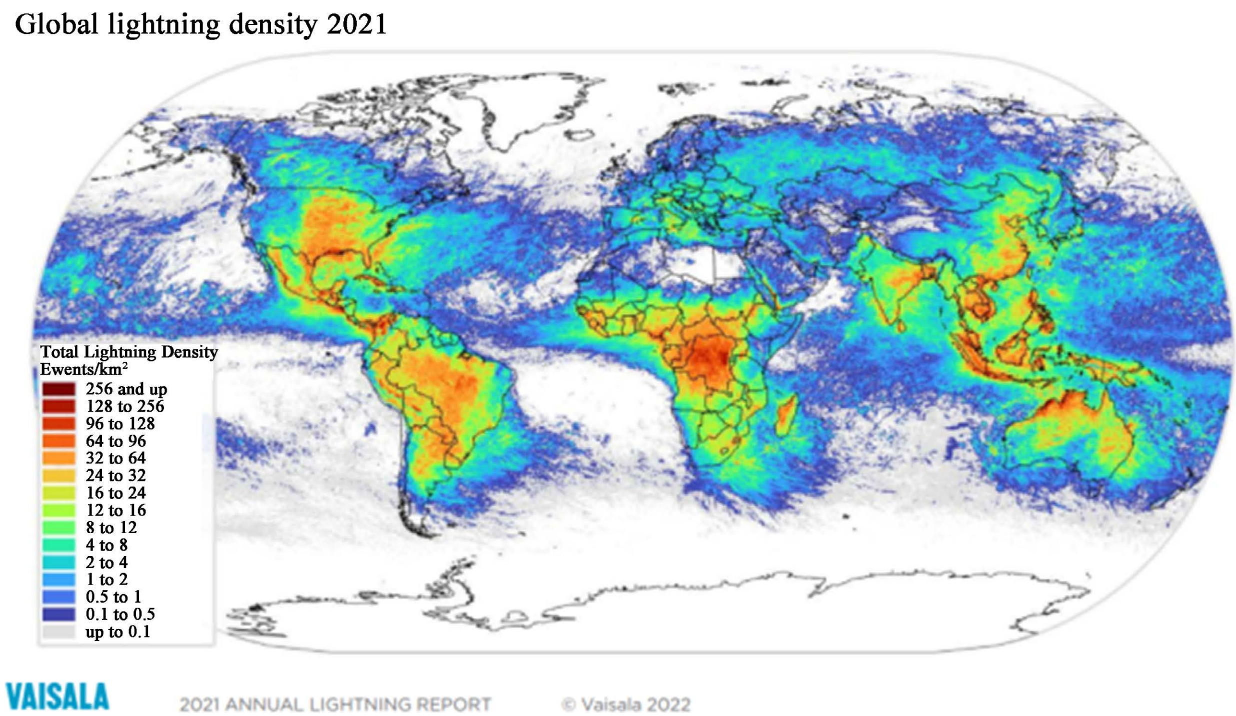

Figure 9. Showing the places with intense numbers of lightning. Observe two critical regions, Brazil and South Africa, and the total lightning density events/km^2.

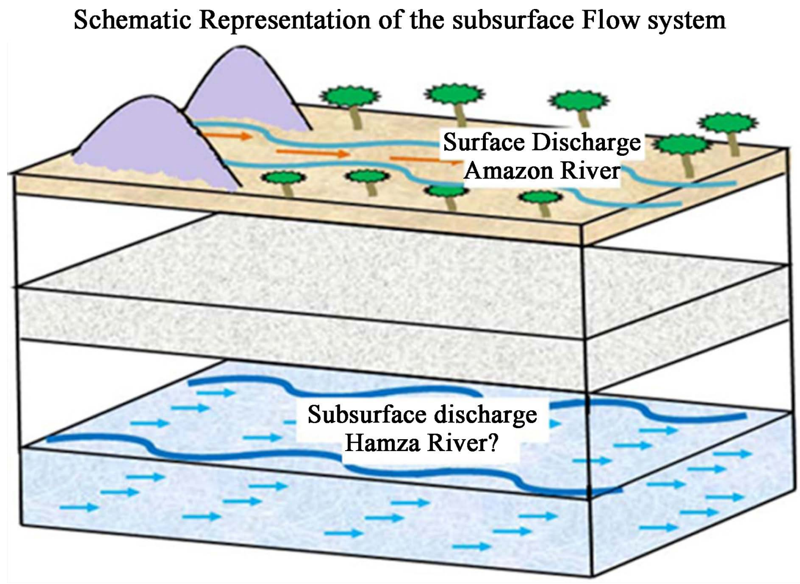

Figure 10. Schematic representation of subsurface water named Hamza River (Mongabay-2011).

create an enormous pressure in the plate that could have bad consequences, breaking the non-maleable material and triggering more earthquakes. However, the observed region is on a very stable plate, and the water is moving to the Atlantic Ocean.

The Guarani aquifer is also found in Brazil and three other countries (**Figure 11**).

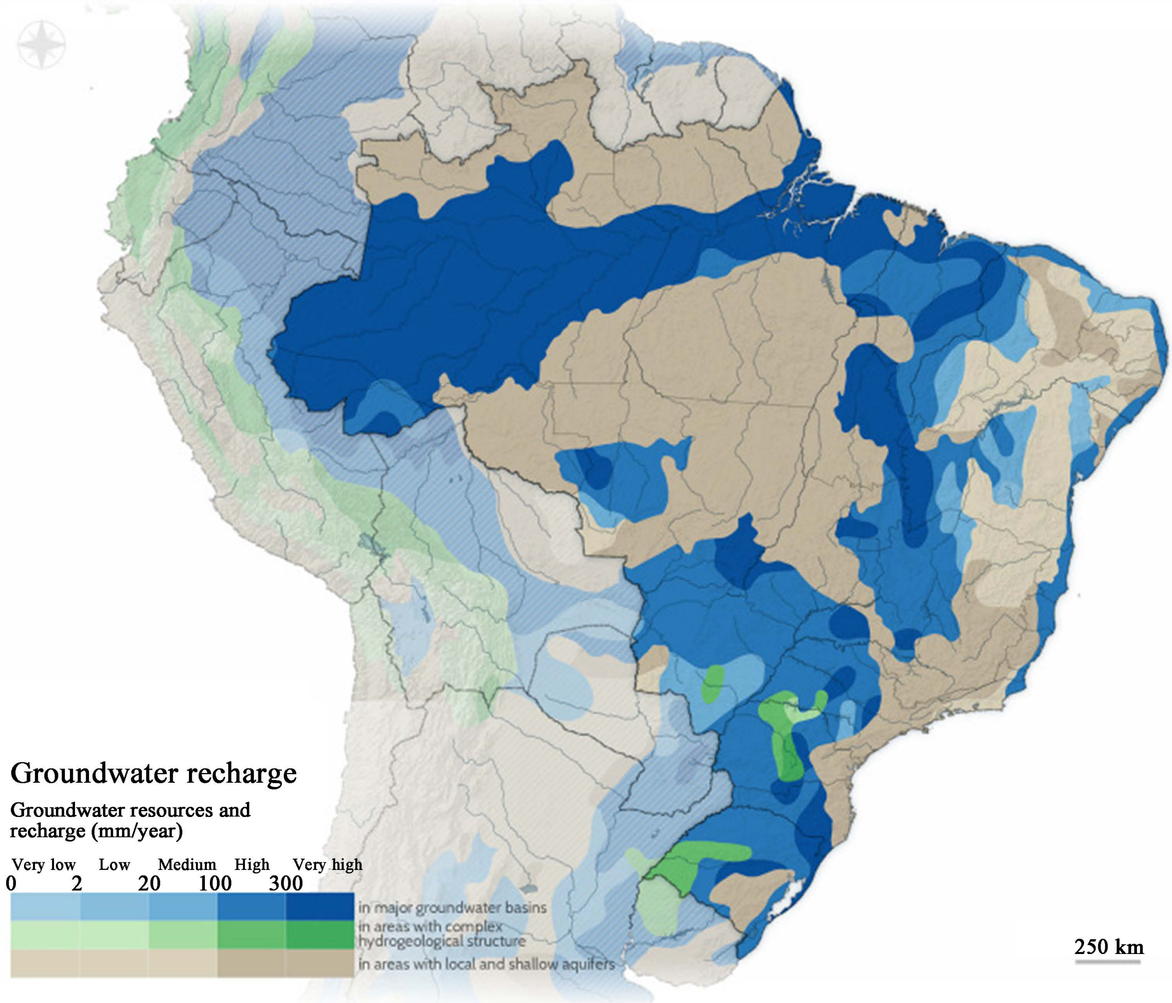

Figure 11. The aquifer shows that Brazil's most significant amount of water is underground.

Our results indicate that the Cumulus nimbus clouds are filled with ionized and charged particles from the atmosphere and inner Van Allen belts. Those particles are attracted to the ground in South America's plenty of underground waters. Thunderstorms in the region shall be the most powerful worldwide. The number of lightning in the area made us conclude that water is a powerful means of attracting charged ionized particles, which shall vary with geomagnetic storms.

Therefore, there is evidence that the clouds are charged not only by friction but also by enticing ionized particles from above and outside the cell storm.

5. Tectonic Studies on the South America Platform and Nazca Subduction

Figure 10 shows a detailed picture of the Nazca-South America collision. There are four volcanic regions: Northern, Central, Southern, and Austral zones. The speed of the Nazca subduction plate is 7 - 9 cm/yr. Below the Chile rise, the rate is slower for 2 cm/yr. The Arica elbow is a volcanic region pointed out in the picture. It displays the connection of Nazca-South America at the edge between the Northern, Central, and Southern Andes. The South American platform is outside the draw. The Nazca-South American collision has three regions with volcanoes: North, Middle, and South. Only about 20 percent of the world's identified tin resources are primary hydrothermal hard-rock veins or lodes. These lodes contain predominantly high-temperature minerals and almost invariably are strongly associated with silicic, peraluminous granites. About 80 percent of the world's identified tin resources are unconsolidated secondary or placer deposits in riverbeds, valleys, or sea floors.

Furthermore, tin placers are almost always found closely allied to the granites from which they originate—some regions with significant tin resources, such as Australia and Bolivia (Brazil). The Bolivian tin belt follows the grain of the Andes as it wraps around from northern Chile/Argentina and deflects into the regional northwest trend of Peru. The mineral camps are spaced and associated with Miocene dacitic dome complexes riddled by high-angle dipping veins.

Mining today in Bolivia is an odd mix of nearly defunct large-scale underground operations by the state miner Comibol (Corporación Minera de Bolivia), highly organized mining cooperatives, small-scale miners that frequently operate with substandard working conditions or cross over into the activities of illegal mining, and a few international mining companies [16].

The largest tin mining camps include Huanumi, Colquechaca, Tasna, Llallagua, Vilaco, Tatasi, Chorolque, Animas, Ubina, and Colavi. The major silver mining camps are at Porco, Potosi, and Pulacayo. A generally weak copper mineralization tract runs through west-central Bolivia, a belt of sediment-hosted copper deposits, from which only the Corocoro mine has modern production. It also shows the significant earthquakes in the Nazca—South America collision.

Figure 12 shows the South American plate and the region's underground water in South American cratons. A recent paper tells the discovery of a massive water knob beneath the Amazon craton. Researchers at Brazil's National Observatory reported the existence of a 6000-km-long bulge of water some 4000 meters under the Amazon. This formation flows west to east (the same as the Earth's rotation). It discharges fresh water in the Atlantic deep underground.

The Amazon craton is filled with water, a diamagnetic material and malleable; therefore, no earthquakes are observed in those regions. The Amazon craton presents structures with ductile compressive tectonics, like the tectonic setting found in the Carajas Archean Province (CAP) [17].

It is important to note that the epicenter of the SAMA is now over Brazil, SP state. The water bulge under the Amazon craton presents diamagnetic and ductile characteristics. It would be possible to do an array of magnetometers in the region detecting magnetic variations from the ground to higher altitudes variation on SAMA. **Figure 13** is the schematic picture of the subsurface water in the Amazon region.

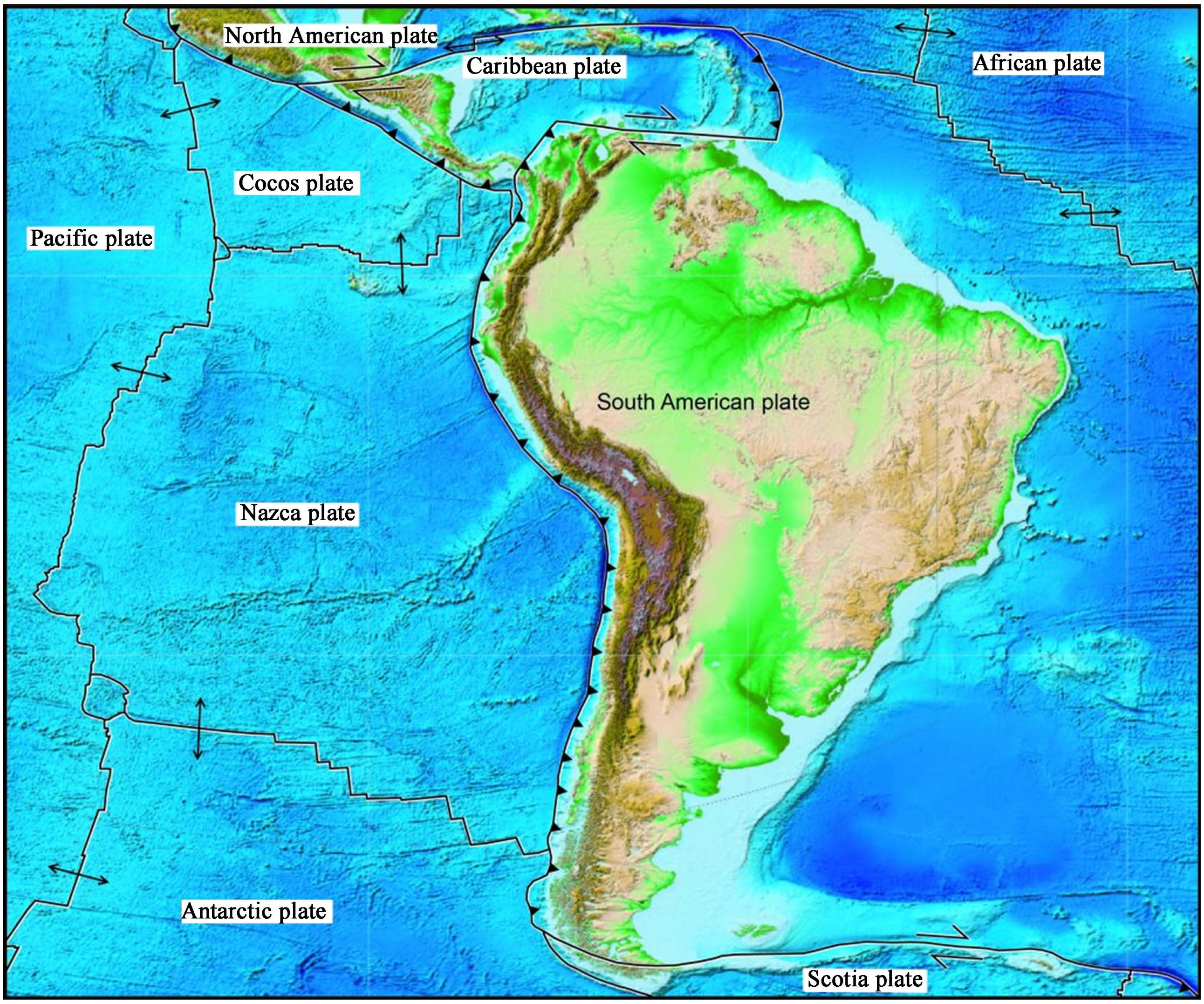

Figure 12. Plate tectonic map of South America and adjacent plates. Boundaries marked with triangles represent convergent zones. Two arrows in opposing directions indicate divergent boundaries. Transform boundaries have arrows showing motion to both right and left. Red and white colors represent high elevations, greens and yellow represent lower elevations, and purple and blue represent areas below sea level—image credit: Tectonic boundary map drawn using GPlates software.

6. The South Atlantic Magnetic Anomaly

The South Atlantic Magnetic Anomaly (SAMA) was detected as early as 1950 as a region of enhanced flux of energetic charged particles. The depth to which ionized particles in the radiation belts penetrate, known as their bounce point along a field magnetic field line, depends on the intensity of the geomagnetic field. The anomalously weak magnetic field in the South Atlantic (compared with the area of a centered dipole) thus gives rise to enhanced charged particle flux in this region, *i.e.*, radiation anomaly. The mission CHAOS-7 investigated changes in the field intensity mapped down to the Earth's surface. The authors also have 182 observatorys **Figure 14**, checked for trends, spikes, and other errors. Unfortunately, those magnetometers are far from the area with a diamagnetic field from buried fresh water under the Amazon craton. A few magnetometer

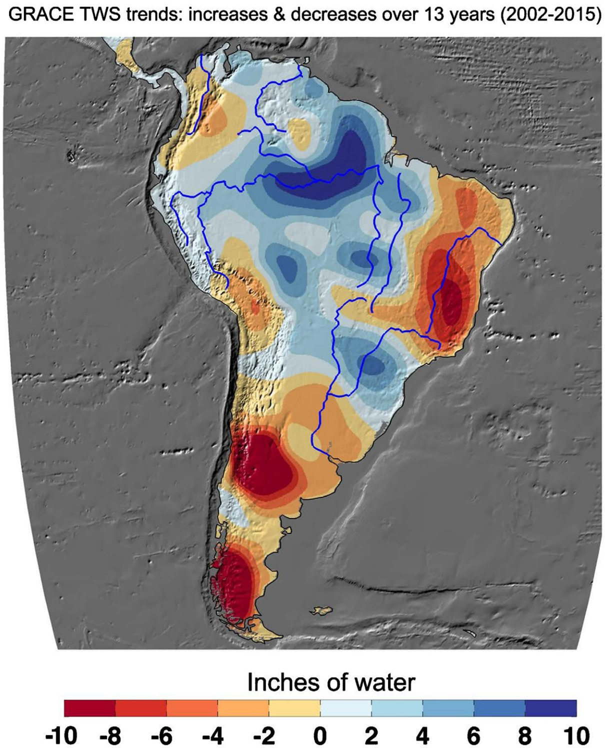

Figure 13. Underground water in South American, Brazil by Grace Satellite (NASA).

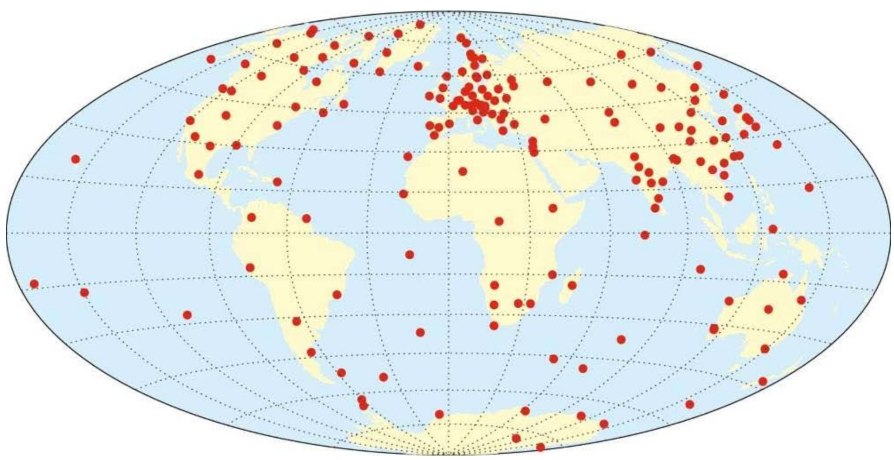

Figure 14. Locations of ground magnetic observatories whose data are used to derivate CHAOS-7. IAGA codes for the observatories are AAA, AAE, ABG, ABG, ABK, AIA, ALE, AMS, AMT, API, API, AQU, ARS, ASC, ASP, BDV, BEL, BFE, BFO, BGY, BJN, BLC, BMT, BNG, BOU, BOX, BRW, BSL, CBB, CBI, CDP, CKI, CLF, CMO, CNB, CNH, COI, CSY, CTA, CTS, CYG, CZT, DED, DLR, DLT, DOB, DOU, DRV, EBR, ELT, ESA, ESK, EYR, FCC, FRD, FRN, FUQ, FUR, GAN, GCK, GDH, GLM, GNA, GNG, GUA, GUI, GZH, HAD, HBK, HER, HLP, HON, HRB, HRN, HTY, HUA, HYB, IPM, IQA, IRT, IZN, JAI, JCO, KAK, KDU, KEP, KHB, KIR, KIV, KMH, KNY, KNZ, KOU, KSH, LER, LIV, LMM, LNP, LON, LOV, LRM, LRV, LVV, LYC, LZH, MAB, MAW, MBO, MCQ, MEA, MGD, MIZ, MMB, MNK, MOS, MZL, NAQ, NCK, NEW, NGK, NGP, NMP, NUR, NVS, OTT, PAF, PAG, PBQ, PEG, PET, PHU, PIL, PND, PPT, PST, QGZ, QIX, QSB, QZH, RES, SBA, SBL, SFS, SHL, SHU, SIL, SIT, SJG, SOD, SPT, SSH, STJ, SUA, TAM, TAN, TDC, TEO, TFS, THJ, THL, THY, TIR, TND, TRO, TRW, TSU, TUC, UJJ, UPS, VAL, VIC, VNA, VOS, VSK, VSS, WHN, WIC, WIK, WNG, YAK, YKC.

observatories are located on the west side of South America. Most are on the Pacific coast, and some are on the Atlantic coast, but none are inside the countries; scientific studies in the region always fight with a lack of information [18] [19].

From 1970 to 2020, the minimum field strength in this area dropped from around 24,000 nanoteslas to 22,000 nanoteslas; however, the anomaly's location has grown and moved westward at a pace of approximately 20 km per year. Over the past five years, a second center of minimum intensity has emerged southwest of Africa (on the South Atlantic Ocean), indicating that the South Atlantic Anomaly could split into two separate cells. However, it is impossible to confirm such affirmations since the material is malleable; it leaves a small part behind and, eventually, will restore the shape. Another possibility is that the material is absorbed by other equally buried materials (as we propose), and this part will disappear [18].

Scientists from the Swarm Data, Innovation, and Science Cluster (DISC) are using data from ESA's Swarm satellite constellation to understand this anomaly better. Swarm satellites are designed to identify and precisely measure the different magnetic signals that makeup Earth's magnetic field. **Figure 14** shows the change in the field intensity at Earth's surface according to CHAOS-7, up to spherical harmonic degree 20, period 2014-2020, with the data provided by three SWARM satellites [19] [20].

The top panel shows the field intensity in 2014, the middle panel in 2020, and the bottom panel shows the difference or accumulated changes over six years. Contours in steps of 500 nT between 22,500 nT and 27,000 nT highlight detailed changes in the structure of the South Atlantic Anomaly. The weakest magnetic field over central South America has strengthened and stretched during those years. A secondary minimum has developed further 40 S. The secondary minimum of field intensity indicated the South Atlantic anomaly dragging ductile material, now deformed by the pulled and delayed in relation from the main center over central South America. The second minimum seems independent from the main center, now reached the continent, located on the Southern Atlantic Ocean. Oceans are not diamagnetic, resulting from a slight magnetism over the Oceans. Therefore, the part bent on the Ocean feels less strength; the effect is a weaker anomaly. Then, it seems the anomaly is splitting but stretching over two different surfaces [21].

The second part, over the ocean, did not suffer this interference from the Earth's surface diamagnetism from the South American continent. Currently, it has a very tenuous value over the South Atlantic Ocean. Imagine that the stronger epicenter is moving north. Suppose the first center still encounters diamagnetism on the ground. In that case, it is impossible to guess if the anomaly will join the two parts again. This apparent rupture between the two parts can be intensified or decreased depending on several features on the ground. It is also possible that the anomaly becomes steady on the continent until the other part joins it. Therefore, the ground conditions and the internal position of the underground malleable material are essential to resume the results and make conclusions.

Since some circumstances can absorb plastic material, the SAMA may have a new shape if it occurs [22].

7. Possible Source of South American Magnetic Anomaly

Earth's magnetic field, also known as the geomagnetic field, is the magnetic field that extends from Earth's interior out into space, where it interacts with the solar wind, a stream of charged particles emanating from the Sun. Electric currents generate the magnetic field due to the motion of convection currents of a mixture of molten iron and nickel in Earth's outer core. These convection currents are caused by heat escaping from the core, a natural process called geodynamics [23].

The magnitude of Earth's magnetic field at its surface ranges from 25 to 65 μT (0.25 to 0.65 G) [3]. As an approximation, it is represented by an area of a magnetic dipole currently tilted at an angle of about 11˚ concerning Earth's rotational axis, as if an enormous bar magnet placed at that angle through the center of Earth. The North geomagnetic pole represents the South Pole of Earth's magnetic field. Conversely, the South geomagnetic pole corresponds to the north pole of Earth's magnetic field (because opposite magnetic poles attract and the north end of a magnet, like a compass needle, points toward Earth's South magnetic field, *i.e.*, the North geomagnetic pole near the Geographic North Pole). As of 2015, the North geomagnetic pole was located on Ellesmere Island, Nunavut, Canada (**Figure 15**).

While the North and South magnetic poles are usually located near the geographic poles, they slowly and continuously move over geological time scales but sufficiently slowly for ordinary compasses to remain valid for navigation. However, at irregular intervals averaging several hundred thousand years, Earth's field reverses, and the North and South Magnetic Poles abruptly switch places. These reversals of the geomagnetic poles leave a record in rocks that are of value to paleomagnetic to calculate geomagnetic fields in the past. Such information, in turn, helps study the motions of continents and ocean floors in plate tectonics.

The magnetosphere is the region above the ionosphere that is defined by the extent of Earth's magnetic field in space. It extends tens of thousands of kilometers into space, protecting Earth from the charged particles of the solar wind and cosmic rays that would otherwise strip away the upper atmosphere, including the ozone layer that protects Earth from harmful ultraviolet radiation. The South Atlantic Anomaly is a weak spot in Earth's magnetic field, which covers the planet from high doses of solar wind and cosmic radiation. This anomaly exists because the Earth's inner Van Allen radiation belt comes closest to the planet's surface, causing an increased flux of energetic particles. This anomaly also causes technical disturbances in satellites and spacecraft orbiting Earth.

Many authors have tried to discover the source of the SAMA, an anomaly in the Earth's magnetic field's ability to move throughout centuries. SAMA is pushing against the Earth's rotation, probably dragged by Coriolis force in the

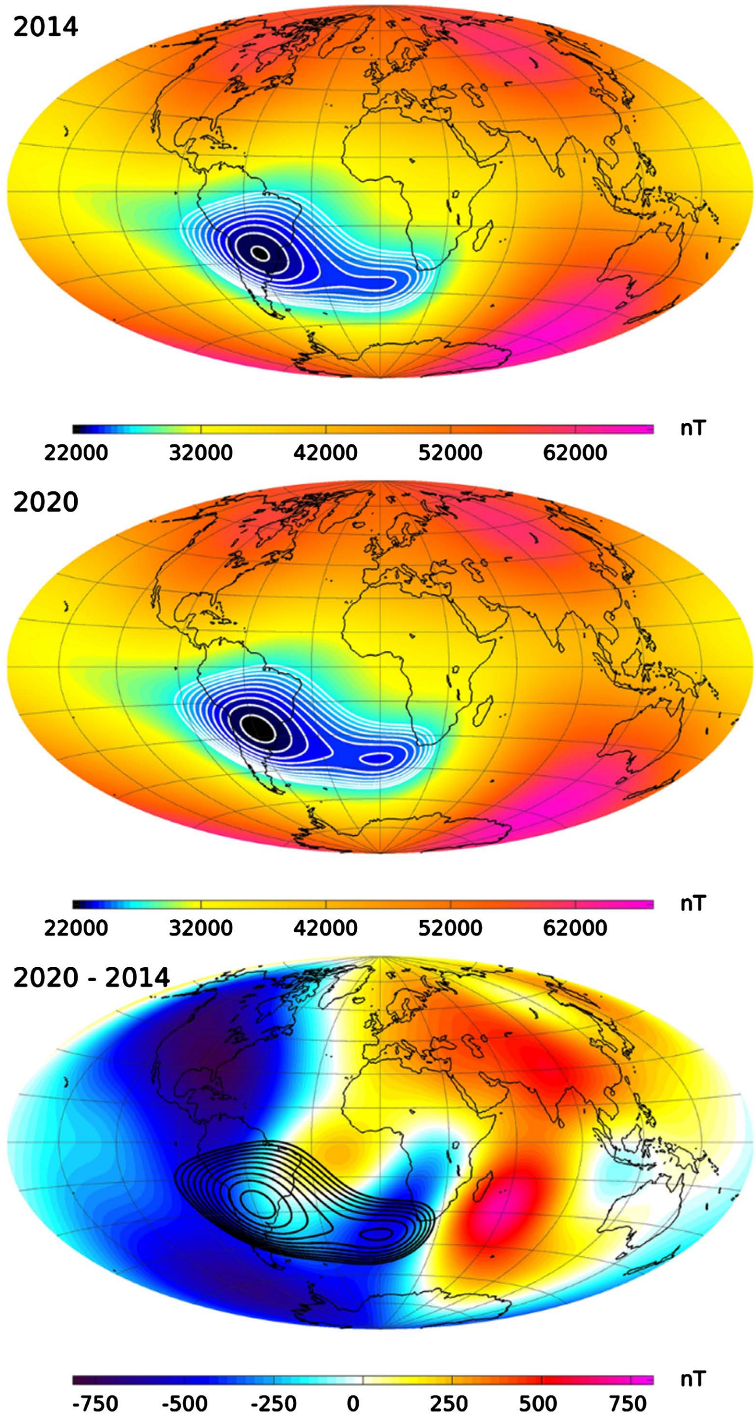

Figure 15. Field intensity at Earth's surface, highlighting the South Atlantic Anomaly. The top and middle of the panel show field intensity differences between 2014 and 2020. The intensity is in steps of 500 nT from 22,500 nT to 27,000 nT. The bottom row shows the difference in intensity between 2020 and 2014 in nT. The picture below shows the measure of magnetic field intensity.

Southern Hemisphere.

The movement is against the Earth's rotation; therefore, it indicates the presence of a malleable material. Those characteristics of deformation and plasticity indicate that SAMA formation is a flexible material; the best guess is fresh water. The presumption that there is a bulge of freshwater underneath the crust is that the anomaly can dislocate, deform, and stretch from Africa towards South America. The area that the geomagnetic anomaly over South America has expanded, covering a good part of the continent, and a small amount is over the Atlantic Ocean.

The South Atlantic Magnetic Anomaly is addressed towards the Pacific following the Coriolis forces in the Southern Hemisphere.

Hartman & Pacca [20] calculated the time evolution of SAMA during the period 1590-2005. It was shown that the anomaly has moved from South Africa and is now in Brazil, traveling westwards toward the northwest Pacific. In another study by Amit *et al.*, they found a westward drift showing a deformation in the SAMA pattern from South Africa and over Brazil.

Therefore, the approximation of the SAMA anomaly to Brazil over the area with another anomaly in the groundwater will cause an enhancement of the anomaly itself [21].

The SAMA is due to the diamagnetism generated below the crust, which is still at the lithosphere and detected from above. One of the consequences will be the enormous quantity of bolts of lightning and strokes below those regions. The Sao Paulo region is situated in the Guarani aquifer, one of the points in Brazil where more flashes of lightning occur. Even though the place that receives the most lightning in the world is South America, there is a location of solid diamagnetism presence. Therefore, we found two anomalies, one associated with the earthquakes in South America and another associated with SAMA, which is now traveling to the continent land [22].

8. Comparison and Consequences of Two Anomalies in South America

The last part of this study compares the anomaly found on the ground from Nazca-South America platform connections and the South Atlantic Magnetic Anomaly.

As the map shows in **Figure 16**, the anomaly is a spot on the magnetic earth's field where the magnetic field suddenly decreases. The flux of ionized particles increases due to the inner Van Allen's belt over the region. The main challenge is to find out what could cause this decrease in the magnetic field and keep the neighborhood intact. The magnetic field strength comes from internal causes below the Earth's surface. Therefore, it is the same thing with the anomaly; it is possible that a highly diamagnetic material was dragged from southern Africa long ago. It is malleable and deformed, traveling against the Earth's rotational movement. The force that could make the material travel against the rotation is the Coriolis force. Coriolis's force will slog the bulge of water over the continents, and it is now partially located in the South Atlantic Ocean and the central part of South America. Since South America has an accumulation of diamagnetic material buried, it would strengthen the Magnetic Anomaly on the continent, and the region on the Ocean would faint. We found evidence of two cores for the magnetic anomaly on the South America platform. The first core is reinforced by the vast amount of diamagnetic material on the Earth's surface. The second core is the remnant of the magnetic anomaly from South Africa, which has not reached the continent yet [23] (See **Figure 17**).

Figure 17 shows the actual shape of the South Atlantic Magnetic Anomaly in 2020. The central part is 22 nT in Brazil, and there is a tale with another center with 25 nT. The body moves against the Earth's rotation but follows the Coriolis force. There is a possibility that in the future, both Magnetic anomalies will be located on the continent and one only center.

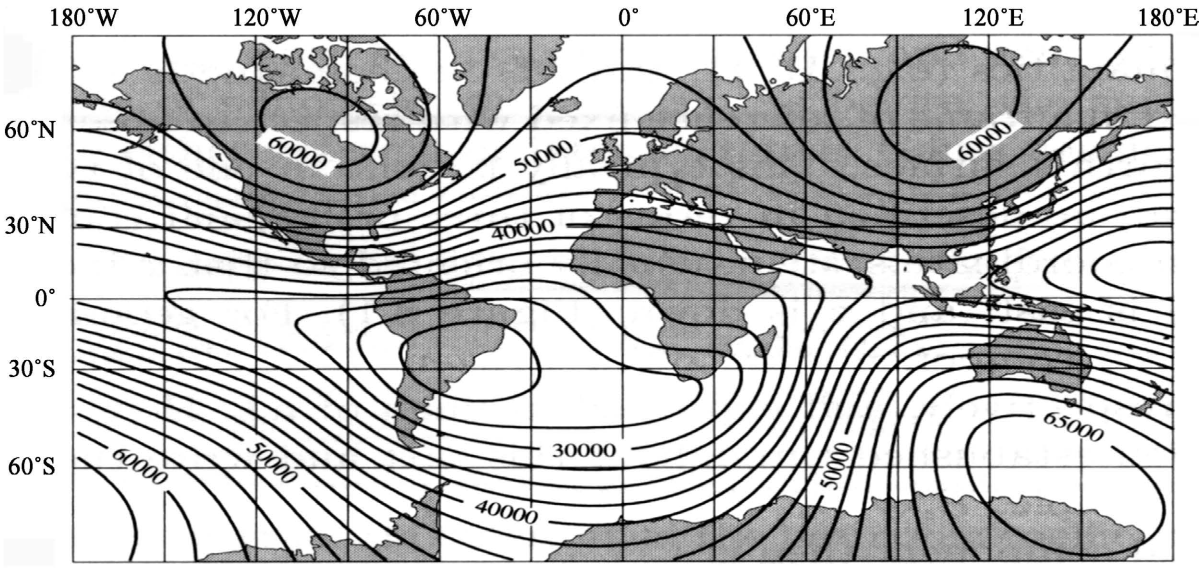

Figure 16. The South Atlantic Anomaly is a spot of low intensity on the magnetic field map. The units on the map are in nT.

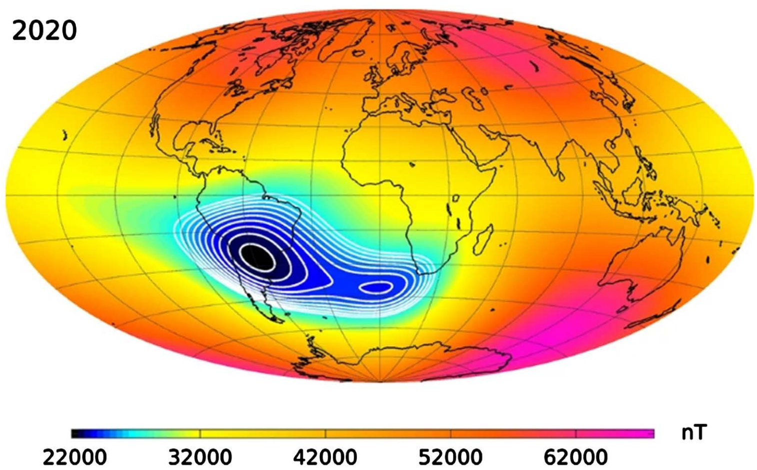

Figure 17. Two south Atlantic magnetic anomaly cores over South America. The second core is in the South Atlantic Ocean.

Therefore, the presence of the malleable element allows the Earth's rotation to stretch it instead of breaking; all those characteristics of this material point out that freshwater is buried and moving against the rotation forces.

Another anomaly is created by the buried water underneath the American Craton being discharged into the Atlantic Ocean, constantly moving in the same direction as Earth's rotation. The displacement of this material of the South American continent occasioned the encounter of another bulge of anomaly underneath the continental land. The encounter of those two anomalies signalizes there are now two bulbs of fresh water or some malleable material in the area. The regional South America earthquake anomaly is derived from the vast amounts of plastic materials on the Earth's crust. Scientists cannot be sure of the dimensions of the water bulb underground in South America. However, the non-tremors in some points underground in South America show that the place is occupied by fresh water, which could reach deep depths in the region.

9. Discussion of Results

This paper is divided into three sections with different results based on anomalies on the earth's ground and into the atmosphere. The first was the evolution of deep and ultra-deep depth earthquakes. The period taken was 1950-2023. Short periods were considered for shallower quakes at 40 - 70 km. The reason is that the results would be precise, reflecting brief periods in those events. As the depth increases, the occurrences will be less, and longer periods will be necessary.

The first result was an anomaly for the deep events in Nazca—South America. Earthquakes occur inside the continental platform instead of the edges, as it happens for shallower events.

We attributed those anomalies to occurrences derived from the enormous amounts of ductile and diamagnetic minerals and elements encountered in the region. A gap was observed in earthquake depths ≥ 500 km, drawing a path with several openings indicating malleable materials as fresh water. The data results showed that an anomaly was present due to the extraordinary diamagnetism in the area. It is corroborated by the recent finding of an underground river flowing towards the Atlantic in the same direction as the Earth's rotation (west to east). The second consequence of diamagnetic material is observed in South America's intense presence of lightning and other electric phenomena. As we learn, water is an excellent diamagnetic material distributed in several South American locations. Those can enhance the electric discharges and other electromagnetic phenomena. Finally, it is evidence of the increased weakness of the South America Magnetic Anomaly. It was documented that the anomaly traveling from South Africa towards the North Pacific indicated malleable material probably located under the crust, even though into the lithosphere. Now, there are few indications or evidence that this is occurring; however, water is the only element that satisfies several requisites as it is diamagnetic and therefore repels magnetism, it is malleable, and it is moving against the Earth's rotation following the Coriolis forces direction or westwards.

This material joins the diamagnetic force generated below the South American crust, strengthening the diamagnetism in the region. One piece of evidence corroborates such an assumption: the increasing of ionized particles much closer to the Earth's surface in the area. The Van Allen belt relates to the increase of electric discharge or bolts of lightning in South America, where we observed most bursts worldwide. This research found that the high incidence of ionized particles in South America is due to diamagnetic material on the ground or below the crust. Similar observations were found in Johannesburg, South Africa, with tremendous flash discharges and electrical storms. The South Atlantic Anomaly movements against the world's rotation are possible due to the material's malleability in the area. Finally, the intensity of the growth of the anomaly over South America is explained as an additional diamagnetism observed from buried elements, and the deformation of this anomaly relates to a high number of ionized particles over South America.

10. Conclusions

In this paper, we concluded that several circumstances indicate the impact of material diamagnetism playing essential roles in the Earth's underground and influencing the atmospheric phenomena. Understanding the importance of working with deeper earthquakes will give more information on unknown parts of the lithosphere. It also will improve possible knowledge of underground anomalies worldwide.

Our research found two anomalies in the Southern Hemisphere around South America. One is the South Atlantic Magnetic Anomaly, and the other is the South American Earthquake Anomaly in the location Nazca which is subducting under South America. The South American Earthquakes show a vast amount of malleable minerals on the crust and a bulge of fresh water under South America, located in the lithosphere; those regions do not trigger earthquakes. The diamagnetic elements attract ionized charges from the Van Allen belts and create places with the most lightning in the world. The same has happened in South Africa since the stretching of the SAMA in 1880. SAMA's movement comes from the Coriolis effect on the buried diamagnetic material concentration pushed by the Earth's rotation in the opposite direction. It is paramount to investigate further global locations with high electricity discharge numbers and search for malleable, ductile, or diamagnetic minerals.

Observations

The several maps created for the earthquakes, solar citations, and tables were made using the catalogs [24] [25].

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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