



A continental profile: illustration showing variations in the relief (*white line*) and crust of South America

# Why the earth shakes in Brazil

Seismologists propose  
a new explanation for  
earthquakes in Brazil

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**O**n October 8, 2010, the earth trembled as never before in Mara Rosa, a city of 10,000 in the northern region of Goiás State. The clock had just struck 5 p.m. that Friday, and people were preparing for the weekend, when the ground shook so hard that it was difficult to remain standing. Trees quivered, walls cracked and tiles fell off houses. Less than a minute later, this magnitude-5 earthquake, one of the strongest on record in Brazil in the previous 30 years, had traveled 250 km and reached Brasília, where several buildings had to be evacuated. “Many people in Mara Rosa thought the earth was opening up and that the world was coming to an end,” says Lucas Barros, head of the Seismological Observatory of the University of Brasília (UnB). In the weeks after the earthquake, Barros and his team installed seismographs in Mara Rosa and neighboring municipalities to track the reverberation of the tremor. Within six months, 800 additional, less intense earthquakes occurred and were used to determine the direct cause of the earth’s instability in this region. Below Mara Rosa, at a depth of approximately three kilometers, there is a wide crack in the earth’s crust, the most rig-

id and outermost layer of the planet. Along this fault, which is five kilometers long, rocks shifted and caused the earth to tremble. “We had to hold public hearings in Mara Rosa and Mutunópolis to explain to people what was happening and what they had to do to protect themselves,” says Barros.

The existence of this fault came as no surprise to the UnB group: Mara Rosa and other municipalities in northern Goiás and southern Tocantins State are located in a geologically unstable region, i.e., the Goiás-Tocantins seismic zone, in which 10% of earthquakes in Brazil have been concentrated. Some geologists attribute the high frequency of earthquakes in this area—a seismic zone (one of nine demarcated in the country) 700 km long and 200 km wide—to the proximity of the Transbrasiliano Lineament, a long scar in the earth’s crust that crosses through Brazil and continues into Africa on the other side of the Atlantic. It is believed that the crust is weaker along the lineament with a concentration of blocks of cracked rock, which, under compression, may move easily and produce earthquakes.

However, not everyone agrees. In many cases the location of the tremor is removed from this series of faults, and along some stretches of the

lineament, no tremors have ever been detected. Those who doubt the direct influence of the lineament on earthquakes in this region believe that there are deeper causes, such as those identified by a group of researchers from the Institute of Astronomy, Geophysics and Atmospheric Sciences (IAG) of the University of São Paulo (USP), based on a recent survey of the thickness of the earth's crust in Brazil.

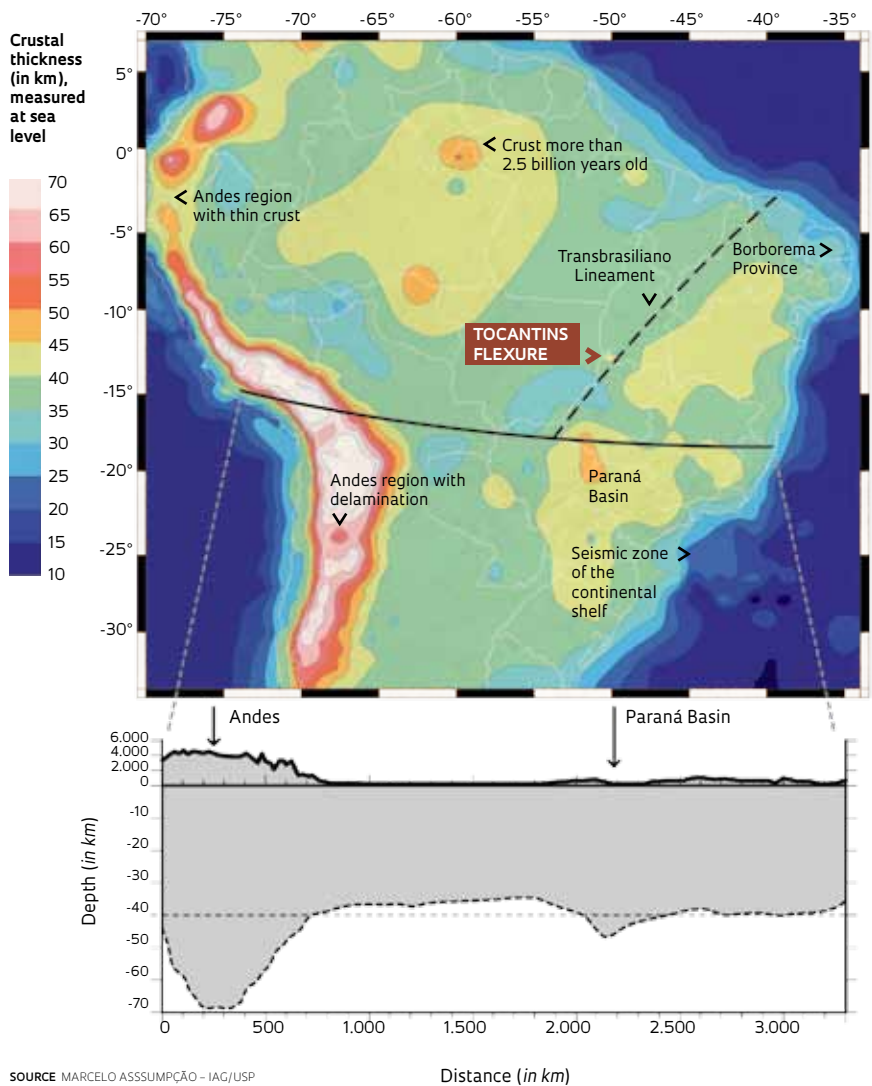
In a paper published in February of this year in *Geophysical Research Letters*, seismologist Marcelo Assumpção and geophysicist Victor Sacek proposed a more complete, and for many researchers more convincing, explanation of the concentration of tremors in Goiás and Tocantins States. In certain areas of this seismic zone, the earth's crust is thinner than in much of Brazil and is bended due to the weight of the mantle; in addition, the geological layer below the crust is denser. Measurements of the intensity of the gravitational field in these areas where the crust is thin indicate that the mantle is thickening in this region. The combination of these two layers of rock—the crust and the upper region of the mantle, which physically behave as a single and rigid structure that geologists call the lithosphere—causes them to slowly rupture like a bending tree branch. In this situation, the lithosphere can break like a plastic ruler that bends when you try to make the ends meet (see infographic at right).

“The lithosphere tends to sink where it is more dense and to rise where it is not as dense,” explains Assumpção, who is the coordinator of the Brazil Seismograph Network that monitors earthquakes in the country. “These tendencies cause stress that produces faults and eventually cause earthquakes to occur.”

**D**uring a conversation in his office in early April, Sacek, co-author of the study, picked up a paperback book to illustrate what occurs in the stretch of the Goiás-Tocantins seismic zone where Mara Rosa is located. “Let’s say that this book represents the lithosphere of the region; there is an increase in the load inside the lithosphere because there is a higher proportion of mantle rocks [which are more dense], and this will cause it to bend,” he explained as he held the book horizontally and pressed on the sides, which caused it to bend downward as though a brick were stuck to the bottom cover. In this demonstration, the upper part was subjected to forces of compression, and the bottom to forces of distention. “Although it is rigid, the lithosphere has some flexibility and withstands distortion to some extent,” Sacek says. “But after a certain point it can bend and break.”

## Under the ground

A survey shows the difference in thickness of the Earth’s crust in Brazil and in the Andes



SOURCE MARCELO ASSUMPTÃO – IAG/USP

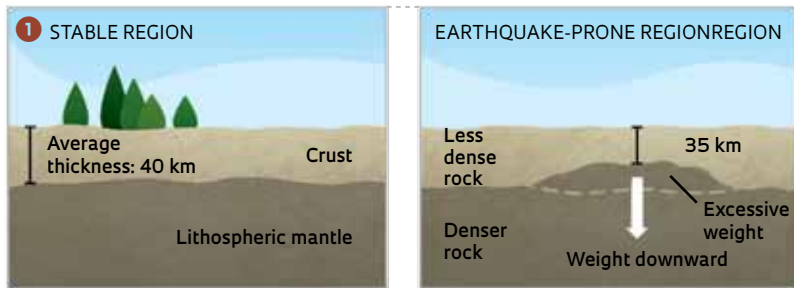
Several years ago, while analyzing a map of earthquake locations in Brazil, Assumpção realized that most occurred in the Goiás-Tocantins region, where in 2004 geophysicist Jesús Berrocal, a former USP professor, had identified a gravimetric anomaly. The gravitational field there is unusually high in Brazil for a plateau region with an average altitude of 300 to 400 meters. In these flat and relatively low lands—for example, there are no mountain ranges—there is no excess weight on the surface to account for the bending of the lithosphere. Therefore, Assumpção concluded that this weight could only be located below the ground, most likely in deep regions such as the more superficial layers of the mantle, as the crust is only 35 km thick.

However, it was necessary to verify whether this concept made sense and if the thickening of

**6,2**  
is the  
magnitude  
of the most  
intense  
tremor  
recorded  
in Brazil,  
in 1955



## GOIÁS-TOCANTINS SEISMIC ZONE

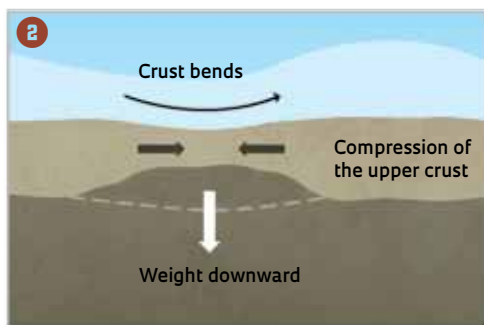


The crust is stable where there are no geological faults and little variation in thickness. The thickening of the mantle in the regions where the crust is thinner may cause additional stresses that promote the occurrence of tremors

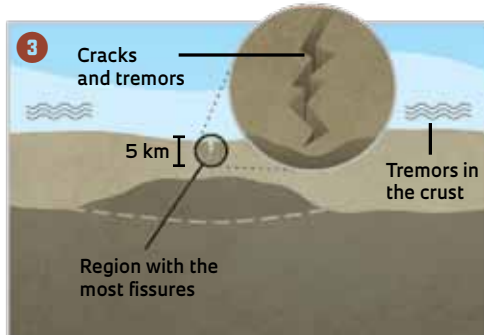


### CONSTANT STRESS

The planet's lithosphere, formed by the crust and the upper portion of the mantle, is divided into plates that move and collide. The shock at the edges of the plates creates stresses that spread through the continent's interior



The difference in weight between crustal rocks and the mantle at the same depth causes the thinner region to bend due to the extra weight below it. This flexure compresses the rocks near the surface



With the stress on the edges of the plates of the lithosphere, this compression is extreme for rocks less than 5 km deep, as they tend to crack and cause earthquakes

coincided with the area where the majority of earthquakes in Goiás and Tocantins occur. Within this large block, which is 200 km wide and five km deep, the forces are so intense that they exceed the limit of elasticity of the rocks, and these forces split the rocks. "This model even explains the depth of the earthquakes, which are generally less than five km from the surface," says Sacek.

He and Assumpção believe that this mechanism—the bending in the area where the crust is thinnest—can also explain the high frequency of earthquakes in other regions of the country, such as the Pantanal Basin and the Porto de Gaúchos seismic zone in Mato Grosso State, where in 1955 the strongest earthquake ever recorded in Brazil occurred, at a magnitude of 6.2 on the Richter scale. Earthquakes with magnitudes greater than five are rare in Brazil and occur on average every five years. However, even minor earthquakes can frighten people who are unaccustomed to living with them and are unprepared for such events. There is a lack of information on how to prepare for tremors, and the weakest houses cannot withstand small earthquakes that would cause little damage to the buildings in a large city. On December 9, 2007, a 4.9 magnitude quake damaged several houses in the village of Caraíbas, located near Itacarambi in the northern part of Minas Gerais State. A wall collapsed and killed a child. "This is the only death ever recorded in Brazil that was directly caused by an earthquake," says geologist Cristiano Chimpliganond of UnB.

The bending of the crust also explains the earthquakes in another seismic zone of Brazil: the margin of the continental shelf between Rio Grande do Sul and Espírito Santo States. At a distance of 100 to 200 km from the coast, the seabed drops off suddenly. On this step, the ocean depth increases from 50 to 2,000 meters. The sediment that the rivers carry to the sea accumulates at the end of this step, increasing the weight on the

the mantle could in fact cause the lithosphere to arch. Assumpção then asked Sacek, a specialist in computer simulations, to develop a mathematical model that would represent the geological layers in this area of Goiás and Tocantins and would take into account all the forces acting on these layers. Sacek developed a model that included the effect of local forces originating a few dozen kilometers away from the earthquake region due to differences in relief, such as valleys, rivers and hills, as well as to variations in the thickness of the crust. In addition, the model considered the effect of regional forces on a global scale that occur thousands of miles away on the edges of the blocks into which the lithosphere divides.

By combining these factors, Sacek identified an area in which the crust is weak; this region

crust. Assumpção believes that this excess weight causes the earthquakes that are detected in this region, as a result of mechanisms similar to those that may be occurring in Goiás and Tocantins. The difference here is that the excess weight is not below the crust but above it.

In 2011, Assumpção and colleagues from Universidade Estadual Paulista (Unesp), the São Paulo Institute for Technological Research (IPT), and Petrobras studied an earthquake that occurred in April 2008, 125 kilometers south of the city of São Vicente, on the coast of São Paulo State. The quake was felt as far away as the city of São Paulo. The point of origin of the tremor was at the end of the step of the continental shelf, and the characteristics of its seismic waves seem to confirm the concept that the event was triggered by excess sediment.

**T**he development of these models of the cause of the tremors in Brazil was made possible only through the discovery of variations in the thickness of the crust within its borders. Assumpção and colleagues from UnB, the Federal University of Rio Grande do Norte (UFRN) and the National Observatory (ON) collected information on the thickness of the crust at nearly a thousand sites in South America, both on land and at sea. Of this total, approximately 200 measurements were taken in the past 20 years with funding from FAPESP and the federal government. On the map that summarizes these data, published in the *Journal of South American Earth Sciences*, the researchers indicated the regions where the crust is thicker or thinner. “The thickness of the crust is one of the most important parameters for understanding the tectonics [the forces and movements of the geological layers] of a region,” says seismologist Jordi Julià from UFRN.

This map is the most comprehensive and detailed compilation ever made for the Brazilian crust. The thickness at all of these points was obtained by combining data captured by three methods that use seismic waves to determine the structure of the geological layers through which they pass. The most accurate method, which is also the most costly, is seismic refraction, in which researchers record along hundreds of kilometers tremors caused by controlled explosions (see *Pesquisa FAPESP* No. 184). The other two methods are based on the monitoring of earthquakes that occur throughout the world each year.

In general, the thickness of the crust in Brazil is similar to that in other continents, an average of 40 km, measured at sea level. However, there are some regions in the country where the crust thins out to less than 35 km. One of these areas—a 1,000-km strip that extends from the Pantanal

in Mato Grosso do Sul to Goiás and Tocantins—has not yet been well delineated because little seismic information is available about the region. In the northeast, where the team of Reinhardt Fuck from UnB performed most of the seismic refraction experiments, there is less uncertainty.

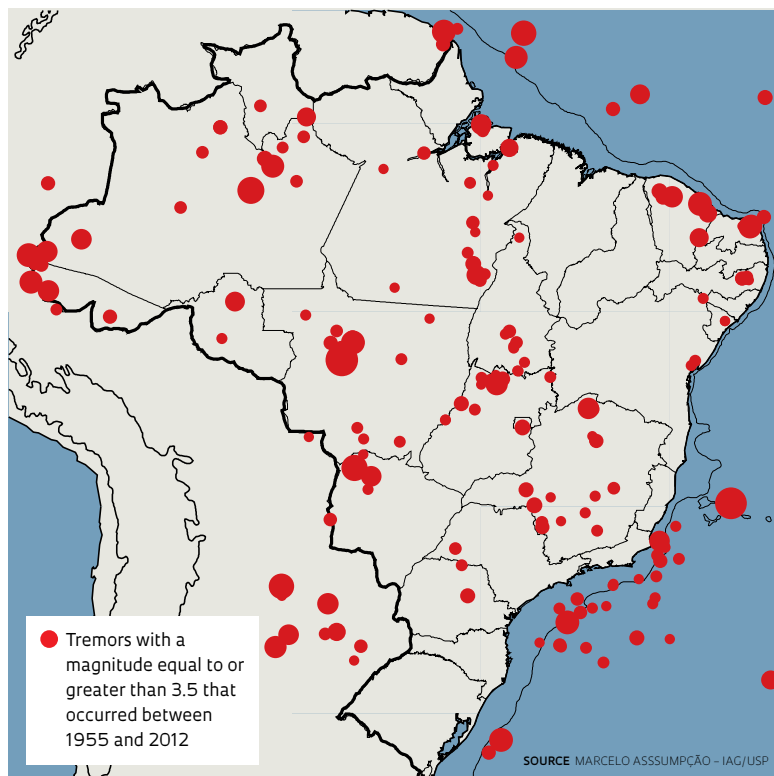
The province of Borborema, a rocky block on which almost all the states in the northeast sit, is the largest area in Brazil with the thinnest crust and has the highest frequency of tremors in the country. At some points in this region, the crust is thinner than 30 km. This thinning appears to have occurred between 136 million and 65 million years ago, when South America separated from Africa.

One of the thickest regions is located under the Amazon forest on the border between Roraima, Amazonas and Pará States. The crust, which is up to 45 kilometers thick, is one of the oldest pieces in Brazil, at more than 2.5 billion years old. “These oldest regions tend to have thicker crust,” says Assumpção.

**“Seismology cannot predict earthquakes, and even if it could, it would be unable to prevent them,” says Lucas Barros of the UnB**

## Where earthquakes occur

Earthquakes are concentrated in regions with thin crust, such as the northeast, the central west and the ocean shelf





The Andes Range: This region has the thickest crust in South America, at up to 75 km thick

However, the thickest stretch of crust in the country lies in a relatively new region, the Paraná Basin, which began forming 460 million years ago. In the interior of São Paulo, near the Paraná River, the crust is as thick as 46 km. Assumpção offers two possible reasons for this thickness. The first, suggested by several studies, is that under the Paraná Basin there may be a block of older crust, called the Paranapanema Craton, that is billions of years old. The second reason involves the intense volcanic activity in this area 130 million years ago. For some unknown reason, the mantle beneath the Paraná Basin became abnormally hot, forming an area that geologists call a thermal plume. This plume may have partially melted the deep layers of the earth, producing basaltic magma that spilled over the surface and created one of the largest volcanic provinces on the planet. The rocks produced strips of red earth and very fertile soil. Some of the material produced in the process remained underneath, and when the mantle cooled, it fused to the lower portion of the crust, increasing its thickness.

Together with researchers from Chile and China, Assumpção expanded the mapping of the crust to the Andes. Under this mountain range, the thickness of the crust ranges from 35 km on the border between Peru and Ecuador to 75 km on the Bolivian high plain. This maximum thickness is similar to the thickness observed in other relatively recent mountainous regions, such as the Himalayas. In general, there is a direct correlation between the altitude of land and the thickness of crust. “The higher the topography, the thicker the crust,” Assumpção explains. “For altitudes above 3,000 meters, it is normal for the crust to be as thick as 70 kilometers.”

But there are exceptions. In northern Argentina, where the Andes rise to more than 4,000 meters, the crust is less than 55 km thick. Again, researchers provide two possible explanations: Either the crust was already abnormally thin before the Andes were formed or four million years ago it became so thick and hot that it lost a portion of its deepest layers, an event called delamination.

On the border between Peru and Ecuador, where the altitude is greater than 3,000 meters, the thickness is only 35 km. In this case, the crust seems to be supported by the motion in the currents of the deeper layers of the mantle, which, although rocky, behave like a highly viscous fluid in geological time, with a flow of a few centimeters per year. The strength of these rising currents is capable of suspending the crust and pushes up the crust one to two kilometers in the mountains. The opposite can also occur: The downward flow can pull the crust down in some regions, as Sacek and Naomi Usami, a geophysicist at USP, observed in the Marañón Basin between Ecuador, Peru and Colombia.

Despite two decades of work, research in this field in South America is still lagging. The United States and Europe developed detailed maps of crustal thickness in the late 1990s. “The state of mapping the crust varies with per capita income across countries,” says Assumpção. “We are only better than Africa.”

In Brazil, the major research institutions in the area joined forces two years ago and created the Seismograph Network of Brazil, which includes 50 seismic stations; the goal is to increase that number to 80. Thus, researchers hope to better monitor the country and increase the resolution of the map. As more earthquakes are observed, additional details of the thickness of the crust can be identified, and with greater detail, models can be produced to more accurately predict areas at risk for large-magnitude earthquakes. “Seismology cannot predict earthquakes, and even if it could, it would be unable to prevent them,” says Barros. “So we have to learn to live with them and protect ourselves from them.” ■

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### Project

Tectonic, climatic and erosional evolution in convergent margins: A numerical approach (No. 2011/10400-0); **Grant mechanism** Post-doctoral research grant; **Coord.** Victor Sacek - IAG/USP; **Investment** R\$153,896.91 (FAPESP).

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