

RECENT EARTHQUAKES IN BRAZIL

By JOHN C. BRANNER

I. THE DISTURBANCES AT BOM SUCESSO, STATE OF MINAS GERAES

On February 3d of the current year the newspapers of this country published a telegram from Buenos Aires, Argentina, stating that a severe earthquake had occurred in the State of Minas Geraes, Brazil, causing great destruction of buildings and loss of life. A queried note on this subject was published in the March number of this BULLETIN, 10, 48. Letters were sent at once to Brazil asking for details and all available information.

Dr. Henrique Morize, director of the National Observatory at Rio de Janeiro, has kindly sent all the available data received at the observatory, and the reports and articles published in the Brazilian newspapers at Rio de Janeiro. Mr. Horace E. Williams, geologist of the Geological Service of Brazil, visited the place, and has sent a brief but clear and important description of the geology of the region about Bom Sucesso in the State of Minas Geraes, where the severest of the shocks were felt. To what Mr. Williams says of the geology I have added what I know at first hand of the geology of southern Minas. Mr. George Chalmers, superintendent of the gold mines at Morro Velho, has contributed a part of the report made upon this subject by Dr. Alvaro da Silveira, and published in a newspaper at Bello Horizonte, Minas. From these sources the following account has been prepared.

Bom Sucesso, in the southern part of the State of Minas Geraes, where the greatest disturbance seems to have been caused, is in south latitude about $21^{\circ} 4'$, west longitude about $44^{\circ} 58'$, and 150 kilometers southwest of Ouro Preto. The surrounding country is from hilly to mountainous, the population is sparse, and devoted chiefly to cattle raising and agriculture. The rocks of the region are mostly Archean granites and gneisses, but here and there over a wide area fragments of old Paleozoic sediments have been faulted and thrust into and beneath the Archean granites. Owing to the great resistance of the quartzites of the sedimentary series to processes of weathering and to the more yielding nature of the granites and gneisses, the harder rocks give

rise to a strongly marked topography, especially where they are tipped up at a high angle as they generally are.

It will be seen presently that the explanation of the earthquakes of Bom Successo is apparently related directly to this geologic structure so characteristic of the region.

Bom Successo has long been noted for its light earthquake shocks and for the thunder-like subterranean rumblings that accompany them. In April 1901 a series of shocks occurred there which caused some excitement, but the description published by Dr. Alvaro da Silveira showed that the intensity did not exceed IV of the R.-F. scale.¹ For as that writer stated, beyond frightening people, the earthquakes did no harm whatever.

After the shocks of 1901 nothing noteworthy happened until June 5, 1919, when there were rather sharp shocks accompanied by the usual dull rumbling sounds. On November 28, 1919, there was another shock and the subterranean sounds were repeated several times. The following account of the disturbance of January 31st and of February 1, 1920, is quoted from a letter written at Bom Successo by the vicar, Rev. Sr. Nicolau Badariotti, under the date of February 2, 1920: "On January 31st, at 8 a.m. the people of the town were startled by a dull subterranean sound as if produced by the explosion of a hundred dynamite bombs. Cracks were then noted in the walls of many of the houses. At eight different times during the day these disturbances were repeated but with less intensity. The night of the 31st, beginning at 11 o'clock, four more sounds were heard. Most of the people were so alarmed that they left their houses and remained in the streets, some of them in tents. Yesterday, February 1st, being Sunday, I purposely did not summon the people to mass so as to avoid any danger that might arise from their assemblage. Several persons came, however, and a little after eight o'clock, while mass was being said, another and very strong roar was heard which sounded to me like the breaking of rocks. When mass was over I advised the people to leave the place for two or three days. This advice was followed to some extent, for a good many families were already prepared to leave. During the day (February 1st) there was another but weaker roar about noon. At seven o'clock in the evening there was still another weak one. At night a faint rumbling was noted, as if from a great distance."

¹ Alvaro A. da Silveira.—Os tremores da terra em Bom Successo, Minas. Bello Horizonte, 1906.

It is somewhat remarkable that the vicar's letter does not mention earthquakes, but only sounds. It is also to be noted that the vicar is careful not to state that the shock or sound cracked the walls of the houses; he simply says the cracks were *observed after* the sounds.

From a dispatch published in "A Noite," a newspaper of Rio de Janeiro, on February 19, 1920, it seems that Dr. Alvaro da Silveira, former director of the Geological Commission of Minas, was sent from Bello Horizonte, the capital of the State of Minas, to ascertain the facts and to make recommendations in regard to what could or should be done. Information gathered by Dr. Silveira in regard to the occurrences of February 1st show that: "At 6:16 a.m. on February 1st a severe shock was again felt, followed by another at 7:45, and still another and stronger one at 7:48 a.m. The rumbling noises were heard that day twenty-six times at Bom Successo intermingled with a few shocks. On February 2d the underground noises were heard only six times, on the 3d eleven times, on the 4th twice, and on the 9th five times, one of which, at 1:20 p.m., was very loud. From the 9th to the 18th the noises and a few slight shocks were noticed several times. . . . After February 1st the people did not return to their houses. Beds were carried into the streets and set up in the open air, or in hastily erected tents. Some ladies had nervous attacks, some people had nausea and others had colic. Everybody tried to leave the place and crowds went to the railway station, carrying such of their belongings as they could take with them. Special trains had to be run to take away the fugitives. It is estimated that two-thirds of the houses in the town were abandoned. The schools were closed; and even the sick in the hospitals left or were carried away, while prisoners in jail were transferred to the jail at S. João d'el Rey."

The quotation above is from an article published in the "Minas Geraes," a newspaper of Bello Horizonte, date not given.

Another article published in "A Noite" at Rio de Janeiro February 8th, mentions earthquakes, but it appears to lay more stress upon the sounds than upon the earthquakes themselves. All available information leads to the inference that the alarm of the inhabitants is due to the sounds rather than to earthquakes.

Observations of H. E. Williams.—In March, 1920, Mr. Horace E. Williams, geologist of the Serviço Geologico of Brazil, was sent to Bom Successo, and was there on March 11th when an earthquake occurred. Mr. Williams writes (March 24, 1920) as follows about his experience, and in regard to the geology of the adjacent country:

"It should be confessed that from the beginning I had much doubt about the intensity of the shocks reported, but on March 11, 1920, a tremor that occurred at 7:15 p. m. promptly removed those doubts, for the shock was strong enough to rock the whole house I was in at the time, and to rattle loose objects that stood upon the shelves. The shock resembled a sudden jolt, as if the floor of the building had been struck from beneath by a great hammer. This jolt was immediately followed by a dull roar like the sound of a cannon fired at a distance of a few kilometers. The movement seemed to be chiefly vertical; and it seems likely that the movements here are always vertical for the reason that a lateral movement of the same intensity would throw down walls that were not very strong. And this is probably the reason that the crude seismographs set up thereabout on various occasions have not registered these disturbances, for they were only devised for the purpose of recording horizontal movements.

The local geology.—"The region about Bom Successo belongs to the great crustalline complex of Brazil—one of the largest areas of the globe that is free from volcanoes and from destructive earthquakes. In the immediate vicinity is the high but narrow ridge, known as the Serra de Bom Successo, about twenty-four kilometers long and composed of friable and porous schistose rocks standing on end and flanked on both sides by granites that are impervious to water. This arrangement of the rocks is well shown where the ridge is cut through by the Rio das Mortes between the stations of Aureliano Mourão, and Ibituruna on the West of Minas railway. The schistose rocks are from 160 to 200 meters in thickness at the level of the stream. On the top of the ridge the impermeable granites that support the sides lower down are lacking, so that the schistose beds have opened like a fan and occupy a width of 350 to 400 meters along the entire crest of the range.

"It is said of the subterranean sounds heard in connection with the shocks that they sometimes seem to start in the north and move southward, and again they start in the south and move northward. The velocity of the transmission of a shock through granite is 2804 meters a second; the velocity of sound through the rocks should be eight or nine times as fast as it is through the atmosphere. This explains why the tremor and the corresponding roar are observed at very nearly the same time by persons four kilometers or more away from the mountain.

"The people of the region may be sure that there is no mysterious danger threatening them. The tremors and noises have nothing to do with outbursting volcanoes, but are simply the readjustment upon each other of the rocks within the mountain. These movements have always been harmless and they will continue to be."

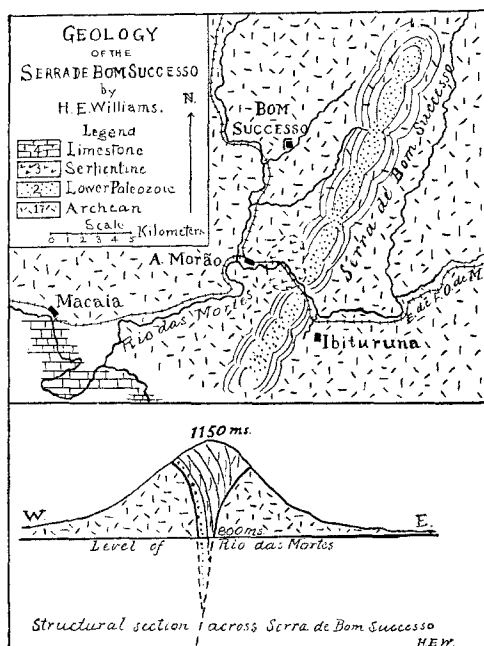


Fig. 1. Geology of the Serra de Bom Successo.

Comments upon the Geology.—Mr. Williams' letter quoted above is accompanied by a small geologic sketch-map of the region about Bom Successo. The sketch has been redrawn and is reproduced as an important part of his valuable contribution.

Being familiar with the general geology of southern Minas and with the structure so clearly suggested by Mr. Williams' sketches, I venture to make the suggestions that follow.

The Serra de Bom Successo is formed by a remnant of early Paleozoic metamorphosed sediments faulted down and thrust into the Archean granites and so closely pressed that the sedimentary beds are left standing nearly on end. The position of the conglomerates at the base of the sedimentary series shows that the fault plane is along the east face of the mountain range. As these metamorphosed sedimen-

tary beds, including conglomerates and quartzites ("itacolumites"), are more resisting than the granites on both sides of them they are left outstanding as the crest of the Serra. The greater thickness of the beds on the top of the range is due to the wedge-like shape of the infaulted mass. The mechanics of the process by which such blocks are thrust into the Archean granites is explained briefly at pages 204-205 of the "Outlines of the geology of Brazil to accompany the geologic map of Brazil," by J. C. Branner.¹ The illustration referred

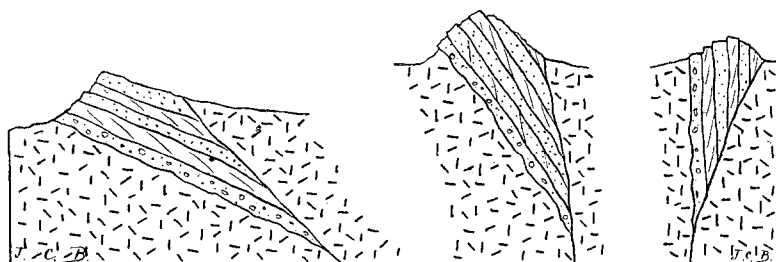


Fig. 2. Early Paleozoic beds thrust into Archean granites by faults and left in topographic relief.

to is here reproduced. A similar case is that given by Harder and Chamberlin in their paper on the geology of central Minas Geraes,² except that the sedimentary beds shown in the latter case have not been so tightly pressed as they have in the Serra de Bom Sucesso. Similar characteristic structures are widely scattered over the great Archean area of Brazil from Rio Grande do Sul to Ceará. Such masses vary in size from a thousand square meters to thousands of square kilometers, and the position of the old Paleozoic beds varies from horizontal to vertical or even to overturned.

In the article sent by Mr. Williams it is suggested that the earthquakes occasionally felt at Bom Sucesso may be due to dislocations caused by hydrostatic pressure within the mountain during and after rains. He is of the opinion that the removal of the matter by the circulating waters taken in connection with the wet talcose clays of the iron-bearing rocks affords conditions favorable for such movements. It seems probable, however, that the existence of the fault running the entire length of the mountain range is quite enough to account for all

¹ *Bulletin of the Geological Society of America*, 30, June, 1919.

² *Journal of Geology*, 23, 368, Chicago, 1915; also reproduced in *Bull. Geol. Soc. Amer.* 30, 265.

the earthquakes and for the subterranean sounds heard in the vicinity. That the oxidation of the iron ores, and the slippery nature of the wet clays may enter into the problem is quite possible, but it is also probable that without the fault there would be no dislocation of the beds capable of producing the earthquakes. It does not seem probable that the limestones along the Rio Grande or elsewhere in the region have any genetic relation to the earth tremors or to the rumbling noises. In other parts of the world no such relations have been found between limestones and earthquakes.

Evidences of displacement might possibly be found along the contact between the granites and the metamorphic sedimentary beds on the southeast side of the mountain. Such evidences quickly disappear and should be looked for as soon as possible after the earthquakes. The chances are that, if such signs of movements are visible at all, the displacements are quite small and may not exceed a single centimeter.

Of course it is not to be inferred that all faults are the seats of seismic disturbances, for some of them are sealed up and inactive, while others are still slipping from time to time. Mr. Willams' sketch-map of the geology of the Bom Successo region shows a fault at right angles to the Serra de Bom Successo passing along Rio Grande close to Macaia. But inasmuch as the intensity of the disturbances is higher at Bom Successo than at Macaia and Ibituruna it seems improbable that that particular fault has any direct connection with the shocks and sounds.

Conclusion.—The seismic disturbances that occur from time to time at Bom Successo in the State of Minas, are probably due to small dislocations on the fault that runs along the east face of the Serra de Bom Successo. This fault, however, is a very old one. It dates back to a period millions of years before the appearance of the human race on this globe, and the movements on it have so nearly ceased that they are rarely strong enough to produce a perceptible tremor of the ground five kilometers away. The nature of the shocks themselves, said to be like an upward blow, suggests that the center of the disturbance is only a few kilometers distant. The many sounds heard in connection with the disturbances are characteristic of small superficial movements or of shocks too feeble to be felt, and instead of foreboding danger, are to be regarded rather as evidence that the earthquakes are not likely to be serious.

So far as can be judged by the information received the intensity of the shocks felt at Bom Successo did not exceed IV of the Rossi-Forel scale, and it is even doubtful if it ever reached IV. Father Badariotti says in the letter quoted above that the disturbances at Bom Successo are not earthquakes, properly speaking, because: "A pendulum sixteen meters long did not swing more than two millimeters during the disturbances of June, 1919." The reason for this view may not prove that there have been no earth tremors, but it does prove that whatever tremors occurred were very weak ones. Earthquakes of such low intensity are quite harmless. In case of future disturbances efforts should be made to gather information in regard to the effects at other places than Bom Successo, especially at Macaia, Aureliano Morão, Ibituruna, and, if possible, along the east side of the serra, and to ascertain the location of the highest intensity. Such data will make it possible to draw the isoseismals on a map and thus to determine the location of the epicenter.

If some persons are nervously disturbed by the earth sounds common in the region, and if they cannot be convinced that such noises are harmless, it only remains for them to go elsewhere. The dislocations that produce the sounds cannot be prevented or abated in any way now known to man. Not even the government can stop the processes of nature within the earth's crust. Certainly the setting up of a seismograph is not going to help matters, however desirable it may be in connection with a scientific study of earthquake phenomena.

What Mr. Williams says of the harmlessness of the disturbances at Bom Successo is perfectly reasonable. The phenomena are as natural as the blowing of the winds, and the falling of the rain from the clouds, and are quite as harmless. Brazil is the steady part of the South American continent, and it is not likely to change its habits suddenly.

II. EARTHQUAKES IN THE VICINITY OF BAHIA

The region of Mesozoic rocks in the vicinity of the city and bay of Bahia, Brazil, is one in which light earthquakes are felt from time to time. Up to the year 1917, however, there has not been enough information available in regard to these small shocks and the rumbling sounds that generally accompany them to make it possible to locate the epicenter or the active fault from which the tremors radiate. Fortunately Dr. Theodoro Sampaio, the distinguished Brazilian engineer living in the city of Bahia, has taken the trouble to collect the available

data in regard to the shock that occurred in that region on November 7, 1917, and has published a report upon it in the *Revista do Instituto Geographico e Historico da Bahia*, no. 45, pages 210 to 222. The paper of Dr. Sampaio is therefore especially valuable as being the first to make it possible to determine, even approximately, the location of the area of highest intensity. The following account is condensed from the data collected and kindly communicated by him.

Mild shocks seem to have continued for several days, but the one of highest intensity occurred November 7, 1917, at 8:50 p. m., local time; there was another at 10 p. m., and a third at 4 p. m. the day following. The most detailed report was received from the town of Rio Fundo, seventeen kilometers northeast of Santo Amaro, and sixty-three kilometers nearly due north of the city of Bahia. The vicar of the parish, Father Liberto Bittencourt, says the shocks were so violent at Rio Fundo that the walls of several buildings were cracked, tiles were loosened and thrown from the roofs, pendulum clocks were stopped, mirrors and glass-covered pictures suspended against the walls were broken, while pottery and glassware were thrown from their shelves. The walls of the church were cracked and a cement drain pipe broken. The shocks caused general alarm, and several nervous persons were overcome.

Data gathered over the area affected seem to show that the intensity was highest along a line connecting S. Bento das Lages and Canabrava. Rio Fundo was apparently close to the epicenter. The highest intensity Dr. Sampaio places at VII of the R.-F. scale, and this fell away until at the city of Bahia it seems to have been between III and IV. At Cachoeira, Feira de Sant'Anna, Maragogipe and Alagoinhas the intensity appears to have been about the same as at Bahia, namely, between III and IV. The isoseismals shown on the accompanying map are drawn from the data given in the published article, though Dr. Sampaio would probably not want to be held responsible for such definite conclusions.

Several subsequent shocks are reported from Rio Fundo by Father Bittencourt as follows: A shock was felt at 9 o'clock p. m. on December 22, 1917, and two occurred on January 12, 1918, at 8 a. m. These last threw down the walls of an old house. On March 4, 1918, there was another tremor at 2 p. m. lasting for several seconds and accompanied by a dull rumbling sound. On March 22 two more shocks were felt, one about noon, the other about midnight. On the 27th and the 29th

of March mild shocks were felt about eleven o'clock a. m. April 14, between 4 and 5 a. m., there was a light shock, and for several days these continued, but the exact dates and hours were not recorded. The last shock reported at Rio Fundo by the Vicar occurred at 8 a. m. April 19, 1918.

The configuration of the ground is said to have been changed at several places, but unfortunately the details of these changes are not specified or the points located, except in the case of one at Colonia, which is about six kilometers northeast of Santo Amaro.

A letter from Dr. Sampaio says there was a repetition in November, 1919, of the earthquakes in the Bahia basin with a still higher intensity than that of November 7, 1917, but in a somewhat different area. The later shocks were most severe in the vicinity of Monte at the north end of the Bay of Bahia, thirty-five kilometers northwest of the city of Bahia.

In addition to the information obtained through Dr. Sampaio I have received from Dr. Henrique Morize, director of the Astronomical Observatory at Rio de Janeiro, copies of the following memoranda sent him from the meteorological stations located at São Bento das Lages and at Ondina and very close to the epicentral area referred to above:

SHOCKS OBSERVED AT S. BENTO DAS LAGES

July 29, 1919, seismic disturbance at 6 a. m.

November 11, 1919, seismic disturbance at 8:55 p. m.

December 13, 1919, shocks at 8:30 p. m., and again at 8:55 p. m.

December 16, 1919, strong shock at 6:55 a. m.

SHOCK FELT AT ONDINA

December 16, 1919, earthquake shock felt at 7 a. m.

The geology of the Bahia region.—The following notes on the geology are added from personal observations, and the accompanying map shows the outlines of the areas of sedimentary and Archean rocks. The geology is of especial interest in connection with the theory long ago advanced by Count de Montessus de Ballore, that synclines and the margins of geosynclines are weak terrestrial structures, and are therefore especially liable to seismic disturbances. The city of Bahia stands on Archean rocks, but the bay, the island of Itaparica, and a zone of Cretaceous and Tertiary sediments forming a geosyncline seventy-five kilometers wide, extends northward to and beyond the S. Francisco River, a distance of five hundred kilometers. No separation of the

Cretaceous and Tertiary is here attempted. Both east and west of this syncline the rocks are Archean granites, gneisses, and schists, cut here and there by Paleozoic dikes. On the west side of the basin the sedimentary beds dip gently eastward, and denudation gives them a ragged margin, but on the east side they are cut off abruptly by the Bahia fault against which they end. In the northern suburbs of the city of Bahia, not far from the Calçada railway station, a quarry exposes the eastern margin of this sedimentary basin let down against the older rocks by the Bahia fault, while about the shores of the bay one may see at many places, at low tide, the sharply wrinkled beds of Cretaceous shales. Mr. Roderic Crandall, who worked with me on the geology of Bahia in 1907, found a fault running along the west side of the bay of Bahia from the west side of Ilha Grande towards São Sebastião. The northward prolongation of this fault toward Nova Sorte would carry it along the line of the high intensity of the earthquake of November 7, 1917, but a little west of Rio Fundo, and one or two kilometers west of Terra Nova. This seems to be an active fault and one of much seismologic and topographic importance, but unfortunately it has not been located further north. The church at Nossa Senhora do Monte is on rocks that dip sharply to the northeast, and the axis of the syncline, which passes through Ilha dos Frades and Paramirim, is only two or three kilometers to the east of it. The extension of this syncline to the north cannot be given at present for lack of detailed information.

We therefore have in the geology of the region about Bahia a fairly satisfactory explanation of the seismicity of this sedimentary basin: it is a geosyncline with one large fault along its eastern margin, and with other faults cutting its slippery and unresisting beds of shale and soft sandstone.

It is very much to be hoped that Dr. Sampaio may be able to continue his valuable contributions to the seismology of the interesting Bahia region.

III. AN EARTHQUAKE IN THE STATE OF CEARÁ

The earthquake that occurred in the State of Ceará, Brazil, on November 24, 1919, was mentioned briefly in this BULLETIN, 9, 140. Since that announcement letters have been received from Ceará, and Dr. Henrique Morize, director of the National Observatory at Rio de Janeiro, has kindly furnished copies of the reports received

Aracahú, not felt.

Aracaty, not felt.

Canindé, long quake; loud noises; general alarm.

Cascavel, tremor felt; roar heard.

Fortaleza, tremor felt, lasting five seconds and accompanied by sounds like distant thunder.

Guaramiranga, tremor felt; roar heard.

Iguatú, not felt. (South of Senador Pompeu and off the area of the map.)

Maracanhú, tremor felt; roar heard.

Maranguape, tremor felt; roar heard.

Mondubim, shock felt; tiles slip; dishes rattle; roar heard.

Pacatúba, tremor felt six seconds.

Porangába, shock lasts four seconds; preceded by roar.

Quixadá, tremor; roar lasting three minutes.

Quixeramobim, very slight tremor.

Sobral, roar like thunder.

Viçosa, nothing felt. (West of Sobral and off the area of the map.)

Dr. Morize writes that the Ceará earthquake of November 24, 1919, was not registered by the seismograph of the National Observatory at Rio de Janeiro.

A letter from Barão de Studart, at Fortaleza, Ceará, contains this additional note: "On February 16, 1920, between 10:30 and 11 p. m., there was another earth tremor at Canindé, and the phenomena was repeated again on February 21."

The Geology.—The area of the State of Ceará over which these seismic phenomena are reported is mostly of Archean granites and gneisses cut by Paleozoic dikes. Along the sea coast is a belt of soft, nearly horizontal Tertiary rocks that varies in width from five to thirty-five kilometers, and laps back over the granites. Within this great Archean area, however, are many Paleozoic remnants that have been let down into the granites by faults as has been pointed out in regard to the geology of southern Minas in the first division of this paper. Unfortunately these Paleozoic areas have never been mapped in Ceará, so that the exact locations of the faults have never been worked out. It seems probable that somewhere in, or just west of, the Buturité Mountains there is an old fault on which slight movements occur from time to time. The fact that the earthquake was felt within so small an

area suggests that the movement which produced it must have been near the surface. It was not recorded at all by the sensitive seismograph of the National Observatory at Rio de Janeiro. Both the geology and the seismologic history of Ceará lead to the conclusion that severe earthquakes are not likely to occur in that State. The slight tremors with their accompanying rumblings are perfectly harmless.

ADDITIONAL NOTES

In Matto Grosso.—It has been reported to the National Observatory of Rio de Janeiro that an earthquake was felt at Corumbá and Cuyabá, State of Matto Grosso, in June, 1919; it is said to have lasted about eight minutes. The exact date is not given.

In Goyaz.—A light earthquake was felt at 6:30 p. m., June 1, 1919, at Santa Luzia, State of Goyaz. It was strong enough to rattle glassware upon the shelves and to disturb the furniture somewhat. It lasted about four seconds, and was accompanied by a rumbling sound.

New Seismologic Stations in Brazil.—At the urgent request of the government of Minas Geraes, the National Observatory of Rio de Janeiro will install a Wiechert seismograph in that State. Another one will be set up at the Engineering School at Porto Alegre, State of Rio Grande do Sul, and a third one, of the Bosch-Omori horizontal pendulum type, will be installed at Cuyabá in the State of Matto Grosso.