THE SONORA EARTHQUAKE OF 1887 [1]

By Jose G. Aguilera

The region in which the earthquake on the 3d of May was felt with greatest intensity and in which the greatest damage was done is the northeast part of the State of Sonora and especially the northern part of the district of Moctezuma and the northeast part of the district of Arizpe. . . .

The Path and Duration of the Earthquake

From the information gathered from all the inhabitants of the villages visited on this expedition with the purpose of obtaining a complete account of the seismic movements of May 3, 1887, we gather the following results: They agree for the most part that during the afternoon, during a time of the most perfect calm, under a sky which was very clear even for that part of the country, which is always blessed with a cloudless sky, suddenly a great vibration of the earth's crust was felt, which, in a few seconds, reduced the town of Babispe to ruins, causing the death of forty-two of its inhabitants and leaving twenty-nine badly injured. The principal shock was preceded by a deep low subterranean roar, which seemed to come from the hills to the north-

[1] The effects of the Sonora Earthquake of May 3, 1887, were described in a brief article by Geo. E. Goodfellow in *Science,* Vol. XI, 1888, and in a more extended paper by Jose G. Aguilera published in the *Anales del Ministerio de Fomento de la Republica Mexicana,* T. X, 1888, accompanied by topographic, geological, and seismical maps. The fault which caused the earthquake resulted in a scarp thirty-five miles in length in Northern Sonora, just south of the United States boundary, and the disturbance was felt over a wide area, extending from Yuma and Albuquerque on the north to the City of Mexico on the south. It was one of the very notable earthquakes that have affected the North American Continent; and since our information concerning it, in English, is rather scant, I have had Aguilera's paper translated. From the translation I have selected the series of extracts which are here presented in the hope that a summary account of the essential facts concerning so important an earthquake may be of interest to members of the Seismological Society. The summary is published with apologies to Mr. Aguilera for the liberties taken with so valuable a scientific document in condensing it, and for the shortcomings of the translation.—Andrew C. Lawson.

east of Babispe. After this very heavy shock there followed others of a slightly less intensity, to the number of two or three.

According to the observations of the very few people who were able to preserve, even in some slight degree, their presence of mind, and for this reason could judge with more accuracy of the progress of the phenomenon, as well as of the terrible destruction which it caused, the principal shock was preceded by certain relatively feeble vibrations. These were not observed clearly by most of the inhabitants because they were asleep at the time. They state that the entire duration of the phenomenon did not exceed forty seconds, that the duration of the shocks was in the same proportion as their intensity, that the shock which threw down the buildings lasted from ten to fifteen seconds and that each of those which followed lasted from five to ten seconds and that they were followed by very short intervals, which were estimated as not exceeding four to five seconds. . . .

From that time until the present earthquakes have not ceased, but they have been of varying intensity. They have always been very much lighter than that of the 3d of May, and the intervals between them, though very irregular, become greater as the time goes on. In the days immediately following the 3d of May the temblors succeeded each other very closely; sometimes six or eight were felt in a day, but later the number decreased to such an extent that during my stay in Babispe, which was for fifteen days during the month of August, I only felt two; one heavy and the other light, the first being an oscillation lasting about five seconds, and the second about three seconds, in the approximate direction of NW.-SE. . . .

The Territory Covered by the Phenomenon and Its Method of Movement

The seismic movement which we are studying did not have the same force for the same distance in every direction, but was more noticeable to the southeast than in any other direction; and extended over a large zone limited on the south by the valley of Mexico, on the east by el Bolson de Mapimi, on the west by the Gulf of California and the Pacific Ocean, and on the north by an oblique curving line which extends from Santa Fe, New Mexico, to the junction of the Gila and Colorado Rivers, passing Prescott, Arizona, on the south. This district, though irregular in outline, marks a triangle whose respective vertices are Santa Fe, Yuma and the City of Mexico; and it embraces, according to the boundaries mentioned above, a surface of

1,200,000 square kilometers. From the shape and dimensions of the district in which the seismic movement was felt, we find that the position of the mountains had a remarkable influence on the movement of the seismic waves. They are not an absolute check to the movement, but weaken it remarkably when its direction is perpendicular to the trend of the mountain, this being the reason that the wave traveled a shorter distance to the east and west, while it extended further to the southeast, because this is the general trend of the orographic elements of the western part of the Mexican Republic. . . .

FISSURES, DEPRESSIONS, LANDSLIDES, ETC., DUE TO THE EARTHQUAKE

In the Hacienda de la Cruz, to the north of Granadas, numerous cracks were produced. . . . To the north of Bacerac at a distance of 3,350 meters along the road which leads to Babispe, is found a series of fissures which occupy a district about 250 meters in breadth between a low range of hills called the Burro Hills and the left bank of the River Babispe. . . .

The ground in which these cracks are found is like that in which all the cracks in the valley are found, composed of alluvium and diluvial clay like that found in all the valleys visited in this expedition.

The cracks formed in the vicinity of Babispe emitted water mingled with a fine yellowish sediment which I could see at the sides of the walls of the cracks. It is a very fine sand exactly identical with that of the river which runs at a distance of 800 meters from the place.

Most of the cracks have appeared in the valleys close to the actual bed of the river. The most distant is about 890 meters from the river's bank upon alluvial soil and diluvial clay. These cracks are always parallel to the direction of the river. The most notable cracks are those nearest to the river, and the depressions become greater in proportion as they approach nearer the river's edge, so that they form a sort of irregular series along the side of the bank. It is unusual to find more than three successive depressions in the same direction and very usual to find two, while a single one is of rare occurrence.

In the eastern edge of the valley of Batepito between the river of the same name, which runs for the most part through the valley, and the slope of the mountains which are a continuation of the range of Teras, the dislocations and other effects of the temblor are seen in their greatest intensity; it is in this part of the valley that we may locate the

epicenter. In the floor of the valley and very close to the left bank of the river the ground is irregularly cracked over an area two kilometers square. Here vertical movements predominated over oscillatory movements, that is to say, that the shock or percussion beneath was transmitted to the surface along a vertical line. The ground in this location is depressed as well as affected by the slipping which accompanied the opening of the great fissure or fault which appeared in the ridges of La Cabellera, Pitaycachi, Los Embudos and Guadalupe, in a direction parallel to that of these ranges, and consequently to that of the valley which they enclose.

The large crack and slipping (fault) begins at a distance of one hundred meters from the right bank of the river Babispe in a canyon which connects the valley of Babispe with that of Batepito, and which, according to our guide, is known as the Cajon del Alamo. The fault appears in alluvial ground which rests upon a bluish grey andesite at a depth of ten meters. The width of the crack is at first very small, as it starts in a mere line, but rapidly widens to 0.15 of a meter, at which width it remains for a considerable part of its course. The walls of the crack are perfectly vertical, and its two edges have exactly the same level. Its depth is very difficult to estimate exactly, as is the case for the entire length of the fault, because the caving of the walls and the rains have filled up the lower part, leaving it still about 10.9 meters in depth.

The fault is found in general through the mountains of La Cabellera, Pitaycachi, and Los Embudos, on the slopes of which it appears as a curving line whose mean direction is parallel to these ridges, which are a continuation of the range of Teras. It presents from a distance the appearance of a great stone wall built on the slope of the ridges, because the left side of the fault has been depressed, and, with it, the whole valley to the east almost as far as the river Batepito, leaving bare the face or cliff of the eastern wall of the fault. At its beginning, for several meters, the fault is divided into two lines which form an angle of 12°, the direction of the larger branch being 38° NE.-SW. and that of the other 26° NE.-SW. For this short distance there is no depression, and the two sides of the cracks have the same level.

From the end of the crack on the right bank of the river Babispe for about 110 meters of its course it has a direction of 5° NE.-SW. It follows the slope of the low hills which form the western end of the

range of Teras in their prolongation to the north, and is found in the strata of alluvium and detritus of the andesite rocks which form the bulk of the Sierra Madre. These are of a thickness of four meters and rest upon the bluish green breccia which we have described as occurring upon the slopes of the ranges and as being formed by the destruction of andesite of various kinds of texture. At this point it meets a slight highland formed of this andesite breccia, resting upon andesite, which for this reason offers a greater resistance. The crack deviates from its original direction, and in bending more toward the east changes its strike from 5° NE.-SW. to 30° NE.-SW., that is to say, it forms in this direction an angle of 25° with its direction previous to meeting this height.

The slipping of the western wall of this crack reaches an amplitude of from 0.6 to 1 meter. The crack follows the ascending elevation of the mountain, leaving to the left the height which compelled it to change its course, and it again changes its direction to 20° NE.-SW. With this same course it continues through the next hill, which it divides almost exactly in halves without exceeding a breadth of 0.8 meter. Its slipping does not exceed one meter, and its depth varies between 1.2 and 2 meters. The fault has the mean direction of 20° NE.-SW. for a considerable distance, which includes that part between its southern extremity and the point where it crosses the road from Batepito to Babispe. In this part the fault ascends and cuts in the same general direction as that of the hills which bound the valley of Batepito to the east. Sometimes it cuts through the little creeks, leaving an exactly perpendicular crack. As it ascends the hills it follows a curve concave toward the west, that is to say, toward the valley, and forms other curves as frequently in the marshes as on the hills. It is noteworthy that the curves on the hills are usually concave toward the valley. We may say that in this section the fault is composed of curving elements which follow for the most part a single direction; but this is not true of the remainder of the fault, in which, as we shall see later, each of these curves is divided into elements of diverse direction, the resultant always following the direction of the tangent to the curve, whether it be concave or convex from the point of view of the valley.

Where the crack crosses the road to Batepito the slipping of the west wall is 2.7 meters, the width 1.5 and the depth four meters. The walls are not vertical but inclined, forming an angle of 75° with the horizontal plane in a portion of the crack and an angle of 88° in

another very close to the first and situated farther north. . . . From this point northward the crack slants first to the north, then to the west, having in a distance of five kilometers a strike of 10° NE.-SW.; then it changes its strike to 20° NW.-SE., which it keeps for a little while, and then changes to 10° NW.-SE. So it goes on, deviating now to the east and now to the west from its general line, but never passing out of these two quadrants.

Close to the basin of La Cabellera the large crack has a strike of 20° NW.-SE., with a width of from two to three meters and its western wall is depressed eight meters. After following this strike for a distance of 600 meters it changes its direction to 10° NW.-SE. At Penasquito it runs north and south with a width of four and a depth 4.5 meters. The opening has been filled up partially by the caving of its walls, which may induce us to think that the recently opened crack had a greater depth than that south of this point.

Upon passing from the Sierra de la Cabellera to that of Pitaycachi the crack changes its course again to 22° NW.-SE. Its western edge is still depressed to a depth of four meters, which may be considered as true of all the distance between this point and that mentioned above. As was the case at every point at which I have seen the crack, it here appears in alluvial ground of which, as I have said before, all the hills are formed, and in which we find the beginning of the mountain slopes.

The fault between this point and Los Embudos continues to change its direction alternately from 20° to 10° or 5° NW.-SE., and afterwards to 5° NW.-SE. Following this angle it reaches the arroyo of Los Nogales, where it forms a bend which changes its course to 10° NW.-SE. The depression of the western wall of the fault to the extent of 1.8 or 2.5 meters continues, and its walls have an inclination of about 80°. In the canyon of Los Embudos the fault has a direction of 30° NW.-SE., and the depression is not more than 2.5. The width and depth are about the same as those spoken of in the last paragraph.

After passing from the Sierra de Los Embudos to that of Guadalupe, the fault changes its direction to 40° NW.-SE. and begins to form a large curve whose mean tangent has a direction of 55° NW.-SE., then runs almost exactly east and west and at last assumes a mean direction of 42° NW.-SE., which it retains to the end of the fault, which is found in the edge of the ravine of Cuchuberachi.

Near its northern end the two edges of the fault have almost the same level, as the depression is scarcely 0.2 of a meter. The incli-

nation, of the undepressed wall is 75° to the east, but we are not to consider this as the true inclination, on account of the slight cohesive force which unites the pebbles and cobble stones and the sand which forms the alluvium of the walls of the ravine where the crack ends. Its width in this part is very slight, never more than 0.4 of a meter for a distance of 500 meters from the end, and at the end it would be a mere line if it were not for the loose structure of the ground. The mean depth for a hundred meters from the end is 7.5 meters.

The large crack whose position and dimensions we have just described is not found alone, but, like most such phenomena, is accompanied by a large number of cracks of secondary and tertiary order, whose lengths vary from a few meters to two and three thousand meters. These are situated for the most part at the sides of the main one and at some little distance from it, forming at times a zone 300 meters in width. The direction of the cracks of secondary order is for the most part parallel to that of the principal one, or else they form acute angles with it, of not more than 15° or 20°. The direction of the cracks of tertiary order is practically perpendicular to that of the principal crack.

As has been said before, the crack caused by this fault or breaking on the slope of the ridges of the continuation of the range of Teras, is not a straight line but a curved line composed of straight and curved elements, which without exception are concave toward the valley, or in the direction of the general depression. We should further note the constancy with which another phenomenon is repeated at every point along the length of the crack, where a straight section meets a curve. This is that the straight section is always prolonged in a direction tangent to the curve for a distance of from 10 to 800 meters, and that when a curve joins a straight section it is never met as by a secant, but always as by a tangent. But in this case there is no crack or crevice which forms a prolongation of the straight element. This constant characteristic of the change from a curving to a straight element, indicates that the crack was formed as we have described above, that it is the same which we were following in the valleys, and that it has a general direction of from 10° to 15° NW.-SE. terminating in lines which are very much inclined toward the west. . . .

The epicenter of the temblor, or the place from which the vibrations radiated, is in the form of a curve of the same direction as the

large fault already described, with a length of approximately two kilometers. Here cracks appear at every possible angle; but we cannot find a common center for them in order to identify it as a central point of the surface transmission of the earthquake. . . .

Besides the numerous cracks which appear in all the valleys near the epicentral region, landslides of much importance occur in the mountains. These caused blocks of as much as 200 cubic meters to crash down to the beds of the valleys and in some cases where the valley was very narrow, the rocks on striking the floor have rebounded to the opposite side. These landslides have been most numerous upon the range of Teras, especially in that part of it which forms the valley of Babispe and Huachinera and that of Oputo and Guasabas. Here there are few peaks or summits of much elevation in which one cannot discover traces of loose stones left by these great blocks in their descent. Next to the Teras range the Nacosari range has the greatest number of landslides. The slipping of the hills did not reach the same proportion at points situated at equal distances from the epicenter nor could it be found that its magnitude diminished as the distance from the epicenter increased, but that its magnitude was inversely proportional to the cohesiveness of the rock, and directly proportional to the intensity of the shock. Thus where the intensity was equal, and the rock which composes the hills has suffered the greatest erosion through atmospheric action, the slipping was noticed to the greatest extent, and also on the summits which held large boulders in a state of unstable equilibrium, where the slightest oscillation was enough to loosen their hold upon their narrow base of support and send them swiftly down into the valley with destructive force. On the other hand, in proof of this assertion, I will say that I have not found a single case of slipping among the granitic mountains, and this because, for a part of their height, they are always free from needles, boulders and protruding crests, the structure of the granite giving no opportunity for the occurrence of those capricious groups of rocks which perform literal miracles of balancing, such as basaltic, trachytic and andesitic mountains sometimes show. As is well known, the erosion does not take this form in the granite, because the rock does not offer the numerous deep lines which cooling usually causes in the basaltic and trachytic rock, and for this reason its bulk is more compact and offers more resistance to shocks and vibrations, especially if it is covered by strata of sand of a more or less coarse texture, which is a rather advanced product of its disintegration.

The slipping does not actually correspond to the intensity of the seismic disturbance in the exact points where it occurs. It corresponds rather to the degree of disintegration of the rock and to its state of equilibrium. There are places in which the shock was very slight, not having sufficient force to destroy even the poorly-built walls of the houses, and where it nevertheless caused great landslides.

The relation which I think I have found between these landslides and the intensity of the earthquake is as follows: within certain limits of intensity they are directly proportional to the horizontal component of the vibration, that is to say, that they will be more abundant and of greater importance where the movement is oscillatory even though it has less intensity, than at a point where the vibration is vertical. In the district in which the temblor is approaching an oscillatory character we first find the landslides, since the loose rocks are dislodged by this oscillation and the force of gravity joins with the force of the shock to cause the slipping. . . .

Although the whole city of Babispe is now in ruins the destruction due to the seismic wave was not the same in every part of it. The number of houses destroyed is much less in the western than in the eastern half of the city, and those on the north suffered more than those on the south. If we consider simply the walls and take into account only their direction, those which run east and west resisted the wave better than those which run north and south. The order in which the walls should be placed in the order of their destruction, is as follows: first, the eastern walls of the buildings, which were almost totally destroyed; second, the western walls, which in the eastern part of the city were destroyed as completely as the eastern walls, but which in the western part of the city offered slightly more resistance; thirdly, the southern walls, which were more completely destroyed than the northern ones.

The direction in which the walls fell is always toward the east for north-south walls, and generally toward the south for the east-west walls. There are some in the center of the town which fell to the north, as if there had been a reflection of the wave against the hill which bounds the city of Babispe in the latter direction.

As I was anxious to apply the method of Mallet to determine the focus, I tried to take the general direction of the cracks in the walls in order to find the angle of emergence of the wave, and I found so much variation and confusion in them that I gave it up at last as a task

which seemed useless. In some of the walls the cracking was vertical, with simple cracks in the lower part which split in two in the upper. Upon encountering a course of bricks which offered more resistance to the shock than did the adobe of which the houses of the towns north of Sonora are generally constructed, the crack would then form the shape of a Y. At other times the direction would be oblique and in the same wall cracks of the same size were found with an inclination of 10°, 30° and 45°. In some cases these were also accompanied by vertical cracks. All the non-vertical cracks dipped constantly toward the east.

I did not have a chance to observe the truncation of the corners of the buildings, but I noticed that in the case of east and west walls this always occurred at the east corner of the wall and never at the west.

From all the foregoing it is concluded that the path of the wave was NW.-SE., tending very much to the west, which may be explained by considering that between the epicentral region which is to the northwest of Babispe, and the town, the Teras range interposes. The latter has approximately this direction and upon its eastern slope stood the village of Babispe upon an incline which marked the last elevation of the end of the range at the edge of the plain where it has a direction almost due east and west.

In the village of Oputo, which suffered most, next to that of Babispe, the walls fell toward the west, and the truncations of the corners were more numerous to the south and west than to the east and north, and the walls which suffered least were the east-west walls. These suffered truncation of the corners on the west.

In Fronteras some houses were destroyed but not as many as in Oputo, and the walls fell toward the west.

The Rancho San Bernardino is the most interesting of the other towns and ranchos which were overthrown by the earthquake, because of the proof which it furnishes of our having found the true location of the epicenter. In this rancho, which is almost to the north of the epicenter, the walls were entirely destroyed. We may remark that they fell toward the north and toward the west.

Among the phenomena which accompanied and followed the temblor, the inhabitants of Sonora especially noticed the remarkable increase in the volume and rate of the tributaries of the river Yaqui, especially in those of Batepito, Fronteras and Babispe. There appeared

new rivulets and others disappeared. Already in describing the cracks I have mentioned the cause of this flood water in a season of the year in which the whole state is usually dry. As a result of these little overflows of the surface which in some places were of considerably more importance, light clouds appeared before sunrise in the days immediately following the earthquake.

Another effect of the earthquake which terrified the frightened inhabitants of these places, was the fire upon all the mountains around the epicenter and even some situated in the territory of Arizona, among others the ridge of San Jose. Some of these it is said continued in flames for many days. To the light and smoke of these, it would appear, is due the report that a volcano had appeared, which the extravagant imaginations of those who had just experienced the terrible erthquake, located in various parts of the State, most probably in the direction from which the flame and smoke appeared most constantly. The explanation of this mountain fire is, in our opinion, that the jarring of the stones forming the many peaks which suffered landslides, generated heat enough to set fire to the dry grass which is especially dry at this season of the year. Beginning in this manner the fire quickly spread making a general conflagration. It is possible, too, that in some places it was only an accidental coincidence between the day of the earthquake and the day in which the burning of the pastures took place, as the latter is no rare phenomenon in this place and generally takes place in the months of May and June.

Determination of the Epicenter and Focus of the Earthquake

Of the various known methods for determining the depth of the focus of an earthquake, that of Messrs. Dutton and Hayden of the U. S. Geological Survey seems to me to be the best, because it takes into consideration all the components of the vibration and considers all the manifestations of the intensity of the vertical, as well as the transverse waves. This method is based upon the law followed by the intensity of the temblor. There exists a fixed relation between the depth of the focus and the distance from the epicenter of the place in which the decrease of the intensity is most rapid. This relation is $1/\sqrt{3}$. From the location of the point at which the decrease of the intensity is greatest with respect to the epicenter we determine the depth of the focus of the temblor.

In order to apply this method, it is necessary to know the epicentral region, and to determine upon the surface, through the effects

of the earthquake, the distance from the epicenter, of the region in which the relation of the decrease to the intensity has reached its maximum. In the present case, judging by the cracks in the earth, it is definitely marked, being about ten kilometers from the epicenter. It is a zone where, although there are many manifestations of the force with which it was shaken, they are relatively slighter in proportion and form a perfect ring, nine or ten kilometers in width, in which the transition has been notably sudden. If we take this as the distance at which the relative decrease of the intensity of the earthquake has reached its maximum, and as that corresponding to the point in which the curve of intensity changes its degree, we find as the depth of the focus of the earthquake of May 3, 1887, eighteen kilometers.

In order to determine exactly the epicenter, it has been necessary, since we could not apply either the method of Sebach or of Mallet, to make use of the damage done by the earthquake and to find the region in which it reached its maximum, taking this as a central point from which radiated the vibrations. In order to do this I continued my observations and studies as far as Hermosillo, noticing both the direction in which the walls had fallen, which gave me, though inexactly, the direction of the epicentral region, and the reports of the inhabitants of the villages, especially the nearer ones, who told me in about what direction they had felt the vibrations of the earthquake. I should add that while I was in Babispe I felt a number of shocks and frequently heard roars and murmurs which in every case came from the northwest. As I continued my explorations to the northeast, north and northwest of the epicentral region, I was enabled to convince myself that the roars and light shocks which I felt came from the same direction in which lies the meridian of the valley of Batepito, near the confluence of the Babispe and Batepito rivers.

As it is here that the effects of the earthquake are shown in their greatest intensity, and the destruction becomes less as you leave this center in all directions, and as the zone in which the intensity has most rapidly decreased is perfectly marked in this direction, I have no doubt that the epicentral region is at 30° 48′ 24″ north latitude, and 109° 5′ 55″ longitude west of Greenwich. These are the coördinates of the central point. The epicenter has the form of a curve two kilometers in length approximately, and running parallel to the great crack which occurs in the slope of the ridges of La Cabellera, etc.

The Velocity of Transmission

Taking as the initial moment $2^h\ 12^m$ p. m., Pacific time, which corresponds to the 120th meridian west of Greenwich, we find the time of the principal shock of the 3d of May to have been $2^h\ 55^m\ 36^s$, according to the time of the valley of Batepito, or $3^h\ 35^m\ 32^s$ p.m., according to the time of the City of Mexico. The time given here is that generally accepted as most probable, but it is not known with exact certainty because the inhabitants of Babispe, Fronteras and San Bernardino, who were the first to feel the shock, on account of their closeness to the epicentral region, did not know that the knowledge of the exact moment in which the phenomenon began, was of any importance. Fortunately the railway officials of the Sonora, Central Mexican and Southern Pacific noted the time at which they felt the temblor at each point, and by availing ourselves of these notes with which Dr. Goodfellow had the kindness to oblige me, we may determine the velocity of transmission, though with less accurate approximation, on account of the fact that in observing this class of phenomena it is necessary to carefully note the exact arrival of the wave.

From Batepito to Guaymas there is a distance of 348 kilometers. The wave was retarded in this distance three seconds, at a time when its velocity was 1,993 meters.

To Nogales is 174 kilometers; time of transit one minute, velocity 2,900 meters.

	Distance Kilometers	Time Minutes	Velocity Meters per sec.
To Benson	174	2	1,450
To Phoenix	414	6	1,150
To Wilcox	165	3	916.6
To Deming	198	2	1,650
El Paso	270	2	2,250
Mexico City[2]	1,570	9.35	2,730
Tombstone	145	1	3,416
Hermosillo	240	2	2,000
Crittenden	177	2	1,475
Fairbanks	177	2	1,475
Between Gila Bend and Maricopa	54	1	900
Tucson to Maricopa	138	1	2,300
Tucson to Gila Bend	183	1	3,050

This is very high and there must be an error in the times noted or in the watch of the observer.

[2] It is almost certain that the time noted in Mexico is not that which corresponded to the arrival of the wave.

From all the velocities calculated we find that at a minimum distance from the epicenter of 200 kilometers the mean velocity is 1,977.6 meters; that at a distance of less than 400 kilometers the mean velocity is 1,197.6 meters, and finally that up to 600 kilometers the velocity scarcely reaches 1,187 meters. Rejecting the velocity which we have found for the City of Mexico, and that for the section from Tucson to Gila Bend, which are incredibly high and doubtless due to a mistake in noting the time, we find a mean velocity of 1,772 meters, which is much greater than the velocity observed in earthquakes for the last few years.

Probable Cause of the Temblor

. . . The earthquake occurred in a region without modern volcanoes, although at many points in the State of Sonora basaltic rocks are found. These, however, appear to have made their appearance, at least such of them as are found in the Sierra Madre, not through true craters but upon lines parallel to the orographic elements, and this fact, together with that that the earthquakes have not yet ceased, persuades me to accept as a probable cause of the series of vibrations which began May 3, 1887, a fracture of the ancient rocks which were dislocated at the time of the extrusion of the eruptive rocks and afterwards covered by the quarternary sedimentary formation. That these have continued in energy, until they have overcome the resistance offered by these quarternary strata, and also the effect of the lateral pressure which the elevation of the continent has each time increased; because in my opinion, the lifting of the Sierra Madre has not yet ceased.

As theories and hypotheses concerning the causes which produce earthquakes are numerous and among them the hypothesis of Perrey has found many adherents, I add the hour at which the moon passed the meridian in the Batepito valley on the 3d of May. This was $9^h\ 4^m\ 6^s$ astronomical time, and in order that you may judge whether the time of the temblor was coincident with the time of the proximity of the moon to the earth, I add also the times of the perigee and apogee of the moon for the month of May. Perigee: $4^d\ 23^h\ 12^m$ astronomical time, $11^h\ 12^m$ a. m., standard time. Apogee $16^d\ 22^h\ 54^m$ astronomical time, which is $10^h\ 54^m$ a. m. of the 17th of May, standard time.

Hermosillo, March 9, 1888.