IOP Conference Series: Materials Science and Engineering

**PAPER • OPEN ACCESS**

# Magnitude estimation of the 1900 earthquake in Venezuela based on its coseismic effects

To cite this article: R Vásquez *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **872** 012034

IOP Conf. Series: Materials Science and Engineering **872** (2020) 012034 doi:10.1088/1757-899X/872/1/012034

# Magnitude estimation of the 1900 earthquake in Venezuela based on its coseismic effects

**R Vásquez[1], A L Guzmán[1], J A Rodríguez[2], S Colón[2], F Audemard[2] and Mauricio Cabas[3]**

[1]Departamento de Sismología, Fundación Venezolana de Investigaciones Sismológicas (FUNVISIS), Caracas, Venezuela
[2]Departamento de Geología de Terremotos, Fundación Venezolana de Investigaciones Sismológicas (FUNVISIS), Caracas, Venezuela.
[3]Universidad de la Costa, Barranquilla, Colombia

**Abstract.** The 29 October, 1900, earthquake occurred in Venezuela triggered six landslides and six liquefactions located in the center-north region of Venezuela and La Tortuga island. Due to the location of the coseismic effects, the barycenter and the focal depth related to this earthquake, it was possible to calculate the magnitude by using several statistical methods. The results show a magnitude in the range 7.4-7.7 $M_w$, with an average value equal to 7.6 $M_w$, which is consistent with the instrumental magnitude of 7.6 $M_w$ obtained by Fiedler (1988) and the macrosismic magnitude by Vásquez *et al.* (2018) equal to 7.5 ± 0.3 $M_w$ estimated by using the Bakun and Wentworth (1997) method.

## 1. Introduction

The earthquake that occurred on October 29 of 1900 is considered one of the most important events in the seismic history of Venezuela due to its location, its great magnitude and the effects it produced on the building environment of the time and on nature. This event was widely felt in the national territory and in Trinidad, producing fatalities, injuries, victims and significant material damage in the epicentral zone located in the central-northern region of the country, mainly in the states of Anzoátegui, Aragua, Carabobo, Capital District, Miranda and La Guaira [1].

Due to the extensive quality documentation gathered and presented by [2], this earthquake has been subjected to a total re-evaluation based on macro-seismic information recently analyzed by an interdisciplinary group of researchers made up of anthropologists, historians, seismologists and geologists that belong to the Fundación Venezolana de Investigaciones Sismológicas (FUNVISIS). Among the studies carried out to date, the following research works stand out: the estimation of intensities according to the Modified Mercalli scale (1956) and the ESI 2007 macro-seismic scale, as well as the calculation of the source parameters [2,3,4]. The results show a barycenter located in the Caribbean Sea, north of Cabo Codera, an average focal depth of 44.5 km and an equal macro-seismic magnitude of 7.5 ± 0.3 $M_w$, which is consistent with the instrumental magnitude of 7.6 $M_s$ presented by [5] through the analysis of seismograms recorded by the Pamplemousses and Kew observatories located in Mauritius and England, respectively.

The coseismic effects derived from the earthquake were well documented and are located mainly in the Venezuelan coastal region (between Puerto Cabello and Barcelona) and extend into the Caribbean Sea to the islands of La Tortuga and Los Roques. Information obtained from primary sources includes cracks, tsunami, liquefactions, hydrothermal anomalies, landslides, lateral spread, seismic avalanches, seiches and wildfires [1]. The objective of this research is to apply different methodologies that allow to calculate the magnitude of the 1900 earthquake based on the location of the barycenter, its focal depth

IOP Conf. Series: Materials Science and Engineering **872** (2020) 012034 doi:10.1088/1757-899X/872/1/012034

and the geographic distribution of the landslides and liquefactions in order to compare the results with those obtained by [3,5]

## 2. Data

An earthquake can trigger a large number of coseismic effects simultaneously and at great distances from the epicenter, including landslide and liquefaction. Landslides are defined as any geomorphological process in which there is vertical displacement of lithological material due to gravity [6] and are generally located in mountainous areas characterized by high slopes and unstable hillsides. According to [7] "*Soil liquefaction is understood as the temporary transformation of saturated granular materials into a liquid state, as a consequence of increased pore pressure (e.g. Bard, 1992). Certain conditions are required for this to occur: (1) they must be young soils with low compactness; (2) the presence of saturated sand layers interspersed with clay layers, and (3) in sedimentary environments of recent formation*". Although the location of landslides and liquefactions are mainly concentrated in the epicentral zone, the surface area covered by them and the number in which they occur increases with magnitude [9-10], as do other earthquake parameters such as maximum intensity, epicentral intensity, area of perception and exposure degree. The study of these cosiesmic effects is of great importance in the field of Earth Sciences because they can cause significant human losses and catastrophic damage to buildings and road infrastructure [11, 12].

Based on the documentation of primary sources collected about the earthquake of October 29, 1900, it was possible to identify the occurrence of six landslides and six liquefactions located in the central-northern region of Venezuela and La Tortuga Island. Table 1 shows the information reported by locality, taken literally from [1] and the geological interpretation that was assigned to each cosmic effect extracted from the article recently prepared by [4].

**Table 1**. Landslide and liquefactions reported for the October 29, 1900 earthquake (taken from Columbus et al., submitted).

| Location | Effect reported in the documentation | Interpretation |
|---|---|---|
| Barcelona | (1) In some saline wells, the water jumped a few meters above its natural level and was then shaken by a strong wind. Fine sand from the previous layer of the alluvial soil came out through the crayfish (Astacus Fluviabilis) caves and also mud. The same thing happened on the northwest coast of this city.<br>(2) On La Borracha island, which is almost to the north of Barcelona, a rocky point fell on the northwest side and cracks opened up to the southwest. | (1) Liquefaction<br>(2) Landslide |
| El Hatillo | Deep cracks were reported in the salinetas, from which dirty water flows. | Liquefaction |
| La Tortuga Island | On La Tortuga Island, a piece of mountainous terrain fell. | Landslide |
| Carenero | Everywhere there were open areas where black, sulphur-smelling water has sprung up. Between Paparo and Carenero, in a space of five leagues, more or less large wells sprouts of a bituminous liquid which, in some places, formed small lagoons. The sinking of the station and of several houses, without expressly mentioning flood. | Liquefaction |
| Caucagua | Cracks on the road from Guatire to Caucagua. | Landslide |
| Guatire | (1) The same witness pointed out that springs and small water volcanoes opened up at several points on the ground, but that he had not seen them personally.<br>(2) Another witness points out that he did not see the cracks, but rather collapses, describing them as "some pieces of a hill that had fallen away, but that cannot be called cracks". | (1) Liquefaction<br>(2 Landslide |
| Panaquire | In several places in the vicinity of this village, cracks about 300 meters and more have opened up; from these openings, a black, muddy sand emerges that gives off a strong smell of Sulphur. There are places where this material formed layers more than a quarter thick at the edge of the cracks and over a long distance. | Liquefaction |

## 3. Methods

Papadopoulos and Lefkopoulos (1993) [9] propose an empirical relationship of the maximum distance at which liquefactions can occur as a function of the magnitude of an earthquake, obtained through the application of linear regression models with information from liquefactions generated by earthquakes in Greece, New Zealand, California, Venezuela, Iran and the Philippines. The relationship establishes that:

$$M_w = -0{,}31 + 2{,}65 \times 10^{-8} R_e + 0{,}99 \log(R_e) \quad (1)$$

Where $M_w$ is the magnitude of seismic momentum and $R_e$ is the distance (measured in cm) of the farthest liquefaction from the epicenter of the earthquake under study.

Based on data from 47 landslide produced by earthquakes in Greece between 1650 and 1995, Papadopoulos and Plessa (2000) [13] propose an empirical relationship between the maximum distance at which this coseismic effect is generated as a function of magnitude for events with magnitude in the range of $7.5 \geq M_s \geq 5.3$ which is equal to:

$$\log(R_e) = -2{,}98 + 0{,}75 M_s \quad (2)$$

Where $M_s$ is the surface wave magnitude and $R_e$ is the distance (measured in km) of the furthest landslide from the epicenter of the earthquake under study.
Bommer and Rodríguez (2001) [14] used information from landslides triggered by earthquakes in southern Mexico, Panama, Costa Rica, Nicaragua, Honduras, El Salvador, Guatemala and Belize to propose a linear regression model of the area (measured in $km^2$) covered by these geological phenomena when they occur as a result of the occurrence of an earthquake as a function of the magnitude of surface waves ($M_s$) for the Central American region, the results of which are shown in Figure 1.

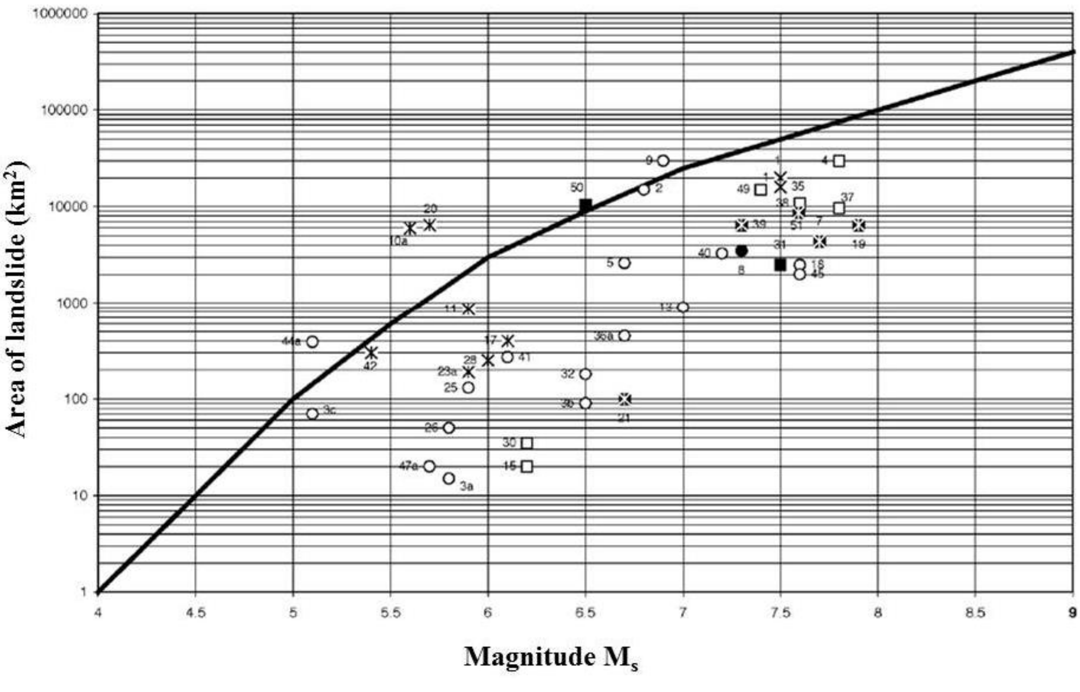


**Figure 1**. Relationship of the area of landslides for earthquakes of magnitude $M_s$ in the Central American region (taken from [14]).

IOP Conf. Series: Materials Science and Engineering **872** (2020) 012034 doi:10.1088/1757-899X/872/1/012034

Making a statistical study of earthquakes in the magnitude range of 5.2 to 9.5 that have generated landslides at the global level, Keefer (2002) [15] proposes a linear regression model equal to:

$$\log(A) = M - 3{,}46(\pm 0{,}47) \quad (3)$$

Where A is the area (measured in $km^2$) covering the landslides generated by an earthquake of magnitude M.

The conversion of $M_s$ to $M_w$ is done using the empirical relationship proposed by Ambraseys and Adams (1996) [16] where:

$$\log(M_0) = 24{,}578 - 0{,}903M_s + 0{,}170(M_s)^2 + 0{,}0043(h - 40)p \quad (4)$$

In equation (4), $M_0$ is the seismic momentum and h is the focal depth (measured in km) of the earthquake under study. It is considered that p=0 for h < 40 km, otherwise p=1.

The seismic momentum $M_0$ is measured in dyn.cm and its relation to the magnitude of seismic momentum $M_w$ is given by:

$$M_w = \frac{2}{3}\log(M_0) - 10{,}7 \quad (5)$$

## 4. Results

The most recent reference on the location of the earthquake of October 29, 1900 is given by the studies of [3] where the barycenter is located in the Caribbean Sea, north of Cabo Codera, in the geographical coordinates 10.8° latitude N and 66.25° longitude W, with an average focal depth of 44.5 km. Based on these results, it is established that the landslide and the liquefaction farthest from the barycenter took place in the town of Barcelona, Anzoátegui State, and the distance between both points is approximately equal to 191.4 km.

Additionally, the enveloping area of the landslides referenced in Table 1 was calculated using the Jarvis March method in the Quantum Geographic Information System (QGIS) and the results are equal to 13,200 $km^2$. Figure 2 shows the geographic location of the barycenter, landslides and liquefactions of the earthquake of October 29, 1900.

Based on the results obtained for distances and areas, it was possible to apply the calculations of the magnitude of the 1900 earthquake using Figure 1 and equations (1) to (3) previously mentioned in the methods section. When necessary, the conversion of the surface wave magnitude ($M_s$) to seismic moment magnitude ($M_w$) was performed according to equations (4) and (5). The obtained magnitudes are shown in Table 2.

IOP Conf. Series: Materials Science and Engineering **872** (2020) 012034 doi:10.1088/1757-899X/872/1/012034

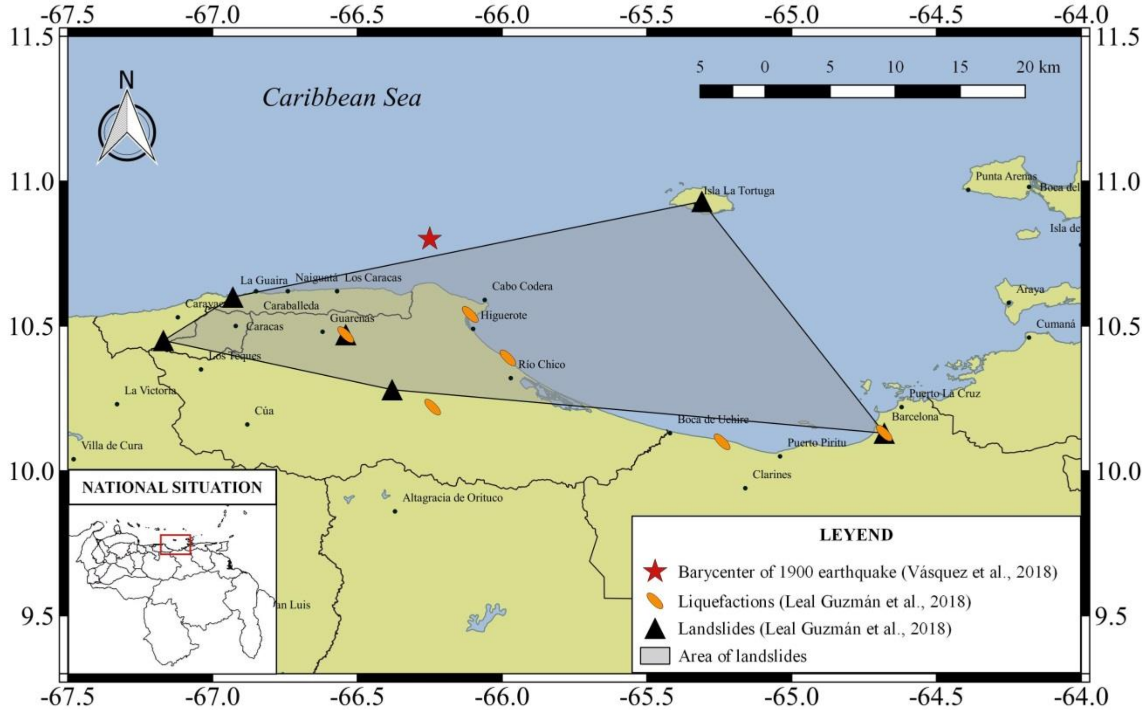


**Figure 2.** Geographical location of the barycenter obtained for the 1900 earthquake, landslides and liquefactions.

**Table 2**. Results of the calculation of the magnitude of the 1900 earthquake based on its cosiesmic effects.

| Method | Cosiesmic Effect | Area (km$^2$) or distance (km) | Magnitude ($M_w$) |
|---|---|---|---|
| Papadopoulos y Lefkopoulos (1993) | Liquefaction | 191.4 km | 7.4 |
| Papadopoulos y Plessa (2000) | Landslides | 191.4 km | 7.6 |
| Bommer y Rodríguez (2001) | Landslides | 13.200 km$^2$ | 7.7 |
| Keefer (2002) | Landslides | 13.200 km$^2$ | 7.6 |

## 5. Discussion and conclusions

For the calculation of the magnitude of the 1900 earthquake, the method of Bakun and Wentworth (1997) [17] was used, which is considered in the literature to be one of the most robust methods for estimating the source parameters of an earthquake based on macro-seismic data. The result obtained from seismic intensities assigned to 84 localities affected by this event in Venezuela and Trinidad [1] is equal to 7.5 ± 0.3 $M_w$ with 95% probability [3], which translates into a magnitude in the range of 7.2-7.8 $M_w$. With the intention of validating this result, information from the cosmic effects was used to apply alternative methodologies that would allow to calculate this important parameter of historical and modern earthquakes.

According to Table 2, values between 7.4 and 7.7 $M_w$ were obtained, which is in the range of magnitudes obtained by the method of Bakun and Wentworth (1997) [17]. The average value is equal to 7.6 $M_w$, which coincides with the instrumental magnitude calculated by Fiedler (1988) [5] [19]. According to Peraldo and Montero (1999) [18], by applying more than three methods to obtain a magnitude whose differences are ≤ 0.5, a quality factor can be assigned for an average magnitude of 7.6 $M_w$ equal to Class B, which immediately follows the instrumental estimate (Class A), what is considered the most reliable. The experience with the analysis of the 1900 earthquake indicates that, when there is a wide and precise documentation on cosmic effects, it is possible to apply these methodologies as a complement to the estimation of a more robust magnitude.

## 6. References

[1] Leal G., A., 2018. Contra temblores. Lecciones urbanas del sismo de San Narciso del 29 de octubre de 1900, en la ciudad de Caracas. Tesis doctoral, Facultad de Arquitectura y Urbanismo, Universidad Central de Venezuela.
[2] Leal G., A., Vásquez S., R., Rodríguez, J. A., Audemard, F. A., 2018. Reevaluación del terremoto del 29 de octubre de 1900 en Venezuela. Primera parte: estimación de intensidades. GEOMINAS, 77: 139-154.
[3] Vásquez S., R., Leal G., A., Rodríguez, J.A., Audemard, F. A., 2018. Reevaluación del terremoto del 29 de octubre de 1900 en Venezuela. Segunda parte: cálculo de los parámetros de la fuente. GEOMINAS, 77: 225-237.
[4] Colón, S., Leal Guzmán, A., Audemard, F., Vásquez, R. y José Antonio Rodríguez, En Prensa. Análisis macrosísmico del sismo Mw~7,6 de San Narciso del 29 de Octubre de 1900, aplicando la Escala Medio–Ambiental de intensidad sísmica ESI 2007. Revista de la Facultad de Ingeniería, Universidad Central de Venezuela.
[5] Fiedler, G., 1988: Preliminary evaluation of the large Caracas earthquake of october 29, 1900, En: Lee, W., Meyers, H & Shimazaki, K. (Eds.) Historical seismograms and earthquakes of the world, San Diego, Academic Press: 201-207.
[6] Vargas, A., 2002. Jean Paul. Deslizamientos inducidos por sismos y sus efectos en abanicos aluviales. Instituto Geofísico del Perú, v.3, p. 125-136.
[7] Rodríguez, L. M., Audemard, F. A. & Rodríguez, J. A., 2006. Casos históricos y contemporáneos de licuación de sedimentos inducidos por sismos en Venezuela desde 1530. Revista de la Facultad de Ingeniería de la Universidad Central de Venezuela, 21(3):5-32.
[8] Keefer, D. K., 1984. Landslides caused by earthquakes. Geological Society of America Bulletin, v. 95, p. 406-421.
[9] Papadopoulos, G. A. y Lefkopoulos, G., 1993. Magnitude-distance relations for liquefaction in soil from earthquakes. Bulletin of the Seismological Society of America, Vol. 83, No. 3, pp. 925 938.
[10] Rodríguez, C.E., J.J. Bommer and R.J. Chandler, 1999. Earthquake-induced landslides: 1980–1997. Soil Dynamics and Earthquake Engineering, 18, 325–346.
[11] Bird, J.F. y Bommer, J. J., 2004. Earthquake losses due to ground failure. Engineering Geology, 75, 147-279.
[12] Keller, E. H. y Blodgett, R. H., 2004. Riesgos Naturales. Pearson Education S.A. Madrid.
[13] Papadopoulos, G. A. y Plessa, A., 2000. Magnitude–distance relations for earthquake-induced landslides in Greece. Engineering Geology 58 (2000) 377–386.
[14] Bommer, J. J. y Rodríguez, C. E., 2002. Earthquake-induced landslides in Central America. Engineering Geology 63, 189– 220
[15] Keefer, D. K., 2002. Investigating landslides caused by earthquakes - A historical review. Surveys in Geophysics. 23 (6), 473-510.
[16] Ambraseys, N.N. y Adams, R.D., 1996. Large-magnitude Central American earthquakes, 1898–1994. Geophysical Journal International 127, 665– 692.
[17] Bakun, W. H., Wentworth, C. M., 1997. Estimating earthquake locations and magnitude from seismic intensity data. Bull. Seism. Soc. Am., 87: 1502-1521.
[18] Peraldo, G. & Montero, W., 1999. Sismología Histórica de América Central, Universidad de Costa Rica, IPGH, México, 347 p.
[19] Islas, O. C., & López, F. M. (2015). El domo generativo. Modelación morfológica y diseño parametrico. Base del estudio de ensambles modulares En la fabricación de prototipos para sistemas CAD-CAN. MÓDULO ARQUITECTURA CUC, 15, 105-132.