**Dear Dr Pierre Lacan:**

We are pleased to resubmit for publication the revised version of MS No.: nhess-2018-63 "Active Faults sources of the Morelia-Acambay Fault System, Mexico based on Paleoseismology and the estimation of magnitude Mw from fault dimensions" We appreciated your constructive criticisms.

We have changed the title by request of the other referees. "Active Faults Sources for the Pátzcuaro-Acambay Fault System (Mexico): Fractal Analysis of Slip Rates, and Magnitudes Mw Estimated from Fault Length". Traditionally this system has been named as Morelia-Acambay Fault System, in spite of, this extends to the city of Pátzcuaro. Thus, we consider that is more accurate to name it as Pátzcuaro-Acambay Fault System (PAFS).

**REFERRE COMMENTS:**

The most substantial revision concerns the organization and the writing of the manuscript. We have addressed each of their concerns as outlined below.

1) General Organization:

-The structure of paper is very confused and is not easy to find the elements to follow the reasoning of the authors.

***We have restructured the paper to provide more clarity. The sections are: 1.Introduction; 2.Tectonic Setting of the PAFS; 3.Materials; 4.Methods for the Study of Faults using Fractal Analysis; 5.Results; 6.Discution; and 7.Conclusions.***

-The introduction should introduce the problematic of the manuscript by removing all the generalities away from the objectives of the paper.

***We have restructured the Introduction and we have highlighted the problem in the study area (Page 2, line 16-31 and Page 3, line 1-16).***

-The Seismotectonic Setting should be organized to set out the elements necessary for understanding the discussion. In its current form, everything is underneath and the state of art is not clear.

***We have restructured the Seismotectonic Setting and added the following subsections: 2.1Paleoseismicity in the PAFS; 2.2Historical and Instrumental Seismicity in the PAFS and 2.3GPS measurements (Page 3, 4, 5, 6 and 7).***

- What morphological evidences have been taken into account delimiting fault segments and main faults. Why so much difference with works published previously. In particular Lacan et al., 2018 calculated 48 km length for the Venta de Bravo fault, you should explain how do you calculate the different length (32.982 km?) and why is this difference so important. Same for the Pastores Fault: 33 km for Langridge et al., 2013 and 38 km for you? and other faults.

***We identified and defined fault segments on a 15-meter Digital Elevation Model. We used the imagery provided by the Instituto Nacional de Estadística y Geografía***

***(INEGI, acronym in Spanish). The criterion for the tracing of fault segments was the union of small traces to form a larger one, but only if the geomorphological continuity was clear. The lengths of fault trajectories, which is the main object of study, corresponded to the lengths of mountain front sinuosity, and the scarp was measured at the maximum hillslope value for each fault.***

***We have expected differences in length with both the previous and the most recent works, due to the different resolutions and techniques used in each study. In cases such as Venta de Bravo fault, where there are several segments that may be the continuation of the same fault, but we do not know exactly which of them are the correct ones based on the 15-meter DEM, are managed as separate segments. However, we are open to improving the fault traces with better resolutions in future works. This information is reflected in subsection 3.1Mapping the Pátzcuaro-Acambay Fault System (Page 7, line 23-30).***

-The methods should be explained more carefully.

***We have rewritten the Methods section and we changed the name section for Methods for the Study of Faults using Fractal Analysis (Page 9, line 12).***

- For the "2.4 Fractal analysis", you lose the reader with details explanations, but you do not explain what you want to calculate? Why do you think it's fractal? What does these calculations represent?

***We have rewritten this section and added extra subsections (4.1Self-similar Behavior in Earth Science, 4.2The Hurst Exponent, 4.3Wavelet Variance Analysis, 4.4Box Dimension, 4.5Variograms, 4.6Intensity Scale (ESI 07), and 4.7Active Fault Definition) to provide more clarity (Page 9-13). Here we can manage the fractal analysis because this fault population presents a self-similar behavior. This means that the log-log plot of frequency versus lengths for the PAFS obeys an inverse power law as you can see in Figure1 (distribution on a straight line). Discontinuous red lines represent the linear regression model fitted using the least squares approach. In the Results section we have mentioned that this power law is binomial, because present two slopes values (Page 13, line 15-18). This bimodality may reveal the existence of at least two different fracture processes in the PAFS. For more detail, we decided to use the Hurst analysis to delineate different zones of deformation processes. Finally, we have characterized by quantitative parameters the dynamics of the seismotectonic activity along the PAFS as we discuss during the Results and Discussion (Page 13-16).***

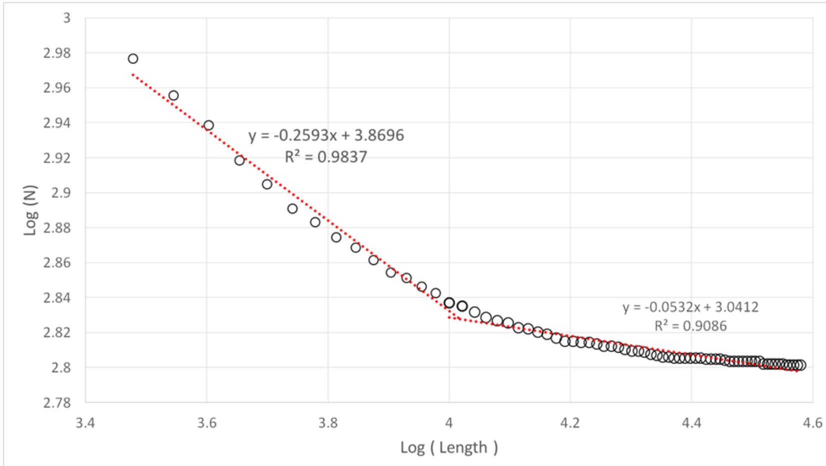

***Figure 1. Log-log plot of frequency versus lengths for the PAFS obeys an inverse power law***

- The Result and Discussion part is confused. I strongly recommend separating the results from one side (explaining the results you get) and after, a discussion section where you discuss these results and their consequences. In the current form, we do not distinguish what is new from what was already known.

***We have separated the Results and Discussion (Page 13-16)..***

-In particular I do not understand the relationship between the results you present and the generation of major earthquakes. What is already known, including previous mapping of faulting in the area should be carefully presented in the seismotectonic setting.

***The research involves fault lengths and its corresponding magnitudes Mw (spatial analysis) and slip-rates estimations of earlier studies (time analysis). The fractal method using in both the spatial and time domains allow to distinguish a non-random system and to identify the persistence of a trend within a time series (here slip-rates by the Hurst Exponent) and the micro-regionalization for the PAFS (spatial analysis of Mw by the Hurst Exponent).***

- The conclusion is also confused. You should clearly state

***We have restructured the section to provide more clarity. According to our analysis, we conclude that (1) the expected mean maximum earthquake magnitude for the study area was Mw 7.0, (2) we defined a micro-regionalization for the PAFS (western, central and eastern) zones by the Hurst exponent based on magnitudes Mw and (3) we have validated the intrinsic definition of active fault proposed here by fractal analysis and variograms analysis (Page 16, line 20-32 and page 17, line 1-15).***

**Dear Dr Mustapha Meghraoui:**

We are pleased to resubmit for publication the revised version of MS No.: nhess-2018-63 "Active Faults sources of the Morelia-Acambay Fault System, Mexico based on Paleoseismology and the estimation of magnitude Mw from fault dimensions" We appreciated your constructive criticisms.

**REFERRE COMMENTS:**

The most substantial revision concerns the organization and the writing of the manuscript. We have addressed each of their concerns as outlined below.

**1) General remarks**

- The main topic of the manuscript (ms) is on the fractal fault distribution and its related seismic activity but this is not clear neither from the title, nor for the abstract and text.

***We have rewritten the title and highlighted the main objective during the text. We have changed the title as "Active Faults Sources for the Pátzcuaro-Acambay Fault System (Mexico): Fractal Analysis of Slip Rates, and Magnitudes Mw Estimated from Fault Length". Traditionally this system has been named as Morelia-Acambay Fault System, in spite of, this extends to the city of Pátzcuaro. Thus, we consider that is more accurate to name it as Pátzcuaro-Acambay Fault System (PAFS).***

- This article needs to be restructured in order to clearly put forward the fractal analysis, the authors do not present new fault data and hence, the presented neotectonic and seismotectonic characteristics cannot be considered as the main topic of this article.

***We have restructured the paper to provide more clarity and highlighted the fractal analysis for the study of faults.***

-The authors mention the existence of 316 fault segments in text and about 22 fault characteristics (in Table 1) of the Morelia Acambay Graben. However, they do not explain how they did select these 22 items among the 316 faults, and which fault segments where used for the fractal analysis. The 316 fault segments deserve to be shown as a supplemental material.

***A fault database was constructed on a 15-m DEM and is showed in the supplemental material. For the fractal analysis, we have used two data: (a) 316 average magnitudes Mw calculated by the surface rupture length on a 15-m Digital Elevation Model and (b) 22 slip-rates recorded in the literature. This information is reflected in section 3.Materials (Page 7, line 22-30, page 8 and page 9, line 4-11).***

-The seismicity and neotectonic database and related catalogs need to be clearly presented in the form of tables with appropriate legends showing the origin of data. A table of paleoseismic, historical and instrumental earthquakes is needed in this manuscript, at least for earthquakes with Mw ≥ 5.4 (according to their concluding remarks).

***We have explained this information in the following sections: 2.1Paleoseismology in the PAFS (Page 5, line 16-34 and page 6, line 1-14) and 2.2 Historical and Instrumental***

***Seismicity in the PAFS (Page 6, line 21-30 and page 7, line 1-14). The seismic catalog, covering from 1912 to 2018, was obtained from the Seismological Service of Mexico (Servicio Sismológico Nacional, SSN; Fig. 2). The data is available on their web page www.ssn.unam.mx. This catalog only has two events with Mw ≥ 5.4 (Acambay and Maravatío earthquakes). We are showed in Table 1 the seismic events that have affected populations within the PAFS.***

-Table 1 needs to include the minimum and maximum, observed and estimated coseismic slip/event for the known faults. Table 1 needs a serious legend.

***We have modified Table 1 in page 29, but we have decided not to include the estimated coseismic slip/event because we focus our work on the temporal analysis of slip rates and on the spatial analysis of fault lengths. Thus, for the temporal analysis of the details of the coseismic slip (timeless term) are beyond the scope of this work. However, we have included, in the subsection 2.2 Historical and Instrumental Seismicity in the PAFS, maximum displacements for three faults with surface rupture (Urbina and Camacho, 1913): the Acambay-Tixmadejé fault (Dmax = 50 cm), the Temascalcingo fault (Dmax = 30 cm) and the Pastores fault (29 ≤ Dmax ≤ 37 cm; Ortuño et al., 2015). Page 6, line 21-26.***

- An interesting issue is the difference between the fracture density and fracture concentration. This section of the manuscript needs to be developed in order to show the meaning of this difference, explain well the correlation between box dimensions and the effects of the size of fracture concentration. The calculation of the Hurst Exponent H and related strong persistent process, Devil staircase and box dimension should be explained more extensively. These aspects that are fundamental in this manuscript should appear in a separated Methodological section.

***This information is reflected in sections 4. Methods for the Study of Faults using Fractal Analysis, 5. Results and 6. Discussion.***

**2)Specific remarks**

-Title: It has to be reconsidered because as presented, it shows that active faults and paleoseismic analysis are the main topic of the manuscript. I think that the fractal analysis from existing fault data should be clearly announced in this title.

***We have restructured the title according to the main topic. Traditionally this system has been named as Morelia-Acambay Fault System, in spite of, this extends to the city of Pátzcuaro. Thus, we consider that is more accurate to name it as Pátzcuaro-Acambay Fault System (PAFS).***

- Abstract: The authors use different magnitude scales (Ms, Mb, Mw). If a seismicity catalogue with homogenized magnitudes exists for Mexico, then the authors should use Mw only in this section.

***We have rewritten the Abstract, however, Ms=6.9 and Ms=5.6 was conserved because they are historical earthquakes (Page 1, line 7-8).***

- The Introduction section is not well written, and although it includes several paragraphs as seismotectonic settings, it does not explain the geodynamic context with clear stress and strain distribution. For instance, Figures 1A and B that are redundant they show only the topography and bathymetry. Figure 1C is supposed to show the seismotectonic setting but it looks only like a geographic indication of the Morelia-Acambay Graben. The introduction needs to be better organized to explain the context and main issue, the used general methodology (fractal analysis) and its application elsewhere in comparable seismotectonic domains, previous works emphasizing the main results and finally the main steps adopted in this ms.

***We have rewritten the Introduction and remade Figure 1 (Page 24). The seismotectonic settings paragraphs are moved to the appropriate section (Page 6, line 21-30 and page 7, line 1-14).***

- (Neotectonic and seismotectonic settings?) Since the Morelia-Acambay Graben has a rich database, a specific section in neotectonics and seismotectonics would therefore be needed after the introduction. In this case, the authors should organize their text and avoid a mix of data. This section needs to present: 1) the seismicity (historical and instrumental) with emphasis on major events and their characteristics, 2) the geodetic results (GPS, conventional), focal mechanism solutions and fault kinematics for the stress and strain distribution, and 3) the paleoseismic data and results including the estimated slip rates with the corresponding time window and related uncertainties. This section has not to be long but it has to focus on major results showing the related references and how completed is the database (reference to tables in supplementary material is recommendable).

***We have divided in three subsections: 2.1 Paleoseismicity in the PAFS; 2.2 Historical and Instrumental Seismicity in the PAF; and 2.3 GPS Measurements (Page 3-7).***

- Line 20 – 21: Please note that historical earthquakes needs to indicated with their intensities (or inferred magnitudes), their severity (number of victims whenever possible).

***We have explained this information in the subsection 2.2 Historical and Instrumental Seismicity in the PAFS (Page 6, line 21-30 and page 7, line 1-14).***

-Line 22: ".. set of earthquakes . . ." of what magnitudes?

***We have added the magnitudes (2.5 < Mw < 3.0) in the Introduction (Page 2, line 23).***

-Line 26_27: These lines are concluding remarks and should be moved at the end of ms.

***We have moved these lines at the end of the manuscript (5.Results; 6.Discussion; and 7.Conclusions).***

-Line 40: Instead of cortical, the term "crustal" is usually used in active tectonics.

***We have changed the term crustal in the Introduction (Page 2, line 20).***

-Line 46: “The kinematics of them . . .” change in Their kinematics . . . This sentence mentions details on the neotectonic episodes and a reference is needed here.

***We have changed the sentence in the section 2.Tectonic Setting of the PAFS (Page 4, line 8).***

-Line 49: normal- right? change in Oblique fault with right-lateral normal component.

***We have changed the sentence in the section 2.Tectonic Setting of the PAFS (Page 4, line 12).***

-Line 55: The 8.2 km depth of the Maravatio earthquake needs uncertainties. The sentence should be rewritten “Subsequently, another earthquake in 1979 with a magnitude Mb = 5.3 and a depth of 8.2 km (Astiz-Delgado, 1980), caused major damage in Maravatío.”

***We have changed the sentence in the subsection 2.2Historical and Instrumental Seismicity in the PAFS (Page 6, line 30).***

-Line 59: “is very probable that this sequence of earthquakes is related to the La Paloma fault of 13 km of length . . .”. How did you infer this? If this is obtained from the two local stations then the “probable” should turn into “possible”. Please explain. Line 59-60: “. . . active from the Holocene” does not mean much. I would suggest considered active because it affects Holocene deposits.

***It is very likely that these earthquakes are related with the La Paloma fault because the focal mechanism is in correspondence to the fault geometry (normal fault with left-lateral component). Moreover, this fault is considered active, because it affects Holocene deposits. This information is reflected in subsection 2.2 Historical and Instrumental Seismicity in the PAFS (Page 7, line 8).***

-Line 63: remove seismic risk and put seismic hazard instead.

***We have changed the term in the subsection 2.1 Paleoseismicity in the PAFS (Page 5, line 18).***

-Lines 65 to 84: In all these paragraphs, slip rates need to be explained (from which field trenches and markers, e.g., lateral or vertical offset of streams, ...) and measurements span which timeframe.

***We have rewritten this paragraph in the subsection 3.3 Slip Rates and their Cumulative Distribution (Page 8. Line 23-30).***

-Line 81: What is the mechanism of the dozen faults?

***The focal mechanism corresponds to normal faulting with left-lateral components in the state of Michoacán. The three focal mechanism solutions along the PAFS reported in the literature are shown in Fig. 2 (Page 25).***

Are they in table 1?

***No, we just settled the values of the slip-rates recorded in the literature, because they are the scope of this work. The focal mechanisms in the PAFS are showed in Figure 2 in the revised manuscript and in Table 2 in the actual response.***

-Line 90: Active faults are ...

***Revised (Page 13, line 2).***

-Line 92: "... speeds of approximately ..."; fault speed is not used in active tectonics. Slip rate is more appropriate. Please apply correction throughout the text.

***Revised (Page 13, line 3).***

-Line 91: The title is inappropriate in this ms. You are only extracting the data from previous works and not mapping and describing the faults of the Morelia-Acambay Graben.

***The title has been changed, but in this work, we have mapped 316 fault dimensions (Length and scarp) on a 15-meter Digital Elevation Model, using imagery provided by the Instituto Nacional de Estadística y Geografía (INEGI, acronym in Spanish). Additionally, we are suggesting fault names based on the names of the nearest towns, in order to homogenize nomenclature for researchers interested in correcting or completing the existing database.***

- Figure 2 is a bad quality map. Unless a clear srtm background topography can be shown, it should be removed, leaving only the seismicity and tectonic data in the map. The dates and magnitudes of focal mechanisms need to indicate in the map and in a table with their characteristics (in the supplemental material).

***Figure 2 has been reconstructed.***

-Line 102: Unless you indicate criteria for selection, the characteristics of the 316 fault segments need to be shown at least in the supplemental material.

***We have showed the 316 faults in the supplemental material.***

-Lines 105 and 106: Fault length, Fault scarp height (?)

***The lengths of fault trajectories are corresponded to the lengths of mountain front sinuosity, and the scarp was measured at the maximum hillslope value for each fault (Page 7, line24-30).***

-Line 111: Distance between a locality and fault zone.

***We have changed the statement in 3.1Mapping the Pátzcuaro-Acambay Fault System (Page 8, line 11).***

-Estimation of Mw magnitudes as shown in Figures 3 a and b needs a reevaluation. Including the uncertainties of fault parameters is critical in the fractal analysis.

***The assumed error for the morphometric parameters measured was not relevant for our analysis because the lowest fault length (3000 m) is lesser than the map resolution (15 m, Page 8, line 3-5). However, we estimate the following range 0.0002 < error <0.007 km. Figure 3 has been modified in order to show the magnitude variations from east to***

***west (the firmagram plot). Even more, the Hurst exponent values were included for the western, central and eastern sectors of the PAFS, as well as we have printed the most known faults names.***

-The section 2.4 on the fractal analysis is devoted almost entirely to the methodological aspect; please indicate it accordingly as for instance "Method of faulting study using fractal analysis". The manuscript is mainly based on this methodology section and it should be presented before the database (seismotectonic) section.

***We have rewritten this section and added extra subsections: 4.1Self-similar Behavior in Earth Science, 4.2The Hurst Exponent, 4.3Wavelet Variance Analysis, 4.4Box Dimension, 4.5Variograms, 4.6Intensity Scale (ESI 07), and 4.7Active Fault Definition (Page 9-13).***

-Line 149: In equation (??), please complete.

***In the last manuscript was the equation (2). In this new version corresponds to equation (1) in the subsection 4.4 Box Dimension (Page 11, line 27).***

-Line 162: . . . as fault planes . . . Also remove speeds, and replace by slip rate.

***We have corrected this term (Page 13, line 2-3).***

-Line 164- 165: " . . . earthquakes of magnitude Mw ≥ 5.2 or related to rupture lengths greater than or equal to 3 km." Why Mw ≥ 5.2 and why lengths ≥ 3 km? How about hidden faults below Holocene deposits? As indicated by Langridge et al., (2013) and Sunye-Puchol et al., (2015) some faults can be hidden by young sedimentary deposits. In this case the fault lengths may increase. This issue needs to be discussed.

***We have changed the minimum earthquake magnitude Mw ≥ 5.5 estimated by Wells and Coppersmith (1994) relation, because this method is best suited for areas with crustal thickness > 15 km and avoids overestimating the magnitudes (see first paragraph of Discussion, page 14, line 5-14). Finally, supported by $\mathbf{D_b}$ and $\mathbf{H_w}$, we can neatly determine the lower limit (3 $km$) of fault lengths for the PAFS. However, we cannot establish a definite upper limit due the faults hidden under Holocene deposits, not identifiable on a 15-meter Digital Elevation. We nevertheless estimated an upper limit of fault lengths (38 $km$) as a first approximation.***

-Line 177-178: The described seismicity, frequency and related b-value which is also a fractal distribution needs to be called earlier along with the fractal analysis in this manuscript. As this work is based on the Magana-Garcia Master thesis, that is not published and difficult to access as a reference, it should be presented with some details in introduction and seismotectonic section (or even in the supplemental material).

***The seismic catalog plotted in Fig.2 (page 25), covering from 1912 to 2018, was obtained from the Seismological Service of Mexico (Servicio Sismológico Nacional, SSN; Fig. 2). The data is available on their web page: www.ssn.unam.mx. The focal mechanism parameters were reported previously by Astiz-Delgado (1980), Suter et al. (1992; 1995), Langridge et al. (2000), Singh et al. (2012), and Rodríguez-Pascua et al. (2012).***

-Line 180: Why this Table 1 is called only in section 3. This reference to the database should be called earlier!!!

***We have called Table1 in subsection 3.3 Slip Rates and their Cumulative Distribution (Page 8, line 30).***

-Line 184: Please give a reference to the Environmental Seismic Intensity scale (ESI 07)

***We have given a reference and described the Scale in section 4.6Intensity Scale (ESI 07). Page 12, line 25-30.***

-Line 189: Hurst (1951) does not exist on the list of references.

***We have added Hurst (1951) in References section (Page 19, line 25-26).***

-Line 191-192: The reference to the Hurst Exponent H and strong persistent process for the slip-rate distribution, along explanations on the Devil staircase should be explained in the methodology section.

***We have rewritten the methodology section and added extra subsections (4.1Self-similar Behavior in Earth Science, 4.2The Hurst Exponent, 4.3Wavelet Variance Analysis, 4.4Box Dimension, 4.5Variograms, 4.6Intensity Scale (ESI 07), and 4.7Active Fault Definition). Page 9-13.***

-Line 192-193: "...cycles or periods with different seismic activity ...", you mean variable seismic cycles?

***This means that periodicities of earthquakes are different along the PAFS. We have rewritten the subsection 4.2The Hurst Exponent (Page 10, line 10-30 and page 11, line 1-13) to set out the elements necessary for understanding the results of H: (a) the spatial domain, strongly suggests that the PAFS is classified in three different zones (western PAFS, central PAFS and eastern PAFS) in terms of their roughness (Hw = 0.7, Hw = 0.5, Hw = 0.8 respectively), showing different dynamics in seismotectonic activity; (b) the time-domain, with a strong persistence Hw = 0.949, suggests that the periodicities of slip rates are close in time (process with memory).***

-Line 200: This has to be included in the Methodology section.

***We have included the fracture concentration in the methodology section (Page 9, line27-31 ang page 10, line 1).***

-Line 221: What us the mathematical behaviour? You mean the mathematical or statistical expression of faulting behaviour?

***The distribution for the PAFS displays a fractal behavior, i.e. this fault population presents a self-similar behavior. This means that the log-log plot of frequency versus lengths for the PAFS obeys an inverse power law as you can see in the Fig.3 (distribution on a straight line) in the actual response.***

| EQ | DATE | MAGNITUDE | LOCATION AFFECTED | REFERENCE |
|---|---|---|---|---|
| 1 | June 19th,1858 | $M_S$ = 7.5 – 7.7 | Morelia and Pátzcuaro | Figueroa 1987; Garduño-Monroy et al., 1998a; García-Acosta and Suárez, 1996; Singh et al., 1996; García Acosta, 2001; Garduño-Monroy et al., 2011 |
| 2 | XIXth century | - | Zinapécuaro-Tlalpujahua | Garduño-Monroy et al., 1998b; Garduño-Monroy et al., 2009 |
| 3 | November 19th, 1912 | $M_S$ = 6.9 | Acambay | Urbina and Camacho, 1913; Suter et al., 1995b, 1996 |
| 4 | February 22th,1979 | $M_s$ = 5.6 | Maravatío | Astiz, 1980, 1986; Garduño-Monroy and Gutierrez-Negrín, 1990 |

***Table 1 Seismic events that have affected populations within the PAFS.***

| EQ | DATE | MAGNITUDE | FOCAL MECHANISM | REFERENCE |
|---|---|---|---|---|
| Acambay | November 19th, 1912 | $M_S$ = 6.9 | strike=102, dip= 70, rake=-90 | Singh et al (2011); Astiz-Delgado (1980); Suter et al (1995); Suter et al (1992); Langridge et al (2000); Rodríguez- Pascua et al (2012) |
| Maravatío | February 22th,1979 | $M_s$ = 5.6 | strike=280, dip= 66, rake=-48 | Astiz-Delgado(1980), Suter et al. (1992) |
| Morelia | October 17th, 2007 | $M_w$ = 2.7 | strike=265, dip= 75, rake=-30 | Singh et al (2012) |

***Table 2: Focal mechanism solutions in the PAFS.***

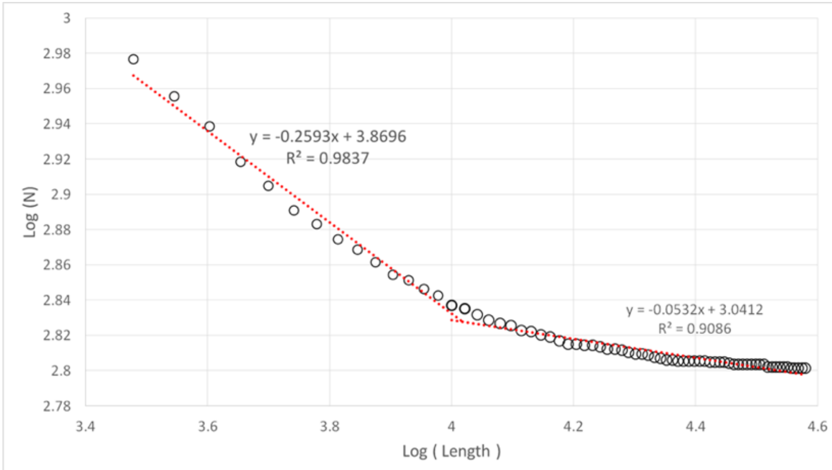


***Fig. 3 Log-log plot of frequency versus lengths for the PAFS obeys an inverse power law***

**Dear Professor Aksoy:**

We are pleased to resubmit for publication the revised version of MS No.: nhess-2018-63 "Active Faults sources of the Morelia-Acambay Fault System, Mexico based on Paleoseismology and the estimation of magnitude Mw from fault dimensions" We appreciated your constructive criticisms.

**REFEREE COMMENTS:**
The most substantial revision concerns with the need of significant improvements on the presentation and structure of the work; more information methodology, the approach and the significance of the results. We have addressed each of your concerns as outlined below.

1) General Organization:
-The figures lack significantly of useful information that are necessary to comprehend the study area. Many cities, locations, fault names mentioned in the text are not available in maps and figures, making it difficult for the reader to orient him/herself spatially.

***We have restructured Figure 1, 2 and 3 (Page 24-26).***

- Although the authors provide some theoretical information on the statistical calculations the connection and relation to the seismic hazard evaluation is poorly given, the geological significance for each input and output are not provided and discussed in the manuscript sufficiently.

***We have restructured the paper to provide more clarity and highlighted the fractal analysis for the study of faults.***

-The aim of the study is confusing because throughout the text authors describe several different purposes: 1-prepare an intrinsic definition for active faults (abstract) 2-estimation of possible maximum earthquake magnitudes (abstract) 3-understand the seismic activity from Patzcuaro to Acambay sector (introduction) 4-define the intracontinental structures that are susceptible to generate moderate and strong seismic events (line 85).
Aside the quantitative results, the study addresses only the first two purposes clearly. Maximum earthquake magnitudes are calculated via fault length measurements and a comprehensive definition is given for active faults. Based on the Hurst Exponent it is concluded that the fault system is active, however the possibility of an inactive fault system is not discussed within the manuscript.

***We have rewritten the aims of the study. The goals have been mentioned in the introduction (page 3, line 12-16) and they are: (1) the estimation of the maximum possible earthquake magnitudes by three empirical relations; (2) the definition of a micro-regionalization of the PAFS using the Hurst exponent based on Mw magnitudes; and (3) the validation of our proposed definition of Active Fault sources for the PAFS by fractal analysis and semivariograms. Consequently, we are proposing the investigation of the dynamics of the Pátzcuaro-Acambay area, in order to improve territory planning and reduce seismic hazard.***

-The authors illustrate (Fig 3) that these relationships give different magnitude estimations for the same fault section but do not discuss how they interpret this difference. No reasoning is provided why authors prefer to take into account the Wesnousky (2008) relationship.

***The analysis of the three empirical relations results of active faults was summarized as follows: (1) The model proposed by Anderson et al. (1996) always yields lower results than the other relationships; however, (2) the highest magnitudes are obtained with the relationship of Wesnousky (2008); (3) the average magnitudes are obtained by means of Wells and Coppersmith (1994) relationship. We have observed that all three relationships work for the PAFS. However, in this paper, we reported the maximum and minimum earthquake magnitudes estimated by Wells and Coppersmith (1994), because this method is best suited for areas with crustal thickness > 15 km and avoids overestimating the magnitudes (see Fig.3 in page 26).***

-The analysis assumes that each fault section has the potential to rupture the entire crust individually; (at all scales like 3-5 km). Why is 3 km the minimum preferred fault length that is included into the dataset? Can these faults also create surface ruptures?

***A key step in this study was to delimit the minimum fault length. For this purpose, we made a test to find the fractal capacity dimension $D_b$ for our database which contains 316 average Mw magnitudes calculated from the surface rupture length by the use of three different empiric relationships. We also calculate the $D_b$ for the same database but including faults less than 3 km (a total of 628 faults). The results were: $D_b$ (316)= 1.33, $D_b$ (628)= 1.77***

***Based on the results of Nieto-Samaniego et al. (2005), they proved that box dimension is in inverse relation with fracture concentration. Moreover, Poulimenos (2000), Cowie et al. (1995), Ackermann et al. (2001) have also shown that the total fracture length is directly proportional to the amount of deformation, i.e., large fractures can accommodate more deformation than small ones. Consequently, we have inferred that the low value of the fractal dimension Db (316)= 1.33 corresponds to greater amounts of large fault lengths: it is well-known that large fractures can accommodate more deformation. Thus, we are interested in the minimum earthquake magnitudes Mw ≥ 5.5 (or SRL=3km) for improving the vulnerability studies, because is acutely necessary in the central portion of Mexico.***

-Furthermore, this analysis needs to consider the spatial distribution and interaction of the faults. An earthquake may rupture several adjacent fault segments; which would necessarily imply a larger earthquake magnitude. Authors need to consider multi-segment ruptures according to fault segmentation patterns and spatial distribution of the faults. Therefore, I consider that the estimation of maximum magnitude needs a revision. Since fault length is a critical parameter in their analysis the mapping procedure should be clearly explained. The authors apply most likely remote-sensing techniques but the mapping approach and the “type and quality” of base-maps is poorly given (“imagery” + 15x15 m DEM). The “morphological” criteria used to classify the faults as “active” should be given definitely.

***Notwithstanding the importance of this kind of study, the linkage mechanism is beyond the scope of this work, due that we need to know the maximum possible length for each fault, and for this purpose we need a DEM with more resolution. Based on the Db and Hw results, we can neatly determine the lower limit (3 km) of fault lengths for the PAFS, but we cannot establish a definitive upper limit due the faults hidden under Holocene deposits, not identifiable on a 15-meter Digital Elevation. We nevertheless estimated an upper limit of fault lengths (38 km) as a first approximation (Page 16, line 17-19).***

-A complex definition for active faults is provided in the manuscript: “an active fault, is defined here as a plane that ground-rupturing with speeds of approximately 0.001 mm/year, with seismic activity associated, at least, in the last 10,000 years and is oriented in favour of the current stress field. The active fault planes must be related to earthquakes of magnitude Mw ≥ 5.4 or capable of generating rupture lengths greater than or equal to 3 km.” Authors need to show that all 316 faults fulfil that definition (for example, have all faults a minimum of 0.001 mm/yr slip-rate? Which studies provide this information?

***This is the first study that works with a set of slip rate estimations in the system with a fractal approach. We support our results based on the fractal analysis for this set: Figure 4 (Page 27) shows that*** **Db** ***= 1.86 is related to a lower concentration of low slip rates in the PAFS, suggesting that larger faults accommodate the strain more efficiently; and with a strong persistence (Hw = 0.949), i.e. the periodicities of slip rates are close in time (process with memory). Moreover, active faults are optimally oriented to the current stress field, in terms of variogram analysis, an anisotropic direction was identified in ENE direction (80º, Fig.5, page 28), as well as the active fault planes are related to earthquakes with a minimum magnitude of Mw ≥ 5.5, or capable of generating rupture lengths greater than***

***or equal to 3 km. Thus, we can prove, in terms of fractal analysis, that the 316 faults studied for the PAFS are seismically active.***

- What type of information provides the CeMIEGeo database on faults?

***The CeMIEGeo provides fault length information around the Cuitzeo Lake (Page 3, line 30).***

-The seismicity of the study area is concentrated to the eastern part (Figure 2). Leaving many earthquakes in the West with no earthquakes at all. How are faults satisfying the Mw ≥ 5.4 criteria?

***We have restructured the Seismotectonic Setting and added the following subsections: 2.1Paleoseismicity in the PAFS; 2.2Historical and Instrumental Seismicity in the PAFS and 2.3GPS measurements. Here, we set out that The Pátzcuaro-Acambay Fault System can be divided into three zones with different geological and geophysical settings (page 4, line 14-35 and page 5, line 1-15), and in the Results and Discussion we present the Hurst analysis. The results in the spatial domain strongly suggest that the PAFS is classified in three different zones (western PAFS, central PAFS and eastern PAFS) in terms of their roughness (Hw = 0.7, Hw = 0.5, and Hw = 0.8 respectively; Fig. 3), with their corresponding magnitudes (5.5 ≤ Mw ≤ 6.9; 5.5 ≤ Mw ≤ 6.7; 5.5 ≤ Mw ≤ 7.0)(Page 13, line 19-21). As we can see in the historical seismicity, paleoseismology studies and the spatial distribution of faults in the western zone, the faults are capable to generate earthquakes with magnitudes 5.5 ≤ Mw ≤ 6.9. Thus, we strongly believe that the area must continue to be monitoring in order to reduce seismic hazard in central Mexico.***

-The entire dataset should be available for download so the results can be reproduced and tested.

***The datasets generated during the current study are available from the corresponding author on reasonable request. The seismic catalog, covering from 1912 to 2018, was obtained from the Seismological Service of Mexico (Servicio Sismológico Nacional, SSN) and it is available on the web page www.ssn.unam.mx.***

-The text provides a theoretical but limited description of the Hurst Exponent analysis. The method tests the tendency of a time-series (here the various slip-rates given in Table 1). However, the slip-rates are controlled by the spatial distribution of the stress field and therefore have a local significance. The authors need to explain why this approach based on time-series is applicable on a dataset that has a spatial significance. In addition, more information is necessary on how slip-rates have been exactly used in the calculations.

***We have rewritten this section and added extra subsections for more clarity: 4.1Self-similar Behavior in Earth Science, 4.2The Hurst Exponent, 4.3Wavelet Variance Analysis, 4.4Box Dimension, 4.5Variograms, 4.6Intensity Scale (ESI 07), and 4.7Active Fault Definition (Page 9-13).***

-Uncertainties and error ranges are not discussed in the manuscript. What are the error ranges for the fault length and slip-rates? How do they affect the results? This questions should be addressed within the text.

***The assumed error for the morphometric parameters measured was not relevant for our analysis because the lowest fault length (3000 m) is lesser than the map resolution (15 m). However, we estimate the following range 0.0002 < error <0.007 km. This information is reflected in subsection 3.1Mapping the Pátzcuaro-Acambay Fault System in page 8, line 3-6. As we can see in table 1, not all the slip-rates errors are reported by previous authors, and they are in the range of 0.02mm/yr.***

-Similarly, the fractal analysis lacks of adequate information on the geological significance of the analysis. What is the meaning of a staircase like pattern from a tectonic/geologic perspective?

***There is a dependence and causality between the Hurst Exponents, fractal Dimension and the PAFS dynamics, we have developed this topic in the Results and Discussion section in the page 13-16.***

-In line 198 the author states the high value of the fractal dimension "may indicate the possibility" for generation of a major earthquake on the faults of the MAFS; which is a highly ambiguous result. More information is needed on how the method is applied. Which dataset is exactly used? What are the 2D boundaries of the study?

***Spatial-temporal methods were applied to the active fault data, and the fractal behavior observed for the entire PAFS allows us to define that the PAFS is seismically active. This is supported by the results of the Hurst analysis for the fault lengths and its corresponding magnitudes Mw (spatial analysis) as well as the slip-rates estimations of earlier studies (time analysis). We have included a better explanation in the section 5. Results in the page 13, line 11-32.***

-However, a distinction should be made among faults mapped within this work and obtained from other sources so readers can better evaluate the contribution of this work.

***This is the first study that works with a fault population in the PAFS defining a total of 316 active faults with fault dimensions (Length and scarp) on a 15-meter Digital Elevation Model with a fractal approach. Moreover, we estimated 316 average Mw magnitudes calculated from the surface rupture length by the use of three different empiric relationships. We perform a major revision in the revised version of the manuscript in order to explain the contribution of our work along the entire document.***

-In addition, the mapping approach should be defined precisely in order to evaluate the reliability of the fault map.

***The criterion for the tracing of fault segments was the union of small traces to form a larger one, but only if the geomorphological continuity was clear. The lengths of fault trajectories, which is the main object of study, corresponded to the lengths of mountain front sinuosity, and the scarp was measured at the maximum hillslope value for each fault (page 7, line 26-30).***

***We have expected differences in length with both the previous and the most recent works, due to the different resolutions and techniques used in each study. However, we are open to improving the fault traces with better resolutions in future works. This information is reflected in subsection 3.1Mapping the Pátzcuaro-Acambay Fault System.***

-The main results of this work are based on a statistical analysis of the fault map and paleoseismic findings. However the results are poorly discussed and their significance in terms of active tectonics is not well addressed.

***We have rewritten the Results, Discussion and Conclusion for clarify how this analysis contributes to the seismic hazard assessment (Page 13-17).***

2) Further remarks on the manuscript

1-Title: The title calls for a manuscript that actually deals with significant amount of paleoseismic field work that permit to determine new seismic sources and their characteristics. However, the work is based on mathematical approaches on previous works. I suggest to revise the title that is more compatible with the used methodology.

***We have changed the title and highlighted the main objective during the text. The current title is "Active Faults Sources for the Pátzcuaro-Acambay Fault System (Mexico): Fractal Analysis of Slip Rates, and Magnitudes Mw Estimated from Fault Length". Traditionally this system has been named as Morelia-Acambay Fault System, in spite of, this extends to the city of Pátzcuaro. Thus, we consider that is more accurate to name it as Pátzcuaro-Acambay Fault System (PAFS).***

2- Abstract: 2/3 of the abstract is dedicated to the seismotectonics of the study area. Most of this general information is neither connected to the applied methods nor the results of this work. The abstract may get more informative if more detail is provided on the approach and methodology. Also, the significance of the results is not sufficiently and clearly expressed.

***We have restructured the abstract to provide more clarity (Page 1 and page 2, line 1-14).***

3-Figure 1 and 2 require additional information on location names, major faults systems and information on concerning the seismic activity. 4-Acambay earthquake location and related surface rupture should be given. 5-Add Focal Mechanisms need information for earthquake magnitude and time. 6-Slip-rates should be placed on the fault map. 7- The corresponding seismic activity is not available.

***Figure 1 and 2 have been reconstructed (Page 24-25).***

8-Figure 3: It is unclear what it represents. Is it based on fault central points from A to B? Requires a detailed figure caption.

***The profile A-B was about the depth of seismicity and we removed the profile A-B in the Figure 2. We do not present it in the manuscript because this is full of information.***

9-The results and discussion section contains theoretical information on the used methods, which should be placed to appropriate section.

***We have moved the theoretical information to the methodology section (Page 9-12).***

10- Figure 4 requires more explanation. Requires labelling and a detailed figure caption.

***We remade this figure (page 27).***

11-In Table 1: The 2 mm/yr slip-rate for the Venta de Bravo fault could not be found in the related citation (Suter et al., 1995).

***We have changed the reference by Suter et al., 1992 (Page 29).***

12-Table 1 Add error ranges for slip-rates, fault length and scarps.

***We have added a few available slip-rates and their uncertainties along the PAFS (Page 29).***

13-Line 173-179 and 184-188: The purpose of these texts within the context of maximum magnitude is not clear.

***We have removed these lines and moved to 2.1Paleoseismology in the PAFS (173-179) and to 4.6Intensity Scale (184-188).***

# Active Faults ~~sources of~~ Sources for the ~~Morelia-Acambay~~ Pátzcuaro-Acambay Fault System ~~,~~ (Mexico~~based on Paleoseismology and the estimation~~ ): Fractal Analysis of ~~magnitude Mw~~ Slip Rates, and Magnitudes $M_w$ Estimated from ~~fault dimensions~~Fault Length.

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**Abstract.** The ~~Morelia-Acambay fault System (~~Pátzcuaro-Acambay Fault System (~~MAFS~~PAFS), located in the central part of the Trans-Mexican Volcanic Belt (TMVB), is delimited by an active transtensive deformation ~~zone~~ area associated with the oblique subduction zone between the Cocos and North American plates, with a convergence ~~velocity~~ speed of 55 $\mathrm{mm/yr}$ at the latitude of the state of Michoacán, ~~México~~Mexico. Part of the oblique convergence is transferred to ~~the central TMVB, just in the MAFS zone,~~ this fault system, where the slip rates range from 0.009 to 2.78 $\mathrm{mm/year}$. ~~The occurrence of great earthquakes like the Acambay earthquake ($M_s = 6.7$~~This has caused historic earthquakes in Central Mexico, such as the Acambay quake ($M_s = 6.9$) on November 19, 1912 with ~~a~~ surface rupture, and another in Maravatío ~~,~~ in 1979 with ~~$M_b = 5.3$ are located into the MAFS. The~~ $M_s = 5.6$. Also, paleoseismic analyses are showing Quaternary movements in some faults, with moderate to large magnitudes. Notably, this zone is seismically active~~but with large periods of recurrence, as revealed by the seismic sequence (2.5 < $M_w$ <3.0) occurred near the city of Morelia in October 2007, with focal mechanisms corresponding to normal faulting with left-lateral components. Moreover, there are some paleoseismic analyses showing quaternary movements of some faults with magnitudes between 6.0 – 7.1~~, but lacks a dense local seismic network, and more importantly, its neotectonic movements have received very little attention. The present research encompasses three investigations carried out in the PAFS: (**1**) the estimation of the maximum possible earthquake magnitudes, based on 316 fault lengths mapped on a 15-m Digital Elevation Model, by means of three empirical relationships; (**2**) the Hurst exponent $H_w$ and its persistence, estimated for magnitudes $M_w$ ~~. The purpose of this work is to probe an~~ (spatial domain) and for 22 slip-rate data (time-domain) by the *wavelet variance analysis*; and (**3**) the validity of the intrinsic definition of ~~Active Faults for the MAFS as well as the estimation of possible maximum earthquake magnitudes , in order to understand the dynamic of seismic activity along the MAFS. For the new~~

~~fault dimensions and using three empirical relationships, we found a maximum magnitude of $M_w = 7$. Additionally, a~~ active fault proposed here. The average results for the estimation of the maximum and minimum magnitudes expected for this fault population are $5.5 \leq M_w \leq 7$. Also, supported by the results of $H$ at: (**a**) the spatial domain, this paper strongly suggests that the PAFS is classified in three different zones (western PAFS, central PAFS and eastern PAFS) in terms of their roughness ($H_w = 0.7, H_w = 0.5, H_w = 0.8$ respectively), showing different dynamics in seismotectonic activity; (**b**) the time-domain, with a strong persistence $H_w = 0.949$, suggests that the periodicities of slip rates are close in time (process with memory). The fractal capacity dimension ($D_b$) is also estimated for the slip-rate series using the *box-counting method*. Inverse correlation between $D_b$ and low slip-rate concentration was observed. The resulting $D_b = 1.86$ is related to a lesser concentration of low slip-rates ~~series were compiled and analyzed, the results show a temporal strong persistence behavior and a high value of fractal dimension ($D_b = 1.86$) related with a less concentration of small slip-rates. In other words, there is not an excess of the deformation in the MAFS in a single or restricted range of scales, and furthermore, this represents a migration of the ruptures to larger scales (~~in the PAFS, suggesting that larger faults accommodate the strain more efficiently (length $\geq 3$ ~~$\leq$ length $\leq 38$~~ km). Thus, in terms of fractal analysis, we can conclude that these 316 faults are seismically active, because they fulfill the intrinsic definition of active faults for the PAFS.



## 1 Introduction

The state of Michoacán in Mexico is ~~one of the zones with major seismic hazard in all the country. This~~ an area of high seismic activity~~is mainly due to~~ , not only due to subduction events, such as the devastating earthquake of 19 September 1985 earthquake ($M_w = 8.1$), but also because of the ~~oblique collision between the tectonic plates in the pacific coast (Cocos and North American plates), and to the~~ existence of crustal faults in the interior~~of the state. Furthermore, there are records of earthquakes that~~ . Historically, several earthquakes have affected populations such as Pátzcuaro and Araró (in 1845 and 1858), Zinapécuaro and Tlalpujahua (in the ~~XIXth~~ 20th century), Acambay (in 1912) and Maravatío (in 1979). More recently, in 2007, a set of earthquakes ($2.5 < M_w < 3.0$) occurred in the vicinity of the city of Morelia, as a consequence of the movement of the active fault named ~~“La Paloma”.~~

~~The goal of this study is to understand the seismic activity from Pátzcuaro to Acambay sector. For this purpose, we analyze the geometry and faults distribution, the paleoseismic data and evaluate the instrumental record of few intraplate earthquakes. In particular, this system is a fractal network of faults, that keep a persistence behavior of the slip-rates trend and its fractal dimensionis related to the existence of a high concentration of larger earthquake-generating faults ($5.4 \leq M_w \leq 7.1$)~~ La Paloma. The major problem here, in central Mexico, is that we are incapable of using seismic and geodesic data of coseismic slip during earthquakes, because we lack a dense local seismic and geodesic network. Indeed, along the PAFS there are only two broad band stations of the Mexican Seismological Service (SSN) in the cities of Morelia (Lat:19.646812, Long:-101.227135) and

Acambay (Lat:19.9845, Long:-99.8823). Moreover, the existing paleoseismological studies are too scarce in relation to the number of existing faults.

### 1.1 ~~Seismotectonic Setting in the Central TMVB~~

Above all, this reveals the need to define the intracontinental structures that are susceptible of generating moderate and strong seismic events, and delimit the damaged area that can produce such events, especially in the center of Mexico, which presents highly populated zones. Of course we used the excellent manifestation and geomorphology of faults, and we analyzed the magnitudes $M_w$ derived from fault dimensions and the slip-rate estimations of earlier studies, as well as spatial distribution by Fractal Analysis. In principle, this branch of mathematics gives us a way of describing, measuring and predicting seismic activity by means of the Hurst exponent and the fractal dimension. We used two main databases: (**a**) 316 average magnitudes $M_w$ calculated from the surface rupture length on a 15-m Digital Elevation Model, and (**b**) 22 slip rates recorded in the literature.

Thus, the goals of this investigation are: (**1**) the estimation of the maximum possible earthquake magnitudes by three empirical relations; (**2**) the definition of a micro-regionalization of the PAFS using the Hurst exponent based on $M_w$ magnitudes; and (**3**) the validation of our proposed intrinsic definition of Active Fault sources for the PAFS by fractal analysis and semivariograms. Consequently, we are proposing the investigation of the dynamics of the Pátzcuaro-Acambay area, in order to improve territory planning and reduce seismic hazard.

## 2 Tectonic Setting of the PAFS

The Trans-Mexican Volcanic Belt (TMVB) is an active continental volcanic arc that ~~crosses~~ spans cross Mexico with an approximate E-W orientation. The TMVB ~~is~~ developed within an extensional tectonics setting ~~as a result of~~ resulting from the subduction of the Rivera and Cocos plates beneath the North American plate. ~~From the point of view of tectonics, the TMVB is divided in three geographic zones with different types of volcanism and structural features (Figure 1) (Pasquaré et al., 1987; Aguirre-Díaz et al., 1998; García-Palomo et al., 2002; Ortuño et al., 2015).~~

~~Especially, we will focus in the central portion of the~~ The central TMVB is characterized by the Tula-Chapala Fault Zone ~~, comprising the cities from Pátzcuaro to Acambay~~ (Johnson and Harrison, 1990), where the kinematics is extensional and transtensional ~~since~~ from the Miocene (Johnson and Harrison, 1989; Martínez-Reyes and Nieto-Samaniego, 1990; Garduño-Monroy et al., ~~2009a~~2009) with a ~~left-lateral~~ left strike slip component (Suter et al., 1992, 1995, 2001; Ego and Ansan 2002; Norini et al., 2006). ~~Suter et al.(1995, 2001)and Ego and Ansan (2002)confirm that this region has been dominated by transtensive stresses since mid-Quaternary~~

Specifically, we will focus on the central and eastern parts of the Tula-Chapala Fault Zone, i.e., the PAFS (Figure 1, 2). The PAFS is defined as a population of several hundreds of normal faults, oriented E-W and NE-SW, comprising the cities between Pátzcuaro and Acambay($102^\circ - 99^\circ$W). Its kinematics is summarized as a left-lateral transtensional system with $\sigma 3$ ~~at~~ trending NW-SE ~~orientation. Additionally, this portion also includes the Taxco-San Miguel de Allende Fault System with a~~

~~NW trending (Demant, 1978; Aguirre-Díaz~~ and $\sigma 2$ trending NE–SW (Suter et al., ~~2005~~1992, 1995, 2001; ~~Alaniz-Alvarez and Nieto-Samaniego, 2005), which coincides with a change in the cortical thickness (Ortuño et al., 2015). The eastern zone of the central TMVB is active with a micro seismicity documented in the literature (~~Ego and Ansan, 2002; ~~Campos et al., 2015; Ortuño et al. , 2015) and is characterized by a left-lateral transtensive deformation with NW-SE to NNW-SSE orientation.~~

~~According to~~ Mennella, 2011). Moreover, according to Mennella (2011) there are three major fault sets in the ~~study area~~PAFS, the first ~~one and oldest is~~ and oldest being the NNW-SSE ~~that is expressed~~ system, expressed mainly by the Tzitzio-Valle de Santiago fault. The other two systems configured lake areas and have the morphology of seismically active faults with E-W and ENE-WSW ~~strike. The kinematics of them shows clear evidence that begins in~~ strikes. Their kinematics show clear evidence from the Miocene (17Ma) with ~~left lateral~~ left-strike slip faulting, that later ~~becomes a normal faults with a left lateral component . This stress field generates, in~~ became to normal with a left-lateral component (Suter et al., 2001; Ego and Ansan, 2002; Mennella, 2011). In the NNW-SSE faults, this stress field generates a reactivation as oblique faults ~~(normal-right)~~with normal right-lateral component. This deformation always keeps the $\sigma 3$ moving from N360° to N340°.

~~Inside the Morelia-Acambay Fault System (SFMA; Suter et al., 1991, 1995 and 2001; Garduño-Monroy et al. , 2009b), the Acambay earthquake ($M_s = 6.7$) occurred on November~~ The Pátzcuaro-Acambay Fault System can be divided into three zones with different geological and geophysical settings: **(1)** The **western PAFS**, between Pátzcuaro and the Tzitzio-Valle de Santiago fault, is an area where three different scenarios have coexisted. First, the andesitic basements of the Miocene (>19~~, 1912 (Suter et al., 1996) and is the only earthquake recorded in the TMVB with a surface rupture (Ortuño et al., 2015). During this earthquake, at least three faults showed surface rupture (Urbina and Camacho, 1913): the Acambay-Tixmadejé fault ($D_{max} = 50$ cm), Temascalcingo fault ($D_{max} = 30$ )and The Pastores fault (Ortuño et al. , 2015). Subsequently, another earthquake in 1979 caused major damage in Maravatío, with a magnitude of $M_b = 5.3$ and a depth of 8.2~~ Ma) were in contact with a volcanic sequence characterized by alternation of andesites and ignimbrites, varying in age from 19 to 7 Ma. These volcanic sequences were contemporary with a sinistral strike-slip faulting with E-W and NE-SW structures, which later moved like normal faults (~~Astiz-Delgado, 1980).~~

~~Nowadays, in the MAFS and very close at the city of Morelia, a sequence of seven earthquakes occurred ($2.5 < M_w < 3.0$)with focal mechanisms corresponding to normal faulting with left-lateral components. This set of tremors occurred in a 33-interval in October 2007 and were recorded by two local stations located within the city (Krishna-Sing et al.~~from 12 to 7 My), ~~2012)~~to finally turn into normal faults with a strike slip component (see Focal Mechanisms, Fig. 2). ~~It is very probable that this sequence of earthquakes is related to~~ The complete western zone has a geometry of listric faults with lengths from 3 to 33 km, generating rotations of the Miocene lithological units that allow the rise of hydrothermal fluids. Since the Miocene, this faulting has caused grabens and semi-grabens, causing the formation of lakes. These lake depressions are controlled by old NNW-SSE faults, which act as relay zones today. So, the ~~La Paloma fault of 13 of length that is considered active from the Holocene (Garduño-Monroy et al. , 2009)~~ coexistence of these faults, lacustrine depressions and hydrothermal manifestations make up the second scenario. The last scenario is where monogenetic volcanism is controlled by existing faults; indeed, this volcanism is abundant, and presents NE-SW alignments (Michoacán-Guanajuato Volcanic Field). **(2)** The ~~rupture of a small segment of this fault can generate earthquakes with magnitudes up to $5M_w$ (Krishna-Sing~~ **central PAFS** extends between the NNW-SSE-trending Tzitzio-Valle de Santiago fault and Maravatío. This sector is basically occupied by the Los Azufres Geothermal Field, which is defined as a volcanic complex with andesitic volcanoes, rhyolitic and dacitic domes, and an important thickness of pyroclastic flows and monogenetic volcanism. In the past million years, magmatic processes have developed, affected by E-W faulting, which also controls the hydrothermal manifestations. Petrological studies show a magmatic chamber located between 4.3 and 9.5 km of depth at the El Guangoche dome (Rangel et al., ~~2012)~~ 2018), probably modifying the fragile ductile limit of the crust. Surely this modification is responsible for shorter fault lengths ranging from 3 to 26 km. Finally, **(3)** the **eastern PASF** is mainly formed by the Acambay graben. Its limit with the central zone is defined by the Maravatío area, where the graben is wider (18 km) and the foot wall in the southern sector is formed by Jurassic basement rocks. The hanging wall displays monogenetic volcanism aligned in preferential NW-SE and E-W directions, parallel to the fault where the 1979 earthquake generated (5.6$M_s$). On the other hand, the eastern limit is narrower (14 km), and occupied by complex volcanoes such as the San Pedro volcano, and by small monogenetic volcanoes, all affected by the E-W fault system that generated the 1912 Acambay earthquake (6.9$M_s$). This magnitude is in accordance with fault lengths and with the paleoseismic study of Lacan et al. (2017), in which the longest fault found (47 km) is defined as capable of generating large seismic events (6.9$M_w$). These faults have translational movements and do not generate tilts in the Miocene sequences, as is the case in the Cuitzeo area, therefore, they do not comprise a geothermal flow.

### 2.1 Paleoseismicity in the PAFS

Although the seismotectonic context of the ~~MAFS~~ PAFS is summarized as ~~a~~ an active left-lateral ~~transtensional systemin several works (Ego and Ansan, 2002; Suter et al., 2001), seismic risk~~ strike-slip system, seismic hazard studies are still considered ~~as partials. This is due to~~ incomplete. The reason for this is the scarcity of data regarding the slip rates and recurrence periods of the prehistoric and historical activity of the fault segments ~~in~~ within the system.

~~Before the Paleoseismology studies in Mexico, these parameters were calculated by the accumulated displacements in the escarpment for each segment and the age of the displaced lithological units. In this sense, for some of the main faults of the system were considered displacement rates of 0.04 , 0.05 and 0.18 (Pastores, Morelia and Cuitzeo faults, respectively; Suter et al., 1992; 2001). Currently, the paleoseismic analyzes of these and other structures in the MAFS have allowed to refine the estimates.~~

~~The first~~ The faults studied with a paleoseismological approach ~~were the~~ at the eastern portion of the PAFS are: (1) The Acambay-Tixmadejé fault (Urbina and Camacho, 1913; Suter et al., ~~1995a~~1995; 1996), where the record of at least five rupture events allowed to ~~calculate~~ reckon a recurrence interval of 3,600 years, ~~mean~~ meaning slip rates of 0.17 mm/year and potential magnitudes ~~of~~ between 6.8~~to 7$M_w$.~~ $\geq M_w \geq$7. (2) The Pastores fault, with a recurrence interval of 10,000 - 15,000 years and 1,100 - 2,600 years (short and long time span), with slip rates of 0.03 to 0.23~~- 0.37~~ -0.37 mm/year and potential magnitudes ~~of~~ from 6.6 to 6.8$M_w$ (Suter et al., 1992; Langridge et al., 2013; Ortuño et al., 2015). (3) ~~Temascalcingo and San Mateo faults (Urbina and Camacho, 1913; Roldan-Quintana et al., 2011; Langridge et al., 2013;~~ For the San Mateo fault, Sunye-Puchol et al. ~~,~~ (2015) found a recurrence interval of 11,~~000 - 12,000~~ 570 years, a slip rate of 0.085 mm/year and potential magnitudes between 6.43 $\geq M_w \geq$ 6.76. (4) The Venta de Bravo fault is capable of producing earthquakes with magnitudes of $M_w \geq$6.9, with a slip rate of 0.22-0.24 mm/year and a recurrence interval between 1,940 and 2,390 years (Lacan et al., 2017). Finally, (5) for the Temascalcingo fault, a current study by Velázquez-Bucio (2018) reports a slip rate of 0.017 mm/year and a recurrence of 28,901 years with a paleo-magnitude of ~~6.4 to 7~~6.5$M_w$.

Other studies using soft-sediment deformations related to seismic activity (seismites) have also been carried out ~~also~~ in the basins of ~~Estado~~ the State of Mexico, such as Tierras Blancas (Rodríguez-Pascua et al., 2010) and Ixtlahuaca controlled by the Perales fault (Benente, 2005; Velázquez-Bucio et al., 2013; 2015), which allowed to estimate the potentiality of the ~~near~~ nearby faults, obtaining magnitudes of $\geq 6M_w$.

In the state of Michoacán, ~~the work has been concentrated in~~ paleoseismology studies have been concentrated on Pátzcuaro, Morelia and Cuitzeo, where almost a dozen faults ~~have been~~ were studied in detail (Garduño-Monroy et al., 2001; 2009; Suter, 2016). For these structures, slip-rates ~~have been~~ were obtained in a range of 0.009 - 2.78 mm/year (long and short time span, respectively), recurrence intervals of 1,200 - 100,000 years (long and short time span, respectively) and ~~potential magnitudes of~~ magnitudes between 5.8 ~~-~~ $\geq M_w \geq$ 7.1~~$M_w$.~~. Moreover, at the northwest of Morelia, the structure named Teremendo fault is studied by Soria-Caballero (submitted). Paleoseismic data show slip-rates of 0.11 mm/year, a time recurrence of 7,726 years, and potential magnitudes of 5.9 $\geq M_w \geq$ 6.8.

~~Above all, these studies highlight the need to define the intracontinental structures that are susceptible to generate moderate and strong seismic events, as well as the affected area that can produce such events, especially in the center of Mexico where they coexist with highly populated areas.~~

## 3 ~~Methods~~

### 2.1 ~~Active Fault definition~~

~~First, this work contributes with the definition of active fault within the MAFS. Faults are those that can rupture~~

### 2.1 Historical and Instrumental Seismicity in the PAFS

The Acambay earthquake ($M_s = 6.9$) occurred on November 19, 1912, in the ~~ground surface in a single maximum magnitude earthquake (Christophersen~~ eastern PAFS (Urbina and Camacho, 1913; Suter et al., 1996). The quake killed more than 150 people and caused the destruction of entire villages. During this event, at least three faults showed surface rupture (Urbina and Camacho, 1913): the Acambay-Tixmadejé fault ($D_{max} = 50$ cm), the Temascalcingo fault ($D_{max} = 30$ cm) and the Pastores fault ($29 \leq D_{max} \leq 37$ cm; Ortuño et al., 2015). Subsequently, ~~an active fault, is defined here as a plane that ground-rupturing with speeds of approximately 0.001 , with seismic activity associated, at least,~~ in ~~the last 10, 000 and is oriented in favor of the current stress field. The active fault planes must be related to earthquakes of magnitude $M_w$ ≥5.4 or capable of generating rupture lengths greater than or equal to 3 . If the active faultpresent seismicity with these characteristics will be considered as a seismogenetic fault~~ 1979, another earthquake with 5.6$M_s$ magnitude and 8.2 km depth (Astiz-Delgado, 1980), caused major damage in Maravatío. In the western zone of the PAFS, some earthquakes have affected populations such as Pátzcuaro and Araró (in 1845 and 1858), and Zinapécuaro and Tlalpujahua (also in the 19th century).

Currently, the eastern PAFS is active with microseismicity, which is documented in the literature (Ego and Ansan, 2002; Campos et al., 2015; Ortuño et al., 2015), and is characterized by a left-lateral transtensive deformation with NW-SE to NNW-SSE orientation. Regarding the west of the PAFS, very close to the city of Morelia, a sequence of seven earthquakes occurred ($2.5 < M_w < 3.0$) with focal mechanisms corresponding to normal faulting with left-lateral components. This set of tremors took place in a 33-hour interval in October 2007, and were recorded by two local stations located within the city (Sing et al., 2012). It is very likely that this sequence of earthquakes was related to the La Paloma fault, considered active, because it affects Holocene deposits (Garduño-Monroy et al., 2009 and Suter, 2016). The rupture of a small segment of this fault can generate earthquakes with magnitudes up to $5M_w$ (Sing et al., 2012).

The seismic catalog, covering from 1912 to 2018, was obtained from the Seismological Service of Mexico (Servicio Sismológico Nacional, SSN; Fig. 2). The data is available on their web page: www.ssn.unam.mx. The focal mechanism parameters were reported previously by Astiz-Delgado (1980), Suter et al. (1992; 1995), Langridge et al. (2000), Singh et al. (2011; 2012), Rodríguez-Pascua et al. (2012).

### 2.2 GPS Measurements

The multi-temporal comparative study (1998/2003 to 2011) of the dynamics in the eastern zone of the PAFS is presented only by Espinosa-Rodríguez et al., 2016. The vertical tectonic movements show rates ranging from +7.3 to +12.8 mm/year in the northern horst of Santa María Tixmadejé, while in the central graben of Acambay they are very weak, of +0.4 to +0.5 mm/year.

### 2.3 ~~Mapping the Morelia-Acambay Fault System~~

~~For the construction of the database belong at the MAFS, we~~

## 3 Materials

### 3.1 Mapping the Pátzcuaro-Acambay Fault System

A fault database was constructed on a 15-m DEM. We used the imagery ~~from~~ provided by the Instituto Nacional de Estadística y Geografía (INEGI, acronym in Spanish)~~and a digital elevation model of the Mexican continental territory with a resolution of 15×15 . On a~~. We identified and defined fault segments on a Geographic Information System (GIS) ~~we identified and defined fault segments with~~ on the basis of the excellent morphological evidences. ~~Also, we used~~ The criterion for the tracing of fault segments was the union of small traces to form a larger one, but only if the geomorphological continuity was clear. The lengths of fault trajectories, which is the main object of study, corresponded to the lengths of mountain front sinuosity, and the scarp was measured at the maximum hillslope value for each fault. We also used the length information of the faults digitalized around the Cuitzeo basin by ~~the group of the proyect~~ project 17 of the Centro Mexicano de Innovación en Energía Geotérmica (CeMIEGeo, acronym in Spanish), based in Morelia, Mexico.

~~The fault sources database obtained is show in Figure 2. The new fault data consists of a total of~~ The assumed error for the morphometric parameters measured here was not relevant for our analysis because the lowest fault length (3000 m) is lesser than map resolution (15 m). Additionally, we are suggesting fault names based on the names of the nearest towns, in order to homogenize nomenclature for researchers interested in correcting or completing the existing database.

Our database consists of 316 ~~segments with length~~ faults of $\geq 3$ km length (Fig. 2) and comprises the following characteristics:

~~Fault nameLength~~ Fault name; Fault length (meters)~~Scarp~~ ; Fault scarp height (meters)~~Start~~ ; Begin UTM coordinates (X1, Y1)~~Final~~ ; End UTM coordinates (X2, Y2)~~Intermediate point~~ ; Intermediate point UTM coordinates (Xm, Ym) ~~Near locality nameDistance to fault~~ for each trajectory; Close locality name; Distance between locality and fault zone (meters); $M_w$(Wells and Coppersmith, 1994); $M_w$ (Anderson et al., 1996); $M_w$ (Wesnousky. 2008).

### 3.2 Estimation of the ~~maximum magnitudes~~Maximum Magnitudes

Maximum ~~earthquake magnitudes are calculated from~~ and minimum earthquake magnitudes were calculated for the same fault section with three magnitude-scaling relationships. We ~~assess~~ assessed fault relationships by the surface rupture length (SRL) ~~for faults using the empirical regression model of~~ using Wells and Coppersmith's empirical regression model (1994) for normal faults ($M_w = 4.86 + 1.32\log_{10}(SRL)$); ~~as well as,~~ we also used the equivalent regression model proposed by Wesnousky (2008; $M_w = 6.12 + 0.47\log_{10}(SRL)$); finally, we ~~also include~~ included the model proposed by Anderson et al. (1996; $M_w = 5.12 + 1.16\log(SRL) - 0.2\log(S)$), where $S$ is the ~~slip-rate~~slip rate.

~~The Wesnousky (2008) relationship represents another way to estimate the maximum expected magnitude and is based on the total fault length for normal faults and crust thicker than 10 .The relationship of Wesnousky was used previously in the MAFS for the complete fault Jaripeo-Morelia-Cerrito (JMC)and for the Cointzio fault (Suter, 2016~~

### 3.3 Slip Rates and their Cumulative Distribution

Before applying paleoseismology in Mexico, the slip rates were calculated with the accumulated displacements in the escarpment of each segment and the age of the displaced lithological units. In this sense, we are considering displacement rates of 2 mm/year, 0.05 mm/year and 0.16 mm/year for some faults in the PAFS, such as Venta de Bravo, C. El Aguila lava and the Cuitzeo faults, respectively (Suter et al., 1992; 2001). Currently, the paleoseismic analyses of these and other faults of the PAFS have allowed to refine the slip-rate estimates made by Langridge et al. (2000), Garduño-Monroy et al. (2009), Sunye-Puchol et al. (2015), Ortuño et al. (2015), Lacan et al. (2017), Ortuño et al. (2018), Velázquez-Bucio (2018) and Soria-Caballero (submitted). Finally, we were able to analyze 22 slip-rate data derived from these earlier studies (Table 1).

### 3.4 ~~Fractal analysis~~

#### 3.3.1 ~~The Hurst Exponent~~

~~We use the Hurst exponent ($H$)as the measure of roughness of the slip-rates distribution, because of its ability to express the asymptotic statistical properties of a random process (Denisov, 1998),~~ In order to characterize the persistence of the slip-rate series, we constructed a cumulative slip-rate plot, organized from east to west, since most of the microseismicity is concentrated in the eastern PAFS, near the Acambay graben (Rodríguez-Pérez and ~~because it merges local and global features of space/time anisotropy inside the unique variable called roughness.In time-series the Hurst exponent measures the growth of the standardized range of~~ Zúñiga, 2017). This cumulative plot obeys the well-known Devil's staircase fractal (Fig. 4a). The Devil's staircase is a non-constant but continuously increasing function. It is defined mathematically as the integral of a Cantor set, whose iterative construction implies that the Devil's staircase is a self-similar object. Thus, the ~~partial sum of deviations of a data set from its mean (Ellis, 2007~~fault movements are the physical manifestation of a fractal behavior.

## 4 Methods for the Study of Faults using Fractal Analysis

### 4.1 Self-Similar Behavior in Earth Science

In several works, the geometrical description of patterns of earthquakes, fractures and volcanoes is studied using the self-similar property of fractals. This self-similarity is fulfilled when the objects look geometrically equal on any scale, and is characterized by inverse power laws (Ishimoto and Ida, 1939; Gutenberg and Richter, 1944, 1954; Mandelbrot, 1983; Bak and Tang, 1989; Korvin 1992; Turcotte, 1992; Ghosh and Daemen, 1993; Mazzarini et al., 2010; Pérez-López et al., 2011), where the exponent corresponds to the value of the fractal dimension [i.e. Bak et al., 1987; Tang and Marangoni, 2006]. Fractals are irregular, rough, and fragmented objects which display self-similarity (roughness is invariant when scaling). A typical example of fractals is the coastline (coastline paradox). The ~~Hurst exponent is especially suitable to characterize stochastic processes (Mandelbrot and Van Ness, 1968) and there are basic differences between persistent ($H > 0.5$)and antipersistent ($H < 0.5$) processes, while the white noise is characterized by $H = 0.5$ (Torres-Argüelles~~ standard technique to scrutinize scale invariance and estimate fractal dimension is the box counting method.

Self-similarity was studied by Nieto-Samaniego et al. (2005) in the Los Planes fault, Baja California Sur, Mexico, using a detailed fractal analysis of fracture arrays. Their sampled fracture traces have box dimensions between 1.51 and 1.87. Moreover, they proved, for a map of any size, that box dimension is in inverse relation with fracture concentration and in direct relation with fracture density (Renshaw, 1997). They have estimated the fracture concentration as the mean distance between centers of fractures divided by the average fracture lengths (Smirnov and Zavyalov, 1997), which characterizes the interactions between adjacent fractures. Smirnov and Zavyalov (1997) evaluated the critical value of the concentration of ruptures from the standpoint of physics. The failure concentration criterion is a measure of the loss of stability in a set of cracks under stress. If the cracks lose stability, they grow, and coalesce to form larger fractures. As a result, they are sufficiently close to one another, and consequently, a high concentration of cracks appears in certain volumes. Other studies have also shown that the total fracture length is directly proportional to the amount of deformation, i.e., large fractures can accommodate more deformation than small ones (Poulimenos, 2000; Cowie et al., ~~2010). For estimating the Hurst Exponent we use the Wavelet transform (Rehman and Siddiqi, 2009), where the characteristic measure of wavelet variance analysis is the wavelet exponent, $H_w$ (Malamud and Turcotte, 1999). Indeed, the time series of interest was the slip-rates distribution belongs to the MAFS.~~ 1995; Ackermann et al., 2001).

~~Consider $n$ wavelet transforms, all of them with a different scaling coefficient; i. e., let $S_1, S_2, ..., S_n$ be their standard deviations from zero. Define the ratios $G_1, G_2, ..., G_{n-1}$ of the standard deviations as $G_1 = \frac{S_1}{S_2}, G_2 = \frac{S_2}{S_3}, ..., G_{n-1} = \frac{S_{n-1}}{S_n}$, and compute the average value of $G_i$ as (TruSoft, 1999):~~

### 4.2 The Hurst Exponent

The predictability of time series began with the original work of Harold Edwin Hurst (1951). He focused on the analysis of fluctuating fluvial time series by analyzing the standard deviation of accumulated water flow. Thus, Hurst established the Nile river's rain and drought cycles. These statistics handle the progression of observations in time. The correlation of the past and the future in the observational time series can be described by the Hurst exponent, $0 \leq H \leq 1$. For independent random processes, with no correlations among samples, $H = 0.5$. For $H > 0.5$, the observational time series is persistence, which means, in average, that the increasing (decreasing) trend in the past induces the continued increasing (decreasing) trend in the future. Persistent time series have a long memory, and a long-term correlation exists between current and future events. On the other hand, when $H < 0.5$, the sequence is characterized by antipersistent behavior. This means that an increasing (decreasing) trend in the past causes a decreasing (increasing) trend in the future. It can be expressed as a time series regression (Xu and Burton, 2006). The concepts of persistent and antipersistent memories in time are well-defined for non-linear processes (Feder, 1988).

$$G_{avg} = \frac{\sum_{i=1}^{n-1} G_i}{(n-1)}.$$

The Hurst exponent ~~is $H = f(G_{avg})$, where $f$ is a heuristic function which describes $H$ by $G_{avg}$ for stochastic self-affine traces (TruSoft, 1999).~~

#### 4.2.1 ~~Devil´s staircase slip-rate distribution~~

~~In order~~ not only works in the time-domain, but also in spatial domain to measure the roughness expressed in quantitative amounts (fractal dimensions and Hurst exponents). The interest in roughness studies has been motivated by Mandelbrot's work, in which he was faced with "The challenge to explain why so many rough facets of Nature are scale-invariant". In particular, the fault roughness can be studied using a fractal analysis (by means of the Hurst exponent or fractal dimension), as presented by Power et al. (1987); Schmittbuhl et al. (1993); Mandelbrot (2002). Also, the roughness of the magnitudes was calculated by means of the fractal image informatics toolbox (Oleschko et al., 2008). The roughness of earthquakes as a powerful tool to characterize the ~~persistence of the slip-rates distribution for faults in the MAFS, we construct the Devil's staircase of the cumulative slip-rates distribution organized from East to West, due the fact that the 1956-2016 instrumental locations in the central TMVB show that most of the microseismicity is concentrated in the eastern part of the MAFS, near to the Acambay Graben with a maximum depth of 15 km (Lacan~~ main features of seismicity and give insight into the inner dynamics of seismotectonic activity was studied by Telesca et al. (2001). For the magnitude estimations $M_w$, we created a firmagram as a plot for the discrete values of $M_w$ versus the Fault number. This compressed graph allows us to visualize the entire data density distribution and the peaks and valleys which are the result of irregularities and fluctuations in time series. The firmagram roughness for the three zones of the PAFS (western, central and eastern PAFS) can be measured, among others, by the Hurst exponent (see Fig. 3).

We used the Hurst exponent as the measure of roughness for the slip-rate series (time-domain) and for the magnitudes $M_w$ distributed along the PAFS (spatial domain). To estimate the Hurst Exponent we used the wavelet transform (Rehman and Siddiqi, 2009), wherein the characteristic measure is the wavelet exponent, $H_w$ (Malamud and Turcotte, 1999).

### 4.3 Wavelet variance analysis

The wavelet transform, introduced by Grossmann and Morlet (1984), is a filter function which is passed over time series and provides information on both space and frequency domains. A family of wavelets can be constructed from a function known as a "mother wavelet," which is confined in a finite interval. Then, "daughter wavelets" are formed by translation and contraction. The transform has a fractal basis, and the variance of wavelets obeys a power law, from which you can calculate the fractal dimension. In general, *wavelet variance analysis* is the most satisfactory measure of the persistence or antipersistence strength when only a small number of samples are available (Simonsen et al., ~~2017).~~ 1998). We consequently selected this method because there are but few available slip-rate samples along the PAFS.

### 4.4 Box Dimension

The box counting method is the standard technique to prove the fractal behavior (scale invariance) and also a common way of estimating the fractal dimension. In order to obtain the fractal dimension ~~for the slip-rates distribution (capacity dimension or box-dimension)~~ of the slip-rate distribution for active faults, we ~~use the Box counting 2D algorithm~~ have used the *box counting 2D algorithm* (Walsh and Watterson, 1993), to obtain the ~~exponent~~ box-dimension ($D_b$ ~~in the~~) in the following relationship:

$$N(e) \approx \frac{1}{e^{D_b}}, \tag{1}$$

~~for the cumulative slip-rates distribution for active faults in MAFS with paleoseismology studies. In equation (1),~~ where $N(e)$ is the number of boxes of linear size $e$ ~~,~~ necessary to cover a data set of points ~~distributed in~~ or objects distributed on a two-dimensional plane. The basis of this ~~method is that, for objects that are Euclidean, equation (1) defines their dimension. The range of values of this fractal dimension lies between one (Euclidean dimension of a line) and three (Euclidean dimension~~

~~of a volume). If the fractal dimension ranges between one and two, the earthquakes or faults are distributed on the interface between a line (Euclidean dimension equal to one) and a plane (Euclidean dimension equal to two) (Pascua et al., 2003).~~

~~A number of boxes proportional to $\frac{1}{e}$ is necessary to cover a set of points lying on a smooth line, proportional to $\frac{1}{e^2}$ to cover a set of points evenly distributed on a plane, and so on. To~~ technique is to measure $D_b$ ~~we counts the number of boxes of linear size $e$ necessary to cover the set for a range of values of $e$; and plot~~ by counting the boxes containing at least one point of the structure. Figure 4b plots the logarithm of $N(e)$ on the vertical axis versus the logarithm of $e$ on the horizontal axis. If the set is indeed fractal, this plot will follow a straight line with a negative slope that equals $-D_b$. ~~The "box counting" technique is the classic way to test fractal behavior because it allows calculate the capacity dimension.~~ For the box dimension calculation, we ~~use~~ used the Benoit 1.3 Software (Trusoft, 1999).

### 4.5 Variograms

Commonly, natural phenomena exhibit anisotropic behavior such as seismic anisotropy, mineral veins, groundwater contaminant plumes, porosity, permeability, and other petrophysical characteristics, where the studied properties depend on the direction. In practice, variograms are studied in different directions to determine the presence or absence of anisotropy. Mathematically, a variogram represents the semivariance of data as a function of the distance that separates a pair of observations [Journel and Huijbregts, 1978]. Generally, it is a function which increases with the distance and is canceled when the distance equals zero.

## 5 ~~Results and Discussion~~

~~The active faults map is presented in Figure 2, defined previously as a fault planes that~~ The spatial structure and anisotropy are revealed by the variogram surface. If the pattern forms an elliptic shape, it indicates the direction of best and poor correlations. Once the anisotropic feature is identified (often presented by an angle spectrum), the directional variograms are computed. A directional variogram can be obtained by calculating variogram at different distances and angles. The isotropic variogram obtained must exhibits a very good spatial structure and it is fitted with theoretical model, such as spherical or exponential functions. We used this variogram analysis to obtain the preferential direction of the faults that we propose as active, and to prove that these structures are optimally oriented in relation to the current stress field in the central TMVB ($\sigma$2=NE-SW; see Fig. 5).

### 4.1 Intensity Scale (ESI 07)

The Environmental Seismic Intensity scale ESI 07 (Michetti et al., 2007) is a new intensity scale, with 12 degrees of intensity, based only on Earthquake Environmental Effects (EEEs). The ESI 07 scale integrates traditional intensity scales, and allows to define seismic intensity based on the entire scenario of effects. According to the ESI 07, all the paleoseismologically investigated faults of the PAFS are capable of generating Class B events (assessment of seismic intensity levels IX to X), with frequent and characteristic geomorphological and geological evidence.

## 4.2 Active Fault Definition

Finally, this work contributes with an intrinsic definition of active fault sources within the PAFS. Active Faults are those that are ground-rupturing with slip rates of approximately 0.001 ~~, with~~ mm/years, with associated seismic activity, at least ~~,~~ in the last 10,000 ~~years, oriented in favor of~~ years, and are optimally oriented in relation to the current stress field ~~, and with fault planes~~ (see Focal Mechanisms, slip rates of coseismic faults and semivariograms). The active fault planes must be related to earthquakes of ~~magnitude $M_w \geq 5.2$ or related to~~ a minimum magnitude of $M_w \geq$5.5, or capable of generating rupture lengths greater than or equal to 3 km. ~~In this figure, all~~ If the active fault ~~sources are represented with solid lines; the faults that are shown in red color represent those that had have studies of paleoseismology. The seismicity, represented by circles, was taken from the catalog of the Mexican Seismological Survey (SSN), focal mechanism from Krishna-Sing et al (2012~~presents seismicity with these characteristics, it will be considered a seismogenetic fault.

# 5 Results

To assess the impact that moderate to strong seismic events can cause on cities in central Mexico, we defined the intracontinental faults capable of generating moderate to strong earthquakes by incorporating quantitative parameters (fractal dimension, Hurst exponent, and anisotropy). In this paper, we examined persistence on slip-rate time series and roughness on $M_w$ series. We can manage these statistical techniques because this fault population presents a self-similar behavior. This means that the log-log plot of frequency versus lengths for the PAFS obeys an inverse power law (distribution on a straight line), but is characterized by a bimodal self-similar scaling law with two slope values. This bimodality may reveal the existence of at least two different fracture processes in the fault system. A key step in this study was to delineate different zones of deformation processes using the temporal/spatial Hurst analysis. The results in the spatial domain strongly suggest that the PAFS is classified in three different zones (western PAFS, central PAFS and eastern PAFS) in terms of their roughness ($H_w = 0.7$, $H_w = 0.5$, and $H_w = 0.8$ respectively; Fig. 3), with their corresponding magnitudes ($5.5 \leq M_w \leq 6.9$; $5.5 \leq M_w \leq 6.7$; $5.5 \leq M_w \leq 7.0$ ). For the time domain, with a strong persistence of $H_w = 0.949$, the result suggests that the periodicities of slip-rates are close in time. The fractal capacity dimension ($D_b$) is also estimated for the slip-rate series. We found that $D_b = 1.86$ is related to a lesser concentration of low slip rates in the PAFS, suggesting that larger faults accommodate the strain more efficiently (length $\geq 3$ km).

We can prove, in terms of fractal analysis, that the 316 faults studied for the PAFS are seismically active. And in terms of variogram analysis, an anisotropic direction was identified in ENE direction (80°, Fig. 5), so these faults are optimally oriented in relation to the current stress. Moreover, they can generate average maximum and minimum magnitudes between $5.5 \leq M_w \leq 7$, which according to the Environmental Seismic Intensity scale ESI 07 correspond to a wide affected area ($1000 \leq \mathrm{km}^2 \leq 5000$). The size of this area means that movements in any of the PASF faults would affect some of the most populated cities of central Mexico, such as Mexico City (population $\sim 9 \times 10^6$), Ecatepec ($\sim$ 1,600,000), Toluca (>800,000), Acambaro (>100,000), ~~Ego and Ansan (2002) and Pacheco et al (1999)the magnitude homogeneous catalog including historical events~~

~~presented by Magaña-García (2017) and Zúñiga et al.~~ Maravatío (~~2017), wich includes earthquakes since 1912 to 2016.~~ $>$80,000), Zinapécuaro ($>$50,000), Morelia ($>10^6$), Pátzcuaro ($\sim 80{,}000$), among others.

~~The results of~~

## 6 Discussion

In order to characterize the ~~maximum magnitudes for the active faults, in order to characterizing the~~ seismic potential ~~for the MAFS, are summarized as~~ of the PAFS, the analysis of the three empirical relations results of active faults was summarized as follows: (1) The model proposed by Anderson et al. (1996) ~~(Figure 3a) is always lower in comparison with others relationships. However~~always yields lower results than the other relationships; however, (2) the highest magnitudes are obtained with the relationship of Wesnousky (2008)~~, up to $\Delta M_w \approx 1.04$ as we can see in Figure 3b. It is important to mention that segments of faults at the southern boundary of the Acambay graben (i. e., the VEBF:Venta de Bravo and PASF:Pastores faults), have been found to rupture at intervals ranging from 600 to 10~~; (3) the average magnitudes are obtained with Wells and Coppersmith (1994). We have observed that all three relationships work for the PAFS. However, in this paper, we reported the maximum and minimum earthquake magnitudes estimated by Wells and Coppersmith (1994), because this method is best suited for areas with crustal thickness $> 15$ km and avoids overestimating the magnitudes.

The $M_w$ distribution organized from east to west is detailed on the Firmagram (Fig. 3). Moreover, we can observe the variability of the Hurst exponent along the PAFS, from $H = 0.8$ (eastern zone), $H = 0.5$ (central zone) to $H = 0.7$ (western zone). The result strongly suggests a micro-regionalization of the PAFS into three main zones. This micro-regionalization is of paramount importance in seismic hazard analysis and in the understanding of fault dynamics. The persistence values ($H > 0.5$) are related to the predictability of future seismic events based on the existing correlation with past events. They are widely consistent with the instrumental seismicity, because the eastern zone is the most active, followed by the western segment of the PAFS. Meanwhile, the central PAFS corresponds to a random process. As a consequence, there is a dependence and causality between $H$ and the PAFS dynamics. The differences between each zone are:

- **Eastern PAFS:** This zone is the most active sector, based on $H = 0.8$ and the obtained magnitudes of $5.5 \leq M_w \leq 7.0$. This is evidenced by the paleoseismological studies and the instrumental seismicity. Regarding persistence, these earthquake magnitudes are susceptible to ground-rupturing, showing an increasing trend towards the future. Coupled with the results of Velázquez-Bucio (2018), ~~000 , depending on whether each fault breaks as a single unit or in separate segments (Langridge et al. 2013; Ortuño et al. 2015). Taken together, a significant earthquake can be expected in the region every 300 to 600 (Zúñiga et al. 2012). In a particular study of the seismicity in the MAFS, Magaña-García (2017) presents a recurrence periods in the order of 9~~it appears that several segments of the Acambay graben are already at their time zero and could break any time. This configures an area with high seismic hazard.

- **Central PAFS:** $H = 0.5$ shows a Brownian process, no trend, for magnitudes between $5.5 \leq M_w \leq 6.7$. We suggest here that $H$ could be related to shorter fault lengths, and consequently there is a lesser amount of deformation in the area.

This result can be related to the emplacement of the Los Azufres Geothermal Field and its magmatic chamber, located between 4.3 and 9.5 km of depth at the El Guangoche dome. Moreover, the E-W Pátzcuaro-Acambay Fault System is affecting the 1 Ma rhyolitic and dacitic domes (Agua Fría), ~~000 to 11,000 base on the $b$-value stability which is consistent with previous paleoseismological studies (Garduño-Monroy et al. 2009a; Sunye-Puchol et al. , 2015).~~

~~The fault name, length, scarp and slip-rate for faults with paleoseismological studies in the MAFS are presented in Table 1. Furthermore,~~ but also the andesitic volcanism, and controlling the distribution of monogenetic volcanism in the ~~$M_w$ estimated (Wesnousky, 2008) and the intensity scale (ESI 07)are presented, as well as the corresponding affected area (). In the last column, we present the cumulative form of~~ area. So, the observed value of $H$ depends, among other things, on the fragile-ductile limit of the ~~slip-rates () too. And the resulting cumulative plot for the slip-rates and the fractal box dimension analysis is presented in Figure 4.~~ crust. All these facts allow to validate that the central zone differs tectonically from the eastern and western sectors, and is characterized by a seismic gap similar to that of the Tzitzio-Valle de Santiago fault.

~~According to the Environmental Seismic Intensity scale (ESI 07)used for measuring the effects of an earthquake on the natural environment, all the faults in the MAFS with paleoseismological studies are capable to generate Class B events, with affected areas ranging from 1000 to 5000 where geomorphological and geological evidences are frequent and characteristic. The size of the affected areas for any of the faults revised in this work cover some of the most populated cities of Mexico, such as Ecatepec, Mexico City, Toluca, Morelia, among others.~~

~~The predictability of time series begins with the original work of Hurst (1951), who focused on the analysis of fluctuating fluvial time series, by analyzing the standard deviation of the accumulated water flow. Thus, Hurst established the wet and dry cycles in the Nile Valley. In our case the Hurst Exponent has a value of $H = 0.949$ and shows a strong persistent process for the slip-rates () distribution. This temporary memory, related to a non-linear dynamic, and in turn, with cycles or periods with different seismic activity (the probability to change in the trend of the series is less than the probability to continue in it)is important in seismotectonic~~

- **Western PAFS:** Persistent values of $H \sim 0.7$ have been reported by other authors (e. g. Scholz, 1997; Schmittbuhl et al., 2006). In our case, this value is consistent with the persistence of earthquake magnitudes ranging between $5.5 \leq M_w \leq 6.9$ (faulting processes with memory). In fact, the ~~slip-rates along the MAFS, in the cumulate form, has the structure of a well-known fractal called the Devil's staircase (Figure 4.Left).~~ paleoseismological studies by Garduño-Monroy et al. (2009) and Soria-Caballero (submitted), indicated similar magnitudes for historic earthquakes in the zones of Zacapu, Pátzcuaro, Morelia, and Cuitzeo. Therefore, the western PAFS is a high seismic hazard zone too, but to a lesser degree than the eastern zone.

~~The box dimension for our Devil's staircase result (~~For the slip-rate time series we reported values of $H = 0.949$ and $D_b = 1.86$~~)~~. The Hurst exponent shows a strong persistence, meaning close periodicities in time for ground-rupturing in the PAFS. $D_b = 1.86$ is consistent with the values obtained by Nieto-Samaniego et al., (2005; $D_b = 1.87$ upper limit), who proved that the box dimension is in inverse relation ~~with~~ to fracture concentration and in direct relation ~~with~~ to fracture density. The high value of the fractal dimension ~~may~~ might indicate the possibility ~~for generation~~ of a major earthquake (Aviles et al., 1987) in the ~~faults of the MAFS, which could crack in an irregular rupture.~~ PAFS faults. The high $D_b = 1.86$ value obtained depends inversely on the failure concentration criterion, which indicates that the critical fault concentration, based on the stability of two faults in a stress field, is directly proportional to the factor $(\frac{L}{l})$, where $L$ is the size of the region and $l$ the mean fault length (Smirnov and Zavyalov, 1997). So, low critical fault concentration corresponds to short fault lengths: it is well-known that lesser amounts of deformation are directly proportional to short faults lengths and low slip rates. Therefore, short faults lengths in the PAFS accommodate little deformation, suggesting that fault lengths of $\geq 3$ km accommodate the deformation of the PAFS more efficiently.

~~The fracture concentrationis an estimate for the mean distance between centres of fractures divides by the average fracture lengths, which characterizes the interactions between adjacent fractures (Nieto-Samaniego et al., 2005), then our data supports the idea that a high value of~~ Finally, supported by $D_b$ ~~represents the loss of stability for the slip-rates for the faults in the MAFS, it is an indicative that we have a critical state of earthquake-generating (Smirnov and Zaviyalov, 1997) in the entire fault system, so this correspond to larger slip-rates (i.e. large scale) . In other words, the critical state in the MAFS corresponds to a smaller values of the rupture concentration parameters (high $D_b$ value) , based on the stability of the faults within the MAFS in the stress field throughout time. The stability was lost when small fractures grew and joined to form big faults, consequently there is a high concentration of the latter, which are capable to generating earthquakes up to magnitudes $7.0 M_w$ in the MAFS (Soria-Caballero et al. , in prep).~~ and $H_w$, we can neatly determine the lower limit (3 km) of fault lengths for the PAFS. However, we cannot establish a definite upper limit due the faults hidden under Holocene deposits, not identifiable on a 15-meter Digital Elevation. We nevertheless estimated an upper limit of fault lengths (38 km) as a first approximation.

## 7 Conclusions

~~The temporal slip-rates~~ Spatial-temporal methods were applied to fault data, and the fractal behavior observed for the entire PAFS allowed to define which segments can be designated as active faults. Therefore, an active fault is defined as a plane that presents ground-rupturing with speeds of approximately 0.001 mm/year, and associated seismic activity at least in the last 10,000 year. Moreover, active faults are optimally oriented to the current stress field, and the active fault planes must be related to earthquakes with a minimum magnitude of $M_w \geq 5.5$, or capable of generating rupture lengths greater than or equal to 3 km. The temporal slip-rate distribution for the ~~faults in the MAFS has a fractal behaviour~~PAFS displays a fractal behavior, with strong persistent characteristics ($H = 0.949$). In this context, we have a statistical measure of the memory of ~~the slip-rates series, so,~~ slip-rate series, and we can infer the predictability of ~~this temporal seriesand~~ these temporal series, to conclude that the entire fault system is active.

~~The fractal dimension of the faults distribution, $D_b$, is a high value ($D_b = 1.86$), that indicates less concentration of small slip-rates,~~ Moreover, we were able to define a micro-regionalization of the PAFS using the relationship established between $H$ and the PAFS dynamics. $H = 0.5$ for $M_w$ behaves like a brownian process,(Central PAFS), and ~~therefore there is not an~~

~~excess of the deformation in the MAFS in a single or restricted range of scales. Consequently, this fractal dimension represents a migration of the ruptures to larger scales (earthquake-generating faults with lengths $\geq$ 3 km).~~

~~The~~ $H > 0.5$ for $M_w$ has a trend (easter PAFS and western PAFS). The result reveals the easter PAFS as the most active zone. With regard to the regional structures and their relationships with magmatism or hydrothermal processes, it is clear that there are three zones within the PASF, where faults with different geometries and also different magmatic processes were observed, surely related to the values of $H_w$ obtained for each zone. In particular, the estimation of maximum and minimum earthquake magnitudes ~~, obtained by means of empirical relationships, which the system can generate, is similar to generate moderate to strong (5.4~~ (5.5 $\leq M_w \leq$ ~~7.1) shallow earthquakes ($h < 20$ ), as well as great area of influence of affectation~~ 7.0) is likely to affect a large area ($1000 \leq \mathrm{km}^2 \leq 5000$) in the ~~center~~ central region of Mexico, where there are many cities with high population density.

~~The mathematical behaviour observed for the entire MAFS contribute to define areas under seismic risk and the improvement~~ As discussed earlier, assessing seismic hazard and improving of the vulnerability studies ~~in Mexico.~~ is acutely necessary in the central portion of Mexico. Finally, we conclude that the PAFS fulfills the intrinsic definition of active fault. The PAFS is likely to cause future social concern. As such, we strongly believe that the area must continue to be investigated by multidisciplinary studies in order to improve territorial planning and reduce seismic hazard in central Mexico.

*Data availability.* The datasets generated during the current study are available from the corresponding author on reasonable request.

*Author contributions.* AMP built the GIS-based database of active faults, supervised by VGM and DSC. AMP and AFS performed the fractal analysis and the estimations of the maximum magnitudes, as well as the discussion of the results. AFS took the lead in writing the manuscript. DCS contributed with the Intensity Scale values for the active faults in the PAFS and together with VGM helped shape the research. VGM also performed the review of the tectonics in the PAFS and helped supervise the project. All authors discussed the results and contributed to the final manuscript

*Competing interests.* The author declares no competing financial interests

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~~**(A)** Geodynamic setting along the Middle America Trench. TMVB: Transmexican Volcanic Belt. **(B)** Tectonic setting in the Transmexican Volcanic Belt (red zone). **(C)** Seismotectonic setting in the Morelia-Acambay Fault System within the TMVB.~~

~~Active Faults in the MAFS. Circles represents the seismicity based on a homogeneous catalog from Magaña-García (2017) and Zúñiga et al. (2017) between 1912 to 2016 based on the seismicity reported by de National Seismological Service of Mexico (SSN). Focal Mechanisms were reported by Krishna-Sing et al (2012), Ego and Ansan (2002) and Pacheco et al (1999).~~ ~~**(a)** Comparison between the estimations of the earthquake sizes for the active faults in the MAFS. **(b)** Magnitudes organized in descendent order based on the maximum value of the magnitude obtained by the relationships of Wesnousky (2008).~~ ~~**(Left)** Fractal model for the cumulative slip-rates () distribution of active faults in the MAFS. **(Right)** Analysis of the capacity dimension or box-dimension with a fractal dimension of $D_b = 1.86$ and a Hurst Exponent $H = 0.949$.~~

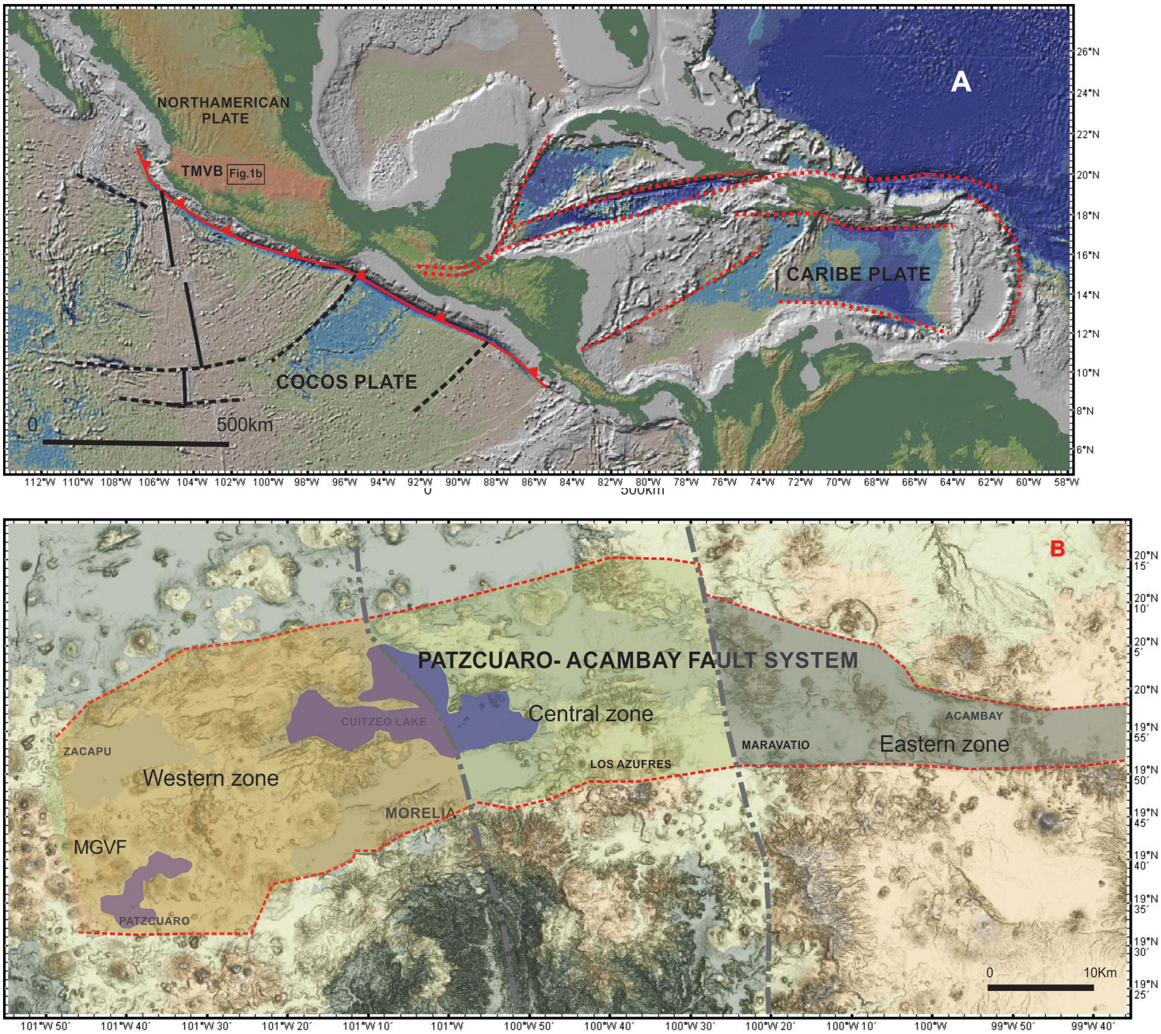


**Figure 1.** (A) Tectonics and geodynamic setting of the Trans-Mexican Volcanic Belt (pink area). Dotted red lines are plate boundaries and the continuous red line is the Middle America Trench. The Pátzcuaro-Acambay Fault System (PASF) is outlined by the black rectangle. TMVB: Trans-Mexican Volcanic Belt. **(B)** Tectonic area of the Pátzcuaro-Acambay Fault System that shows the limits (thick dashed gray lines) between the three zones of the PASF (western, central and eastern zones). MGVF: Michoacán-Guanajuato Volcanic Field.

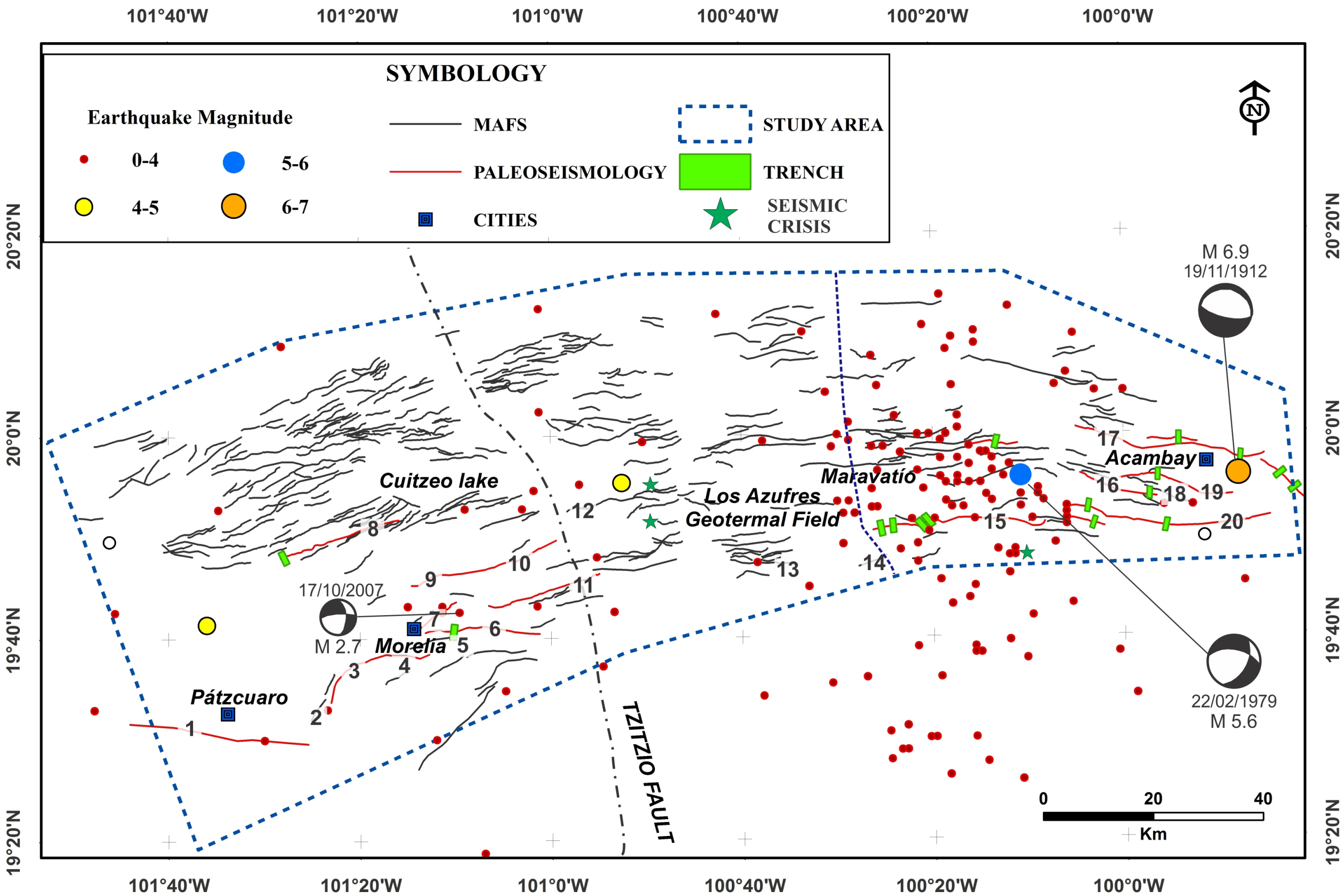


**Figure 2.** Structural map of the Pátzcuaro-Acambay Fault System. Active Faults are represented by continuous black lines. Continuous red lines are the faults studied with paleoseismological approach. The purple dotted line is the limit between the central and eastern zones. Numbers show faults described in Table 1. Green stars represent the seismic crisis in Pátzcuaro and Araró (in 1845 and 1858) and Zinapécuaro and Tlalpujahua (in the 19th century). Circles represent the seismicity from 1912 to 2018 based on the catalog of the National Seismological Service of Mexico (Servicio Sismológico Nacional, SSN). Focal Mechanisms were reported by Astiz-Delgado (1980), Suter et al. (1992; 1995), Langridge et al. (2000), Singh et al. (2011; 2012), and Rodríguez-Pascua et al. (2012). The ascending numbers are referred to in Table 1.

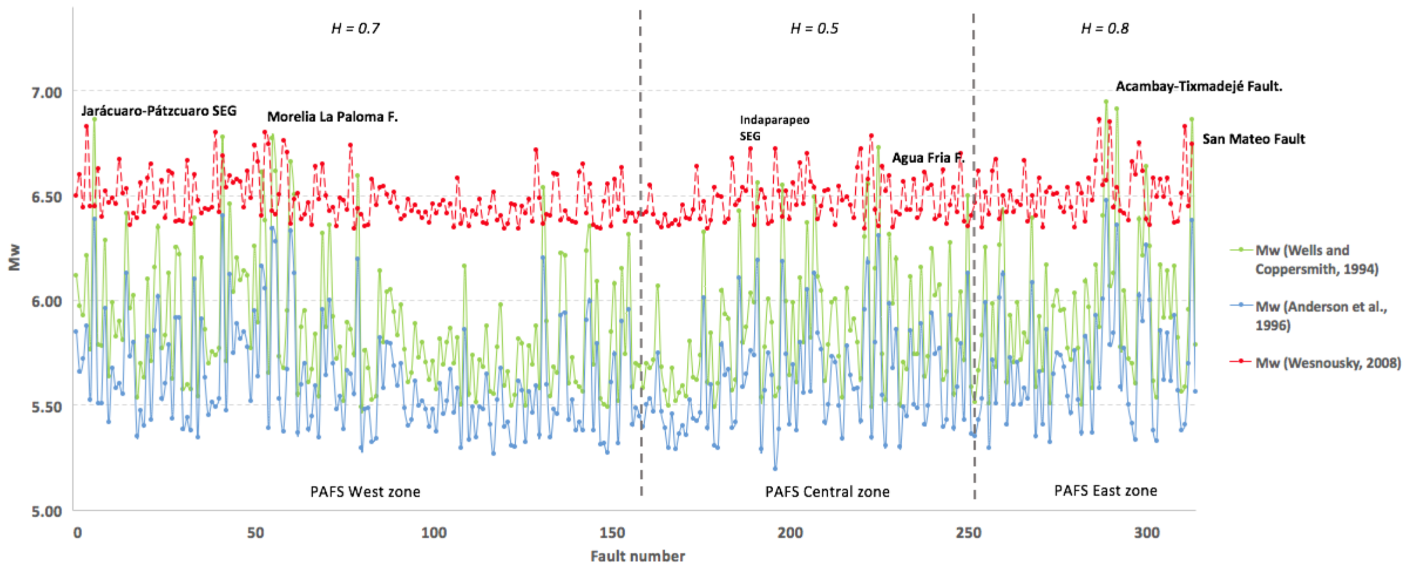


**Figure 3.** Firmagram roughness graph for the earthquake magnitude variations calculated by the surface rupture length (SRL) for the PAFS using: Wesnousky (2008, data in red); Wells and Coppersmith (1994, data in green) and Anderson et al. (1996, data in blue). By optical visualization we observed that Wells and Coppersmith (1994) and Anderson et al. (1996) are underestimating the data with respect to the magnitudes determined by the equivalent regression model proposed by Wesnowsky (2008). Dashed gray lines are delimiting the three zones that define the micro-regionalization of the PAFS (western PAFS , central PAFS and eastern PAFS ) in terms of their Hurst exponent ($H_w = 0.7, H_w = 0.5, H_w = 0.8$ respectively), showing different seismic rates for each zone. Some fault names were printed in the figure.

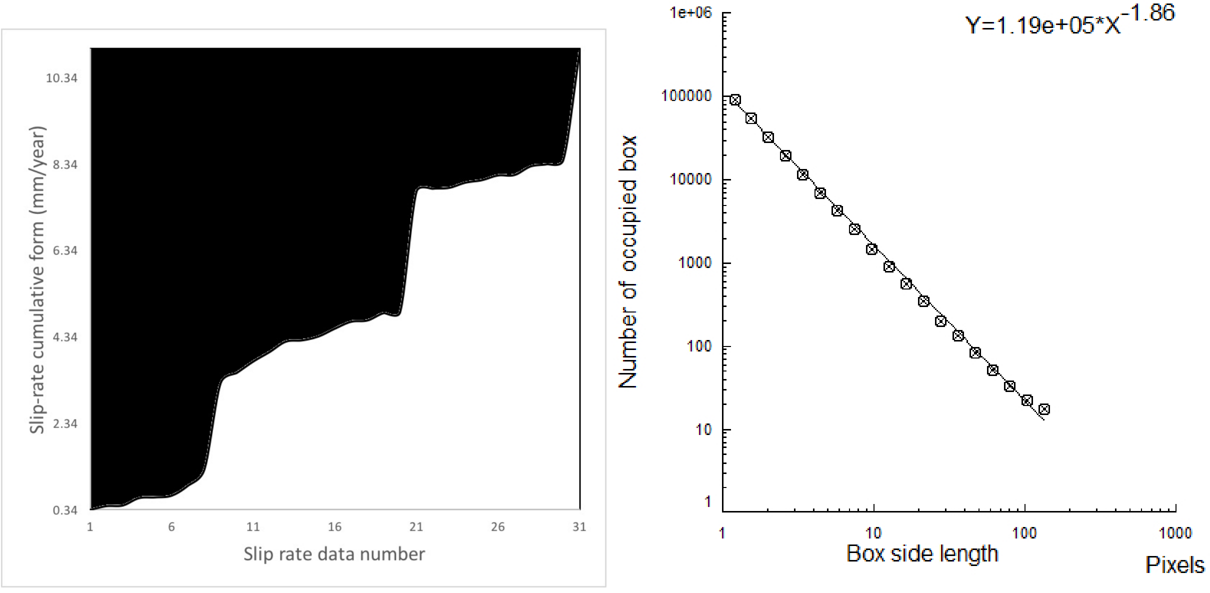


**Figure 4.** **(a)** Devil's staircase fractal for the cumulative slip-rate $(\mathrm{mm/yr})$ distribution of active faults from the east to west in the PAFS (see Table 1). **(b)** Log-log plot of number of boxes ($N(e)$) versus box side length ($e$). The slope of the straight line is equal to the capacity dimension or box-dimension. The resulting $D_b = 1.86$ is related to a lower concentration of low slip rates in the PAFS, suggesting that larger faults accommodate the strain more efficiently.

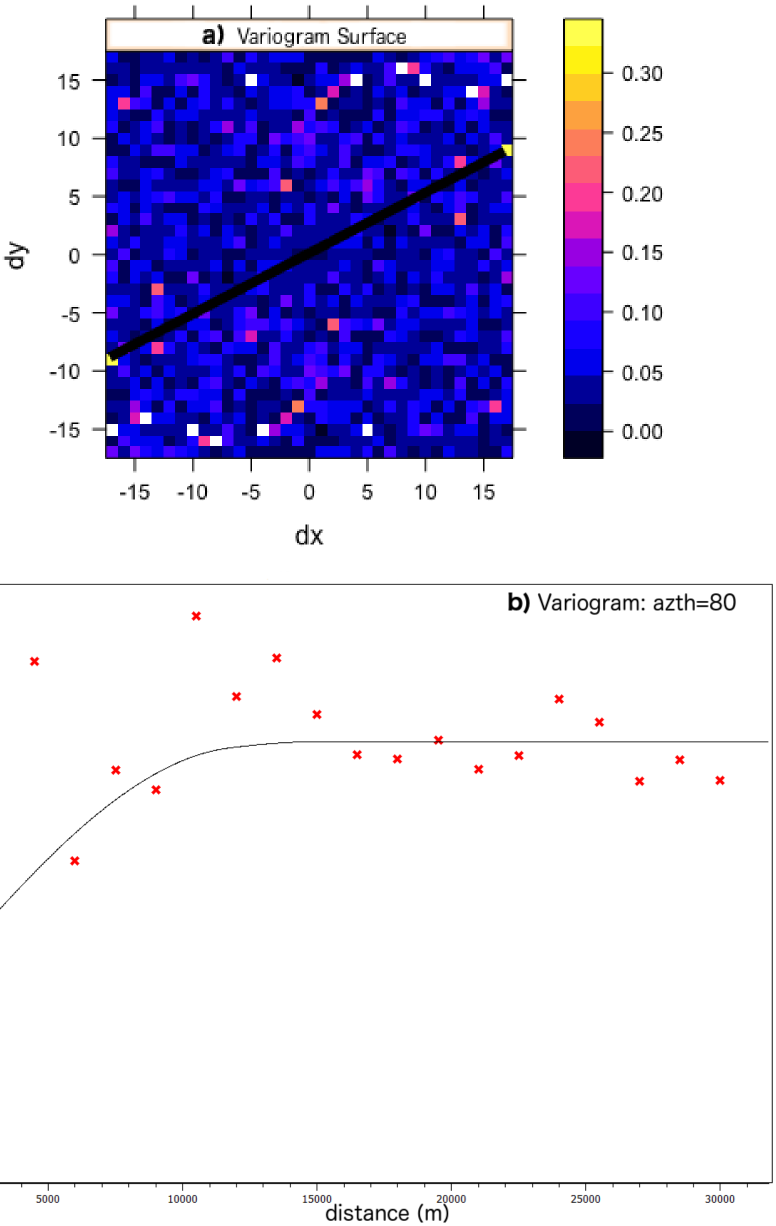


**Figure 5.** **(a)** Variogram surface of fault lengths in the PAFS, with a straight line showing the direction of the best spatial autocorrelation. At the center a pattern forms a shape of an ellipse, suggesting that the best correlations are observed in NE-SW direction. **(b)** Anisotropic variogram of fault lengths, which exhibits a good structure in ENE direction (80°), and matches with a spherical model (black continuous line). So, this faults are optimally oriented in relation to the current stress in the PAFS ($\sigma 2$). So, this anisotropic direction indicates that the spatial distribution of faults is mainly due to extensional stresses, and is consequently subject to deformation generated by the current stress field in the PAFS ($\sigma 2$, NW-SE).

**Table 1.** ~~Faults with slip-rate information~~ Slip-rate estimations of earlier studies organized from east to west along ~~different faults in~~ the ~~MAFS~~PAFS.

| Fault name | Length (km) | Scarp (m) | Slip-rate (mm/yr) | Slip-rate cumulative-form | References | $M_w$ esti… (~~Wesnousky, 2008~~… |
|---|---|---|---|---|---|---|
| (17)Colluvium ~~60*(ATIF)~~60* | | | 0.17 | | Suter et al. ~~,~~ (2001) | |
| (17)Acambay-Tixmadejé | 36 | 650 | 0.17 ± 0.02 | 0.34 | Langridge et al. ~~,~~ (2000) | ~~6.85~~ 6 |
| (19) San Mateo | 21 | 115 | 0.085 ± 0.025 | 0.43 | Sunye-Puchol et al. ~~,~~ (2015) | ~~6.75~~ 6 |
| (18)San Pedro Alto | 6 | 136 | 0.0159 | 0.44 | Velazquez-Bucio (~~in process~~2018) | ~~6.48~~ 6 |
| (16)Temascalcingo | 15 | 230 | 0.17 | 0.61 | Ortuño et al. ~~,~~ (2018) | ~~6.67~~ 6 |
| (16)Temascalcingo | 15 | 230 | 0.0173 | 0.63 | Velazquez-Bucio (~~in process~~2018) | ~~6.67~~ 6 |
| (20)Unnamed Basalt 59* ~~(PASF)~~ | 15 | | 0.04 | 0.67 | Suter et al. ~~,~~ (2001) | |
| ~~Pastores~~ (20)Pastores (P) | 38 | 243 | 0.23 | 0.90 | Ortuño et al. ~~,~~ (2015) | ~~6.86~~ 6 |
| | | | 0.37 | 1.27 | | |
| (15)Venta de Bravo | 33 | 300 | 2 | 3.27 | Suter et al~~,~~. (1992) | ~~6.83~~ 6 |
| (15)Venta de Bravo | 32 | 300 | 0.24 | 3.51 | Ortuño et al. ~~,~~ (2018) | ~~6.83~~ 6 |
| | | | 0.26 | 3.77 | | |
| (15)Venta de Bravo | 47 | 50-300 | 0.22 | 3.99 | Lacan et al. ~~,~~ (2017) | ~~6.91~~ 6 |
| | | | 0.24 | 4.23 | | |
| ~~Ciudad~~ (14)Cd. Hidalgo Basalt 65* | | 20 | 0.03 | 4.26 | Suter et al. ~~,~~ (2001) | |
| ~~Ciudad~~ (14)Cd. Hidalgo Basalt 47* | | 70 | 0.09 | 4.35 | Suter et al. ~~,~~ (2001) | |
| (13)San Andrés Dacite 50* | | 60 | 0.18 | 4.53 | Suter et al. ~~,~~ (2001) | |
| (12)Cuitzeo Basalt 37* | | 120 | 0.16 | 4.69 | Suter et al. ~~,~~ (2001) | |
| (12)Cuitzeo Basalt 39* | | 20 | 0.03 | 4.72 | Suter et al. ~~,~~ (2001) | |
| (11)Charo-Queréndaro | 21 | 80 | 0.17 | 4.89 | Garduño-Monroy ~~V.H.~~ et al.~~,~~ (2009) | ~~6.75~~ 6 |
| ~~Tarimbaro y Álvaro~~ (10)Tarimbaro-Á. Obregón | 28 | 200 | 0.025 | 4.91 | Garduño-Monroy ~~V.H.~~ et al.~~,~~ (2009) | ~~6.80~~ 6 |
| | | | 2.78 | 7.69 | | |
| (9)Quinceo Basalt 41* | | 40 | 0.07 | 7.76 | Suter et al. ~~,~~ (2001) | |
| (9)Quinceo Basalt 44* | | 10 | 0.02 | 7.78 | Suter et al. ~~,~~ (2001) | |
| ~~Morelia Central~~ (7)Morelia C. Camionera | 10 | 60 | 0.12 | 7.90 | Garduño-Monroy et al. ~~,~~ (2009) | ~~6.58~~ 6 |
| (6)Morelia La Paloma | 21 | 300 | 0.057 | 7.96 | Garduño-Monroy et al. ~~,~~ (2009) | ~~6.74~~ 6 |
| (8)Teremendo | 23 | 70 | 0.11 | 8.07 | Soria-Caballero (~~in process~~Submitted) | ~~6.76~~ 6 |
| (5)Morelos | 8 | 50 | 0.009 | 8.08 | Garduño-Monroy et al.~~,~~ (2009) | ~~6.53~~ 6 |
| (4)Cointzio | 14 | 100 | 0.2 | 8.28 | Garduño-Monroy et al.~~,~~ (2009) | ~~6.66~~ 6 |
| (3)C. El Aguila lava 42* | | 40 | 0.05 | 8.33 | Suter et al. ~~,~~ (2001) | |
| (2)Huiramba | 5 | 50 | 0.1 | 8.43 | Garduño-Monroy et al.~~,~~ (2009) | ~~6.43~~ 5 |
| (1)Jarácuaro-Pátzcuaro | 33 | 277 | 2.5 | 10.93 | Garduño-Monroy et al.~~,~~ (2009) | ~~6.83~~ 6 |

*Scarp refers to the top of the faulted rock unit.

Here, we reported the maximum earthquake magnitudes obtained with Wells and Coppersmith (1994). The ascending numbers are referred to in Figure 2.