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Seismicity characterization of the Maravatío-Acambay and Actopan regions, central Mexico

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A B S T R A C T

We studied the seismic activity in the Maravatío-Acambay and Actopan regions in Central Mexico. These regions are of great importance due to the occurrence of shallow crustal normal-faulting earthquakes that caused widespread destruction near their epicenter and as far away as Mexico City. That was the case of the 19 November 1912 Acambay (M_w 6.9). We determined statistical seismicity characteristics such as the Båth's law (the size of largest aftershock with respect to that of the mainshock), the *b*-value and *p*-value. For the Maravatío aftershock sequence, we obtained a *b*-value of 0.88 and *p*-value of 0.68. Based on reported seismicity, we obtained a *b*-value of 1.12 for the Actopan region. We estimated the size of the largest aftershock of the Acambay event in the range of $4.7 < M_w < 5.9$. By using the fragment-asperity model, we also performed the analysis of the magnitude distribution. The analysis showed similar values for the non-extensivity parameter (*q*-value): $q = 1.6465$ and $q = 1.6555$ for the Maravatío aftershock sequence and for the seismicity in the Actopan region, respectively. The similitude in the *q*-values could be associated with the similarities in the tectonic environment. In this model, the constant of proportionality (a) between released energy and the size of fragments showed that more energy is released for the Maravatío aftershock sequence than for the regular seismicity rate in the Acambay region. Finally, we analyzed the relation of the seismicity and the tectonic environment by quantifying the seismic coupling and the thickness of the seismogenic layer. The estimated seismogenic layer for the Maravatío-Acambay and Actopan regions are 14.6 km and 20.8 km, respectively. The seismic coupling coefficient at the Venta the Bravo fault in the Maravatío-Acambay region and Actopan region are 0.21 and 0.46, respectively. Our estimation of the seismic coupling coefficients shows that the regions can be classified as low-to-intermediate-coupling zones.

1. Introduction

Crustal intraplate earthquakes occur in regions that are characterized by very low strain rates. Although their potential for widespread destruction is large, they occur less frequently compared to plate boundary events. However, the mechanisms by which shallow crustal earthquakes occur have been poorly understood (Campbell, 1978; Hinze et al., 1988; Iio and Kobayashi, 2002). The characteristics of the seismic activity in a certain region can give important and reliable information about the structure of the crust and the stress distribution associated with the earthquake occurrence. Some models have been proposed to describe the seismic activity, focused mainly on two aspects: the earthquake occurrence and the aftershock behavior. The earthquake frequency-magnitude distribution (Gutenberg-Richter law) is described by a parameter known as the *b*-value which is the slope of the linear relation after a certain minimum magnitude (Gutenberg and Richter, 1944). For intraplate regions, it varies from 0.77 to 2.1 (Triep and Sykes, 1997; Allen et al., 2004; Stein and Newman, 2004). The aftershock behavior is described by the aftershock decay rate (*p*-value) and it ranges from 0.5 to 2.5, but normally it comes closer to 1.0 in tectonically active regions (e.g., Liu, 1986; Kisslinger and Jones, 1991; Utsu, 1999). For shallow crustal events, *p*-value ranges from 0.70 to 1.80 (Kisslinger and Jones, 1991; Bayrak and Öztürk, 2004; Yadav et al., 2012).

Traditionally, the *b*-value has been used to characterize the seismicity in a region despite the limitations of the Gutenberg-

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Richter law for describing the smallest magnitudes (usually due to poor instrumental coverage), as well as for large magnitudes (due to shortness of time record). Recently, considerable efforts have given support to the study of the earthquake dynamics from the point of view of Tsallis nonextensive statistics (Tsallis, 1988, 1999). Nonextensive statistics, represents a consistent theoretical framework for the investigation of some properties of complex systems at their nonequilibrium stationary status, such as fractality, multifractality, self-similarity, long-range dependencies (Tsallis, 1988, 1999). By using the nonextensive formalism, a more realistic magnitude distribution model is proposed (known as the Fragment-asperity model) (Sotolongo-Costa and Posadasm, 2004; Silva et al., 2006; Telesca, 2011), providing an excellent fit to the seismicity of several seismic regions (Vilar et al., 2007; Telesca, 2010a, 2010b, 2011; Michas et al., 2013; Villianatos et al., 2014).

The Trans-Mexican volcanic belt (TMVB) is a seismogenic zone that transects the central part of Mexico with an east–west orientation, oblique with respect to the trench line. Seismicity in the TMVB is moderate compared to other seismogenic zones in Mexico. Few studies dealing with seismicity characteristics in the TMVB have been published (e.g., Urbina and Camacho, 1913; Astiz, 1980; Zúñiga et al., 2003; Quintanar et al., 2004; Singh et al., 2011, 2012). The seismic risk and hazard of the TMVB have not been studied in detail due to the scarcity of instrumental data. The Maravatío-Acambay and Actopan regions are located in the Central segment of the TMVB. These regions have relatively good instrumental data. The 1979 (m_b 5.3) Maravatío earthquake and its aftershock sequence were well-recorded. There has been an improvement in the earthquake location in the Actopan region because of the increment of seismic stations and its proximity to Mexico City. In this context, an analysis of the aftershock sequence and seismicity, which occurred in the Maravatío-Acambay and Actopan regions, respectively, is important as it provides useful information on the characteristics of earthquake sources in the Central segment of the TMVB. In this article, we characterized the seismicity in these regions. We determined statistical parameters such as the *b*-value, *p*-value and size of the largest aftershocks. We also applied the fragment-asperity model to infer source characteristics in these regions. We relocated seismic events to accurately estimate the thickness of the seismogenic layer as well as determine the seismic coupling.

2. Tectonic setting

The TMVB is an east-west, 1200-km-long, 100-km-wide, active Miocene-to-Quaternary, calc-alkaline continental volcanic arc (Fig. 1). The TMVB is associated with the subduction of the Cocos and Rivera plates beneath the North America plate (Suárez and Singh, 1986; Ego and Ansan, 2002) (Fig. 1). The central part of the TMVB is characterized by a 100- to 150-km-wide zone of normal

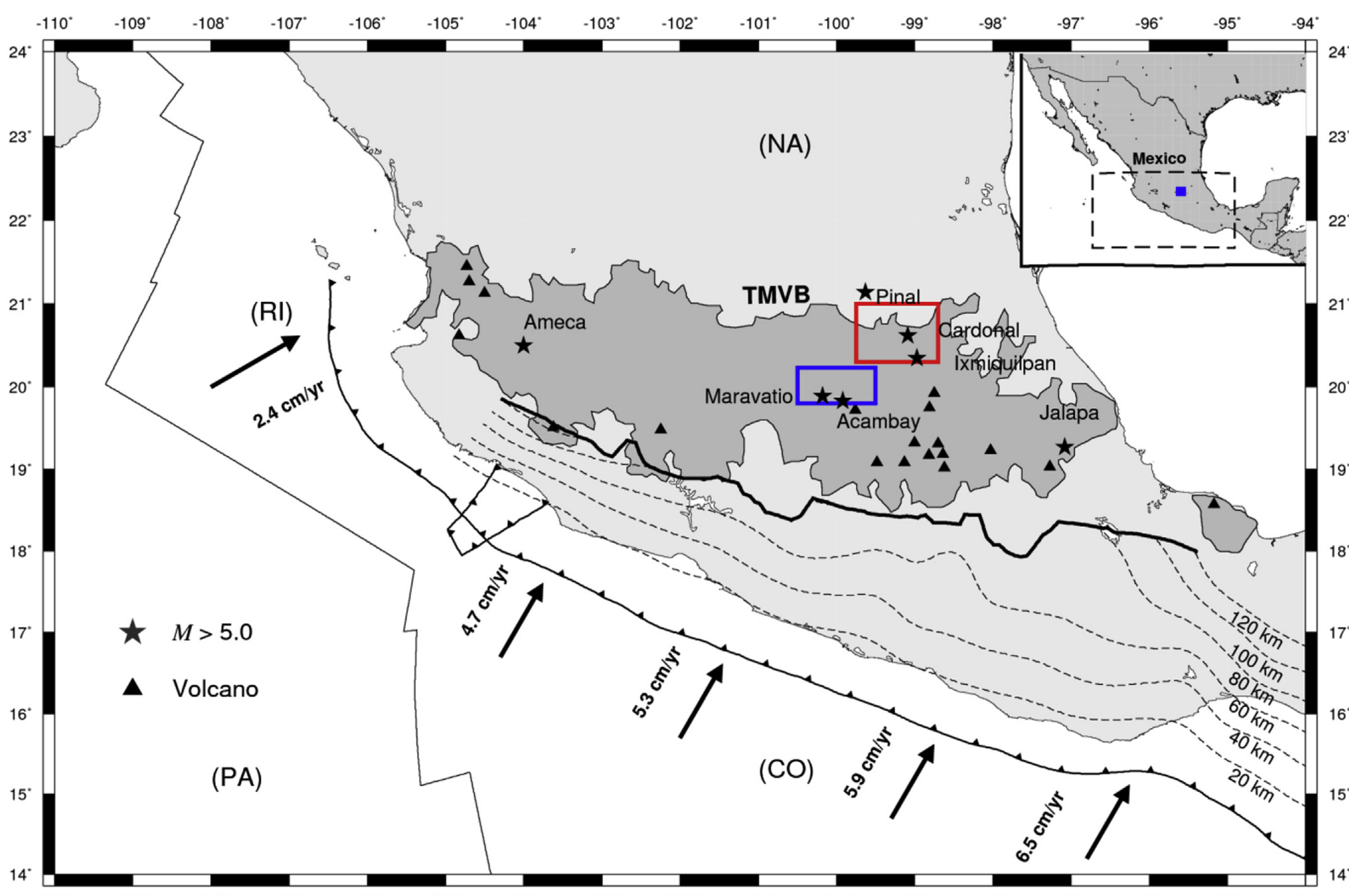

Fig. 1. Main tectonic features in Central Mexico. NA is the North American plate, CO is the Cocos plate, PA is the Pacific plate, RI is the Rivera micro plate, and TMVB is the Trans-Mexican Volcanic Belt. Black triangles are volcanoes and the black-bold line delimits the boundary of the TMVB. Dashed lines show contour lines of the subducted slab at 20, 40, 60, 80 and 120 km depth. Stars are shallow crustal earthquakes in the TMVB with $M > 5.0$ (Ameca, 1567/68; Pinal, 1887; Acambay, 1912; Jalapa, 1920; Ixmiquilpan, 1950; Cardonal, 1976; and Maravatío, 1979) (Suter et al., 1996; Suter, 2015). Color rectangles show the Acambay (blue) and Actopan (red) regions, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)