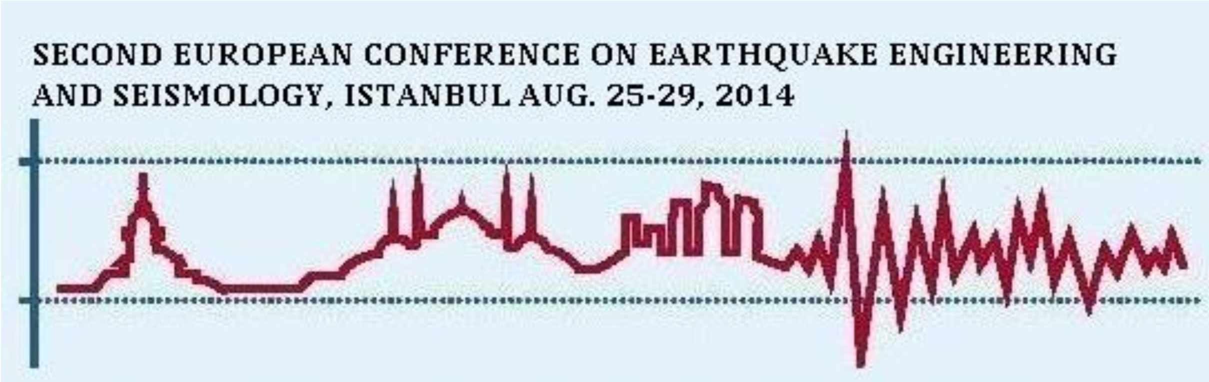

THE HIGH SEISMIC HAZARD OF VILLAVICENCIO, COLOMBIA

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ABSTRACT

According to a seismic microzone study (INGEOMINAS, 2002), Villavicencio, Colombia has been defined as a city facing high seismic hazard. The study based in previous works of Chicangana et al. (2011, 2013), presents seismological and morphotectonic aspects that corroborate that finding and discusses the possible consequences of an earthquake of great magnitude, since the city´s vulnerability increases due to deficient infrastructure and the lack of government plans with respect to both prevention and assistance to a population that is not prepared for this type of natural disaster.

INTRODUCTION

Villavicencio, a city of 460,000 inhabitants, is the main administrative and economic hub of the Colombian Llanos region, east of Bogotá. This city extends over an area with a high seismic risk according to seismology experts and public institutions like the Geological Survey of Colombia and the Colombian Seismic Engineering Association (AIS - Ingeominas, 1996; Paris et al., 2000; Alfaro and Ramos, 2001; Ojeda and Alvarado, 2002; AIS, 2009; Chicangana et al., 2012; 2013a and b).

The historical records register earthquakes for Villavicencio and toward the east of Bogotá on October 18, 1743 (this one was the most important and the first one to have been absolutely confirmed): August 31, 1917, and recently the Quetame Earthquake that struck on May 24, 2008 with M = 5.9.

Villavicencio and its neighboring area were inspected for seismic activity mainly on the East Front Fault System – EFFS (Paris et al., 2000). The EFFS used methods and tools such as: remote sensing, field work, and the analysis of seismological information taken both from a historical catalogue and the instrumental data recorded between 1993 and 2012 by the National Seismological Network of Colombia (NSNC).

Keeping in mind Villavicencio´s socioeconomic characteristics, we checked its vulnerability in the event of an earthquake by assessing the roles of the administrative authorities that are responsible for making the decisions and communicating the information over the seismic risk in the city. Finally, a possible post-earthquake scenario is described.

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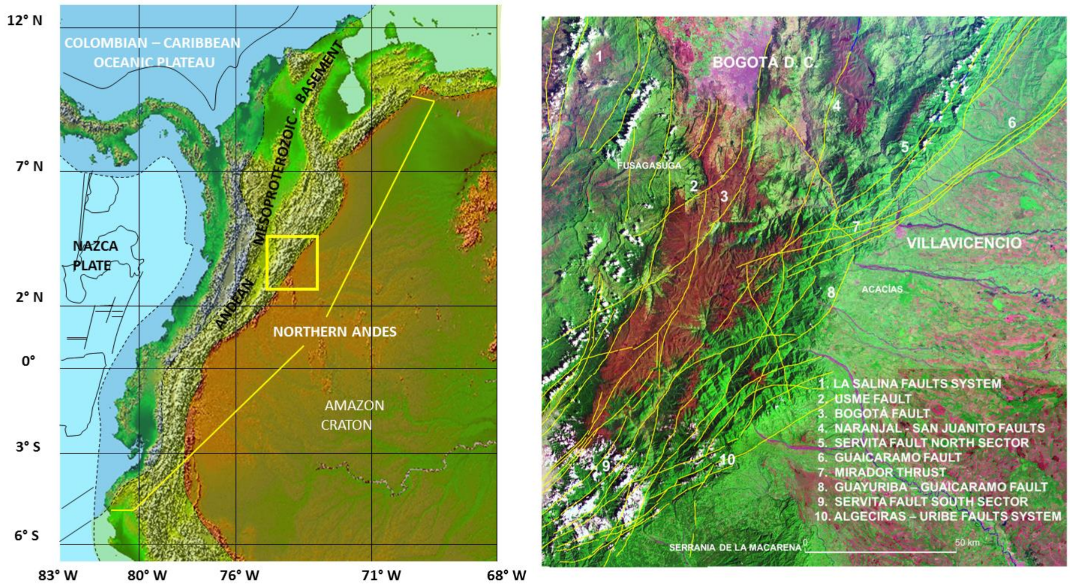

Figure 1. Left. Area in the yellow square: Central part of the Colombian Eastern Cordillera, and the plates that constitute the north western corner of south America such as Nazca, the Colombian - Caribbean Oceanic Plateau (Caribbean Plate), the Andean Mesoproterozoic Basement (North Andean block), and the Amazon Craton. Right, zoom in of the area in the yellow square on the left showing Bogotá, Villavicencio and the faults related to the EFFS like Algeciras - Uribe, Servitá, Guaicaramo, and Guayuriba.

SEISMOTECTONIC AND GEOTECTONIC SKETCHES

Four plates converge in Colombia, (Figures 1 and 2), from West to East these plates are: Nazca (it subducts beneath Northwestern South America), the Caribbean, the North Andean Block, and the Amazon Craton (which is the South American fixed plate). According to Mora and López (2011), the Nazca plate has a displacement toward the east with a velocity of 70 mm/year. As result of this, the Colombian continental crust reacts with regional seismicity which splits it into three cortical levels: the surficial seismicity (depth 0 – 50 km), the intermediate seismicity (depth 50 – 160 km), and the very deep seismicity (depth > 160 km).

The surficial seismicity is generated by the Caribbean and continental plates constrictions derived from the push of the Nazca plate subduction. The intermediate seismicity derives from the collision of the subducted plates such as Nazca and the Cretaceous – Paleogene Farallon Plate which produces lithospheric delamination (Chicangana and Vargas, 2008) and finally, the very deep seismicity comes from the collision between the mantle transition zone with the subducted plate of the Farallon – Nazca.

In Villavicencio, the surficial seismicity (Figures 3 and 4) reacts to tectonic activity of the main EFFS faults such as Algeciras – Uribe, Guaicaramo, and Servita faults. The seismic activity close to Bogotá and Villavicencio is related mainly to the tectonic activity of the Servitá fault (Chicangana et al. 2013). The Servitá fault is a big fault thrust which causes the sedimentary Devonian – Carboniferous rocks to rest over the Lower Cretaceous sedimentary rocks. The Servitá fault is one of the two master faults that have generated the orogenic growth of the Colombian Eastern Cordillera in the last 3 million years.

Villavicencio is located very near to the Servitá fault and over the deformation front that defines the Llanos Foothills. The orogenic growth had two effects that increased the seismic hazard in the Llanos Foothills. The first one was the large accumulation of sediments due to high erosion rates produced by the fast growth on the mountain front in this region. The second one was the constant seismic activity due to the former effect, which is the tectonic activity of the Servitá fault itself and its associated minor faults planes that causes the thrust of the North Andean block with the Amazon Craton (Figure 5). Villavicencio´s seismic hazard then has two origins: the high values of ground accelerations and the proximity to the big seismic source like the Servitá fault and its tectonic activity that derived in the growth of the Colombian Eastern Cordillera.

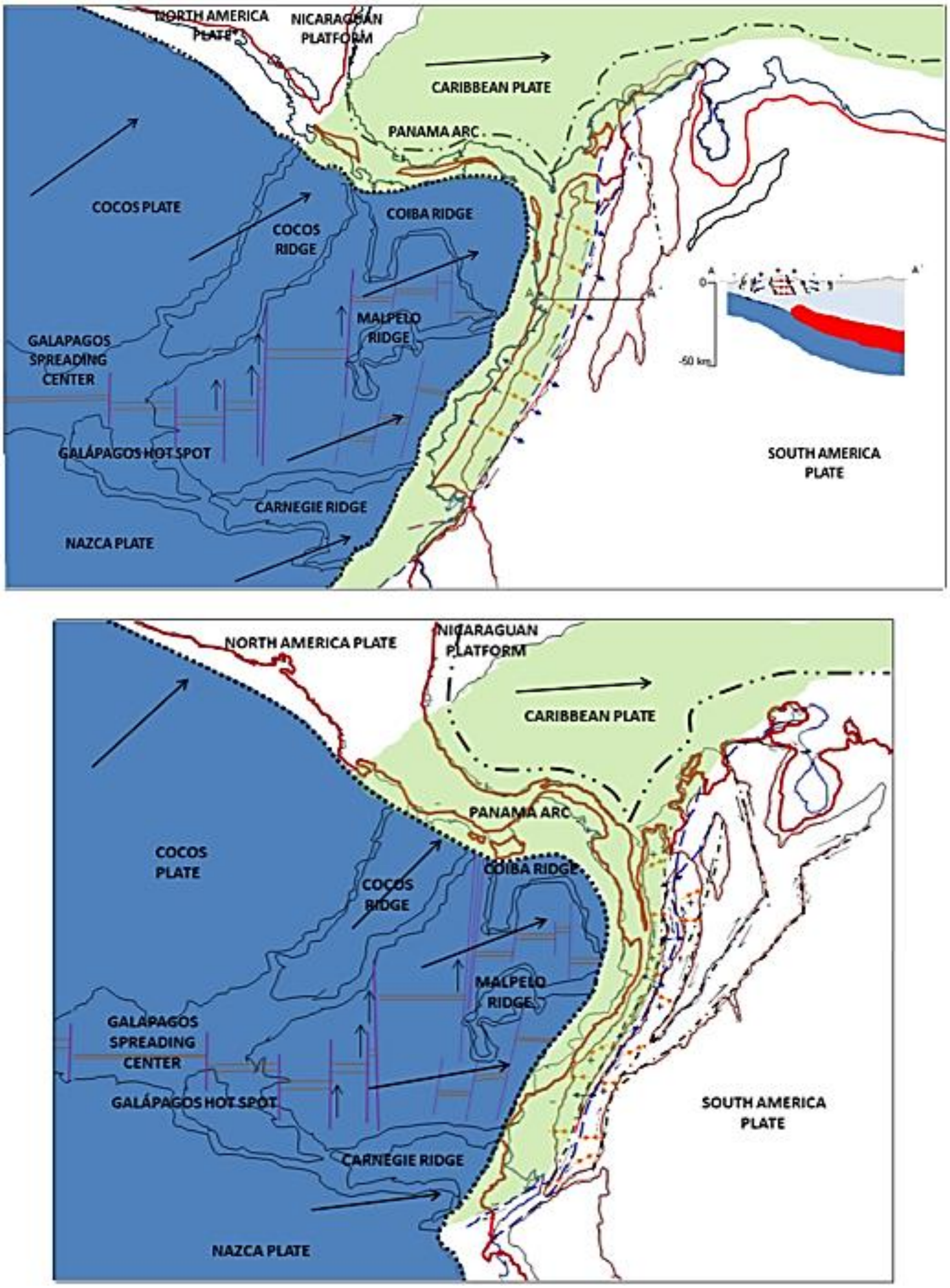

Figure 2 Hypothetic geodynamic scheme showing the evolution of the orogenic setting for the Caribbean plate (Blue), the Nazca plate (Green) and NW South America during Late Miocene - Early Pliocene lapse, with A – A´ profile (above), and during Late Pliocene - Early Pleistocene lapse (below).

SOME METHODS APPLIED IN THIS WORK

In this study we have taken additional approaches such as the seismotectonic analysis of this region and of the geotectonic development of the Colombian Llanos Foothill; the urban area soils geotechnics characteristics evaluated in a previous study by the Colombian Geological Survey (Ojeda and Alvarado, 2002), social and economic parameters like the people's QOL (quality of life), housing quality, and the local governmental actions regarding the risk management for seismicity.

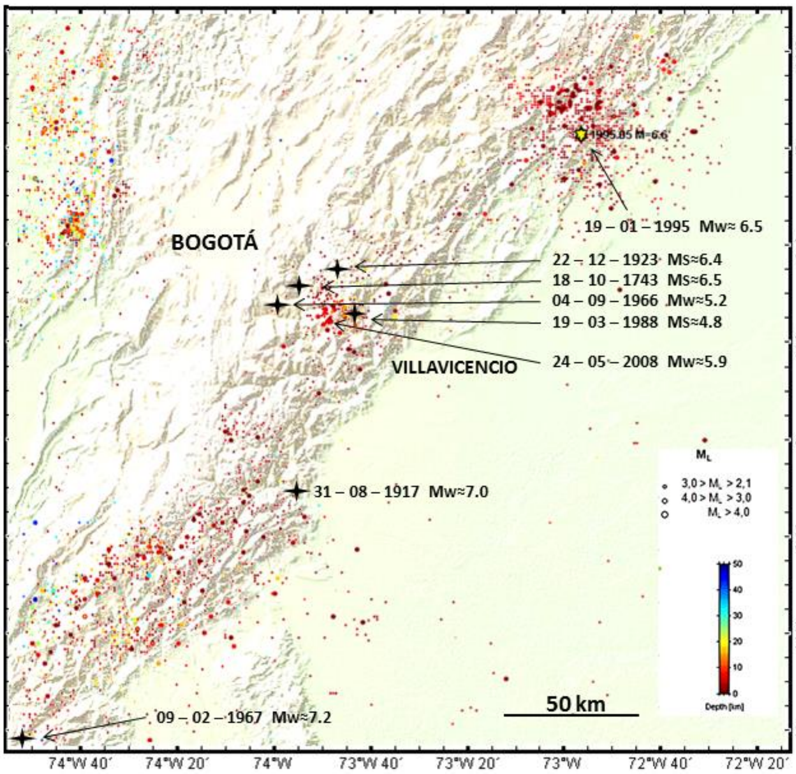

Figure 3. Historical earthquakes for 1743 - 1988 lapse with NSNC instrumental seismicity records for the period between 1993 and 2008 in the Villavicencio and Llanos foothills region in Central Colombia.

RESULTS

A M ≥ 6.5 earthquake in the Llanos Foothills or the eastern flank of the Eastern Cordillera in the same region where the 2008 M = 5.9 Quetame earthquake occurred, would leave the urban area of Villavicencio under a catastrophic scenario due to different factors, e.g.:

The lousy physical – mechanical proprieties of its soils.
According to Ojeda and Alvarado (2002), the rapid urban expansion toward the plains and the foothills can have accelerations nearing 2 g with periods of up to 2.5 seconds (Figure 5).

Sixty-five percent of Villavicencio´s population corresponds to the lower socio-economic tier. The majority of this group has settled in urban areas whose soils have up to 2g accelerations (Figure 5). This may also explain why the seismic hazard of this city increases dramatically due to the precarious building materials of their dwellings (Turkstra, 1998), which was observed in this study. We also found that it is not an exclusive characteristic of the slums, it is also seen in the middle and high end areas of the city since they have not followed the seismic design code, under the name Norma Sismo Resistente 2010 or NSR-10 in Colombia, as can be seen in Figure 6.

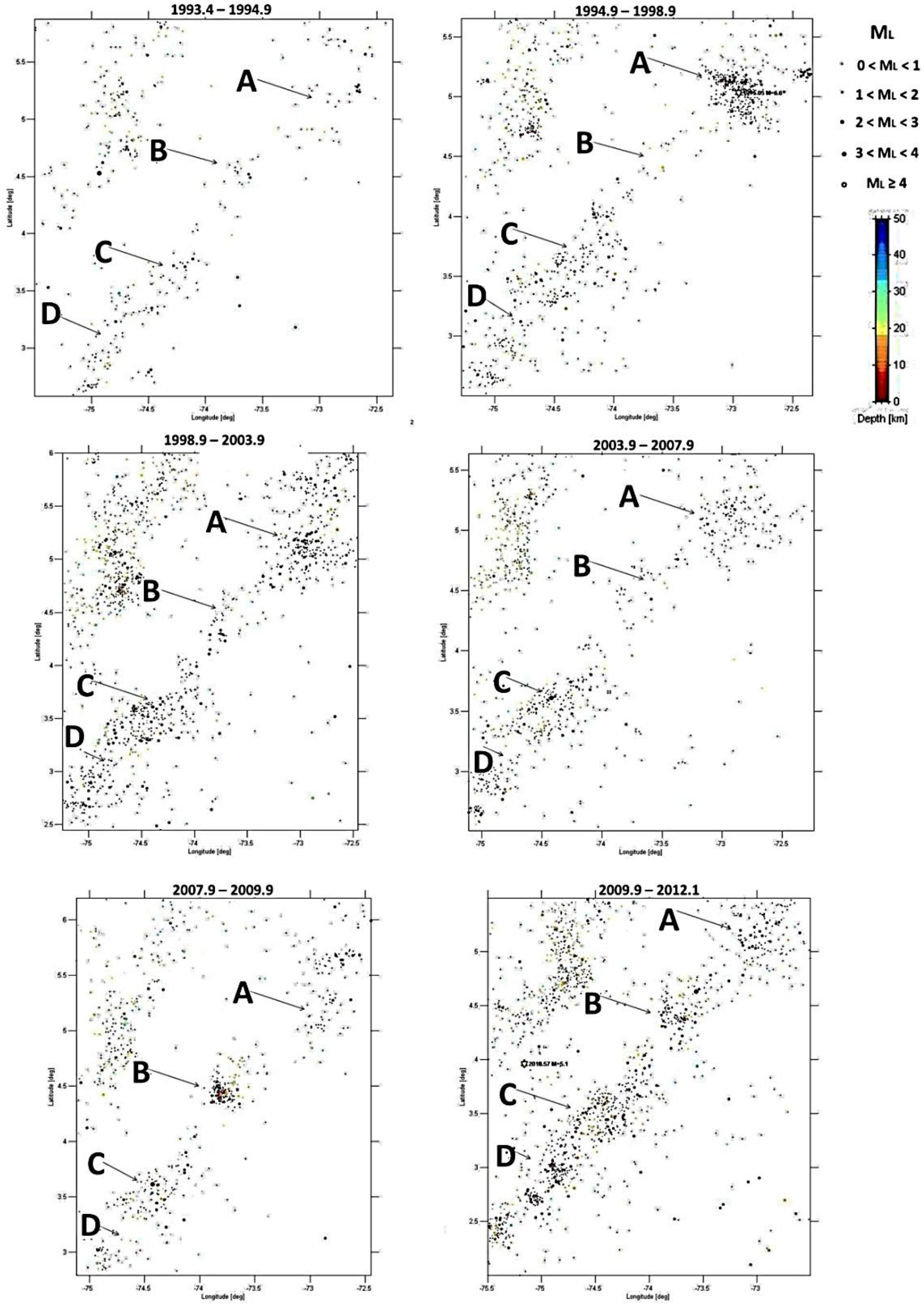

Figure 4. Six time lapses of NSNC instrumental seismicity records for the period between 1993 and 2012 in the Villavicencio and Llanos foothills region in Central Colombia. A. Seismicity related to the Guaicaramo fault. B. Seismicity related to the Servitá fault. C and D, seismicity related to the Algeciras - Uribe fault.

Our analysis shows an absence of an appropriate Land Use Plan for the city that should include seismogical and geotechnical studies. This shortcoming increases the seismic vulnerability because

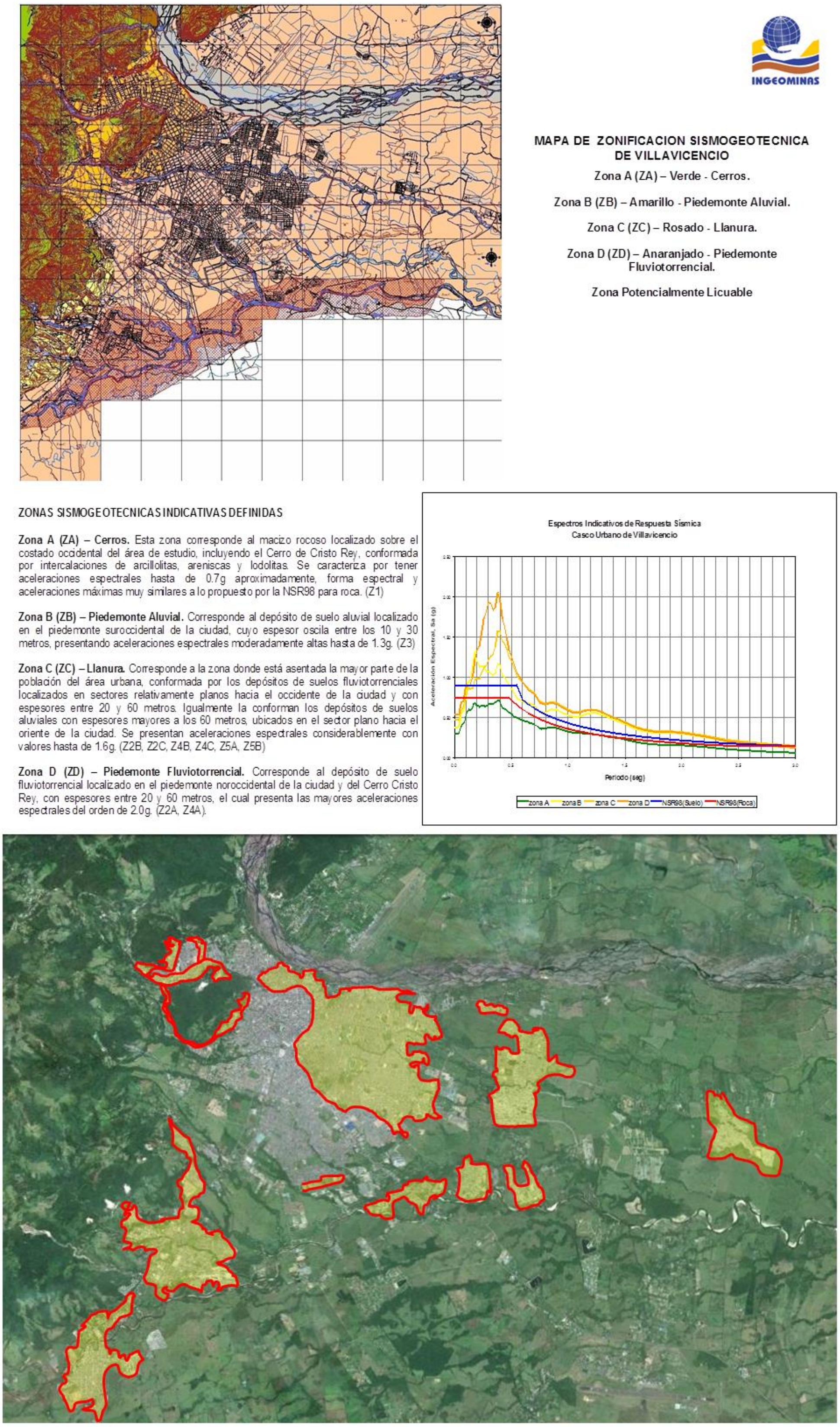

Figure 5. Above. Villavicencio´s seismogeotechnic zone map with its soils´ accelerations after Ojeda and Alvarado (2002). Below. In orange, spatial distribution in the urban area of the population belonging to a lower socio-economic tier after Chicangana et al. (2013a)

Figure 6. Some examples of the bad quality buildings in Villavicencio. Notice the lack of implementation of the seismic design code in several buildings and houses. Photos in Chicangana et al. (2012).

there is neither a regulation of the takeover of land by the people nor an application of the seismic design code for construction.

The lack of support by the Government of Villavicencio for organizations like the Red Cross, the rescue crew, the fire department, among others, which altogether make up the National Prevention and Attention Disaster Plan System as stipulated by the 93/1998 bill and the recent 1523/2012, is another factor that increases the seismic hazard.

The lack of the implementation of the seimogeotechnical zoning may have two effects:

1. The population´s inability to act in order to prevent, anticipate, mitigate, or react quickly in the event of an earthquake.
2. Government negligence due to factors like the concentration of power, long term plans, government incompetence, and corruption.

These factors raise the vulnerability and makes dealing with the effects of an earthquake and the post-disaster scenario more challenging.

THE POST - DISASTER SCENARIO

If there is a M > 6.5 earthquake with its epicenter near or about 20 km from the urban area of Villavicencio, there would be 3000 deaths, 15,000 people would be injured, and close to 300,000 people will be affected by the loss of their homes. These calculation of deaths is based on previous similar tragedies like the one experienced in Armenia after the 1999 M= 6.2 Quindío earthquake, and the 1983 M=5.5 Popayán earthquake.

This post-disaster scenario carried out was based on the socio-economic and cultural aspects of Colombia. Financially, the losses would represent three points of the GDP since the city´s financial operations would come to a halt and the main road that connects Villavicencio to Bogotá would be closed due to landslides; this would also affect the agricultural, the livestock, and the oil operations.

Rebuilding the city would demand a great investment for the country since Villavicencio is a key productive area of Colombia.

CONCLUSION

In this study we show that the EFFS faults can generate earthquakes as confirmed by both the historical and instrumental seismicity records. The regional neotectonic aspects and active tectonic evidence at a local level have been identified in these structures. They are related to a recent tectonic movement that has led us to conclude that a high seismic hazard underlies in this region of the Llanos Foothills.

The economy in Villavicencio´s region would lose a total of more than 3% of the GDP and more than 25% of GDP if the centre of the country is affected, a region right where Bogotá is located. This forecast model, which summarizes the results shown here, is based on economic and sociocultural features on a layout of a seismic vulnerability previously done (Chicangana et al., 2012 and 2013a) and following the post-disaster results taken from the UN´s human development index (IDH) established for Colombia in a historical context after the 1983 earthquake in Popayán and the 1999 earthquake in Quindío.

ACKNOWLEDGEMENTS

This work is the result of the research and actions taken to spread the word to social entities like the scholars, the civilians, and the Government of Villavicencio and the Department of Meta about the range of the seismic hazard in Villavicencio and the Llanos Foothills, in the Administrative Department of Meta, in Colombia.

Our token of appreciation goes to the Corporación Universitaria del Meta in Villavicencio; The Geophysics Group of the Department of Geosciences of Universidad Nacional de Colombia in Bogotá, GEOSLAC in Bogotá, and to Jaime Andrés Ochoa García for his contribution in the translation and improvement of this text.

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