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RESEARCH ARTICLE

Analysis of Colombian Seismicity as a Way to Explain and Understand The Bucaramanga Nest

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Abstract

Colombia is region with high seismicity due to the convergence of Panama Block, Nazca and Caribbean plates with the South American Plate, however there is a complex area named The Bucaramanga Nest which was the motive of this research means of its complexity, being that there have been different studies which have not been able to explain the reason of this phenomenon, for that motive this work has as objective finding this answer by the use of 3679 earthquake information in Colombia, with a Mw higher than 3.5. Having information from all the earthquakes, they were localized on its epicenters to notice how they were distributed, after that, five lines were chosen to make, along them, The Benioff Zone, obtaining the geometry of the slabs for Nazca and Caribbean plates, knowing the angle of subduction of them and how it changed, also, thirty earthquakes near the five lines were selected to see the focal mechanisms along the slabs and knowing the fault system in The Bucaramanga Nest. Beside all it was said before, it was modeled an approximation of the subduction zones by a contour map along the studied region. At the end, it was able to reach an answer about the reason of why The Bucaramanga Nest happened, defining its vertical and lateral extension too.

Keywords: Bucaramanga Nest, Slab, Nazca Plate, Caribbean Plate and South American Plate

1. Introduction

South America is a region with complex seismicity, having every kind of plate boundaries, and Colombia is not the exception, being a good example of this, due to it exhibits three limits of tectonic plates, which are South American Plate, Caribbean plate and Nazca plate, although Taboada, et al. (2000) mentioned a fourth plate, being added The Panama Block as the last one and, for that reason, all this interaction has become Colombia in a seismic active area where it can be found some nests as The Cauca and Bucaramanga nest, being the last one the most important and the reason of different studies and this research too.

A nest could be defined as a high seismological activity confined in a volume and it can be noticed in certein subduction zones (Zarifi, et al., 2007), however, the remarkable things is because of the activity in The Bucaramanga nest is clustered in a spaced much smaller than other nest around the world (Pennington, et al., 1979) within a 30Km-cube centered at 6.8ºN and 73ºW inside an average depth of 160Km (Frohlich, et al., 1995), and with a relative paucity activity compared wiht the surronding areas (Schneider, et al., 1987).

The reasons of this intense activity is still unknown and it could be owing to lack of local data and tectonic complexitivity (Zarifi, et al., 2007), nevertheless, there are some researchings where different models are proposed, such as The Bucaramanga Nest befalls by partial melting (Shih, et al., 1991), otherwise, it is said that Nazca and Caribbean plates have no volcanism correlation (Chen, et al., 2001). On the other hand, there are different ideas for example, the Caribbean plate is the only plate that intervents and there is no relation with Nazca plate wich has effect in the Cauca Nest (Malavé & Suárez, 1995), also the subducting slab, which is supposed to be The Caribbean Plate, tears off (Cortés & Angelier, 2005).

Antoher model proposed says that The Bucaramanga Nest is induced because of an overlaping of Nazca Plate over Caribbean Plate in north (Van Der Hilst & Mann, 1994) or at the boundary between them (Corredor, 2003) and, also, with the interaction between these plates, the Nazca slab could tear off due to a transition to Caribbean Plate (Vargas & Mann, 2013) (Fig. 1).

In spite of the different existing models and the uncertainty about plate boundaries mentioned before, the principal objetive of this research is to find why and how The Bucaramanga Nest happens, studying a set of seismological data in Colombia, provided by USGS, doing analysis of the information by profiles, mapping, tectonical setting and focal mechanism.

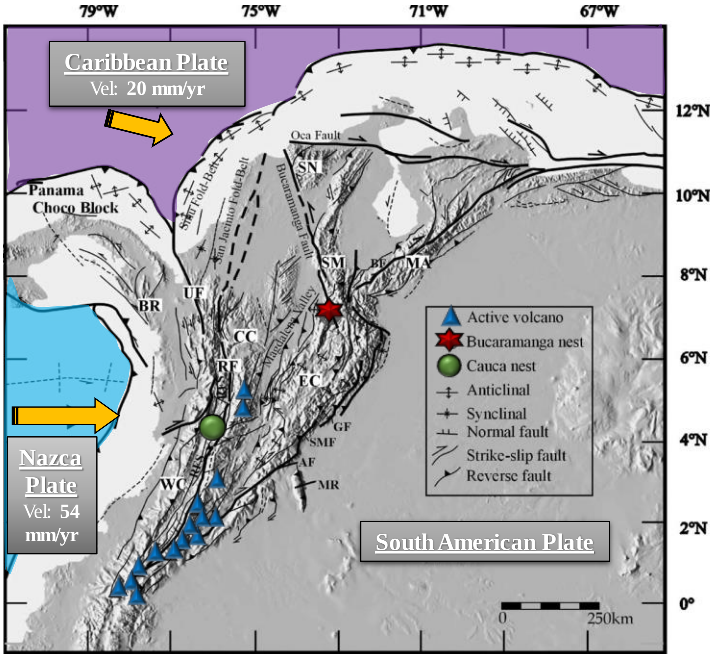

Fig. 1. Regional tectonic system. BR: Baudo Range; WC: Western Cordillera; CC: Central Cordillera; EC: Eastern Cordillera; RF: Romeral fault; UF: Uramita fault; BoF: Bocono fault. Modified from: Cortés & Angelier (2005)

2. Regional Tectonic Setting

The South American northwestern area is an interesting zone due to its tectonic activity (Moncayo, et al., 2018) for that reason, Colombia is, still, an discussed issue without reaching an agreement (Ojeda & Havskov, 2001), however, the last proposed model suggests the convergence of four plates (Nazca, Caribbean and South American Plate and The Panama Arc) (Taboada, et al., 2000).

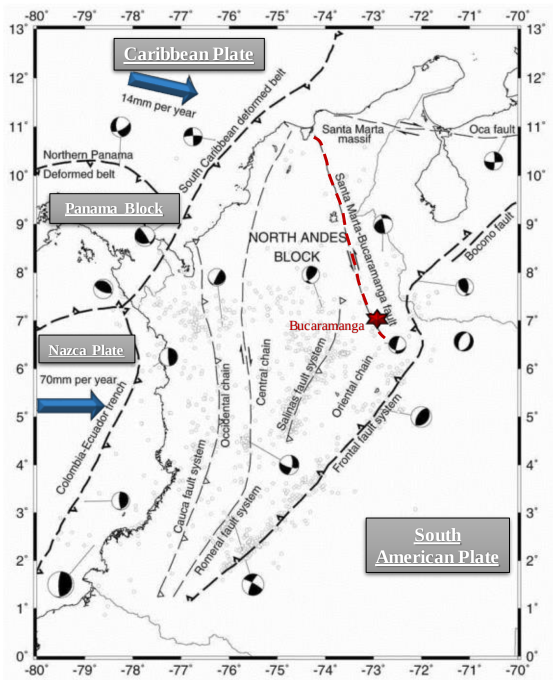

Fig. 2. Colombian tectonic features. Modified from Ojeda & Havskov (2001)

On the other hand, this region gives a good case of stress field, being that, it is evolved in it because of an oblique convergence of The Panama Arc collisions at subduction zone (Egbue, et al., 2013) and the GPS studies gives a context to understand the widespread of this arc and its collision with South America (Vargas & Mann, 2013).

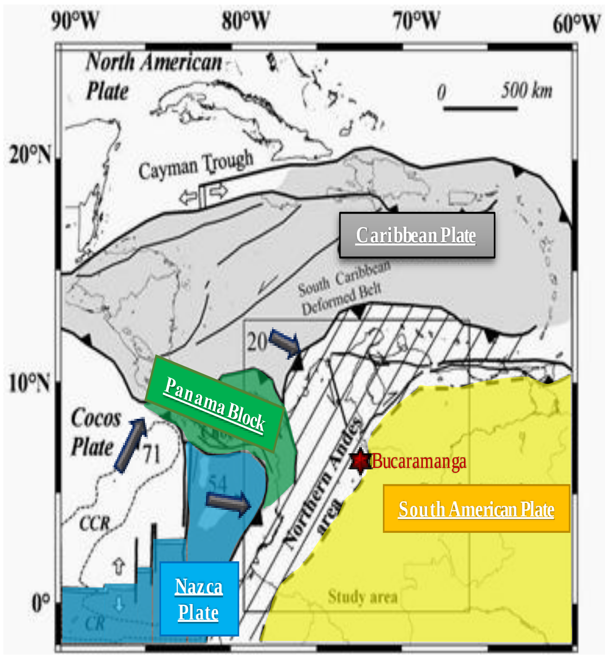

Fig. 3. Configuration and plate boundaries. Modified from Cortés & Angelier (2005)

Besides The Panama Block, there are the other three existing plates; one of them is The Nazca Plate, which has a displacement of around 5-7 cm/yr (Freymueller, et al., 1993) subducting The South American Plate on the southwest region. In addition, another subductingplate is The Caribbean Plate with an average movement of 2 cm/yr from NW to NE (Trenkamp et al., 2002); nonetheless, the boundary Caribbean-South American plate is still not well-defined (Ojeda & Havskov, 2001).

The South American Plate has a block named North Andes Block, which received all the strain from the other plates and block. Also, this block has a strike-slip fault (Santa Marta-Bucaramanga Fault) and a frontal fault system which are surrounding The Bucaramanga Nest (Fig. 2) and all the interaction between plates can be seen on Fig. 3.

3. Methodology

To reach all the results it was followed the next steps and, at the end, they were integrated to obtain the principal objective.

3.1. Data upload

It was downloaded information (Table 1) from different 3679 earthquakes from the USGS site (Fig. 4) which will be analyzed.

Table 1. Data parameters

Data name	Minimum Value	Maximum Value
Date	November 1921	June 2018
Latitude (º)	1	13
Longitude (º)	-78.5	-70.5
Magnitude (M_w)	3.5	-
Depth (Km)	-	200

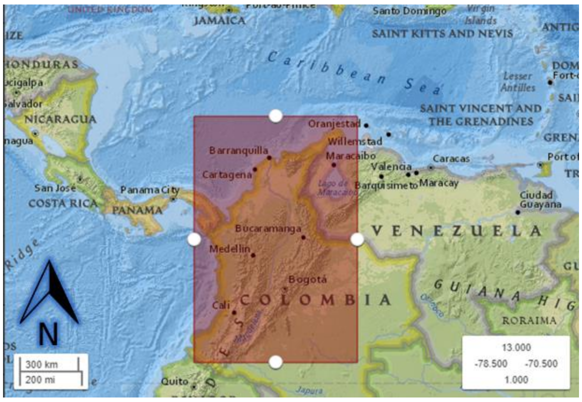

Fig. 4. Location of the worked area. The red square is where the earthquakes are located

3.2 Benioff Zone and Focal Mechanism Analysis

After downloading the data from USGS, five lines (Fig. 5) were chosen to make the Benioff Zones graphing depth vs distance along the five lines and noticing in Origin Pro how the slab configuration is.

In addition, it was selected 30 earthquakes that had associated focal mechanisms. This information was conjugated with the Benioff zone to know how the fault systems are, giving information about The Bucaramanga Nest configuration.

Finally, in this point, it was calculated an approximately angle of dipping for every Benioff zones.

3.3 Mapping the subduction zone

Having all the data, the earthquakes were localized with their coordinates in a XY area, where it was made a contour map using the depth information and, in this way, getting an approximation of subduction geometry.

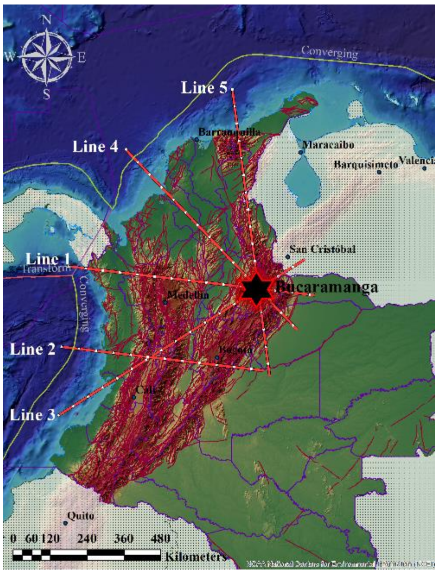

Fig. 5. Location of the lines

4. Results

Following every step mentioned on methodology, the results obtained were:

4.1. Data upload

All the seismic data was uploaded as it is shown on Fig. 6. In this image, it can be notice two earthquake clustered datas, one on SW that is The Cauca Nest and other on the NE, near Venezuela, and it is The Bucaramanga Nest Fig. 6.

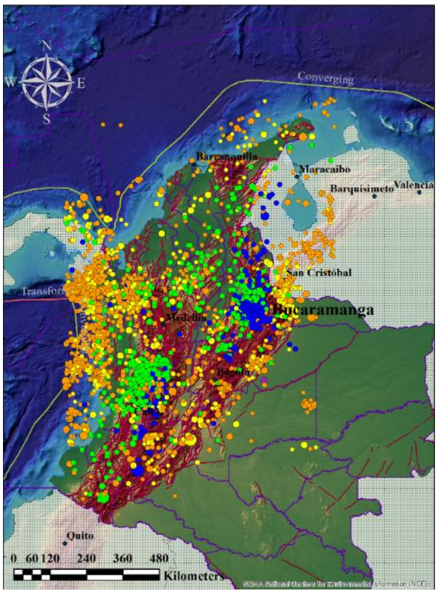

Fig. 6. All the seismic data located. The meaning of the colored circles are the depths; Orange: 0-33Km; Yellow: 33-70Km; Green: 70-150Km; Blue: 150Km or deeper

Besides the observed clusters, it is possible to appreciate a tendency on the earthquake depths from the plate limits (West, Northwest and North) to the both nests and the depth around The Bucaramanga Nest is consistent, approximately 160Km deep.

4.2 Benioff Zone and Focal Mechanism Analysis

All the 30 earthquakes were located near the lines shown on Fig. 5 to observe how the kind of existing faults. Also, five focal mechanisms were located on The Bucaramanga Nest as it is noticed on Fig. 7.

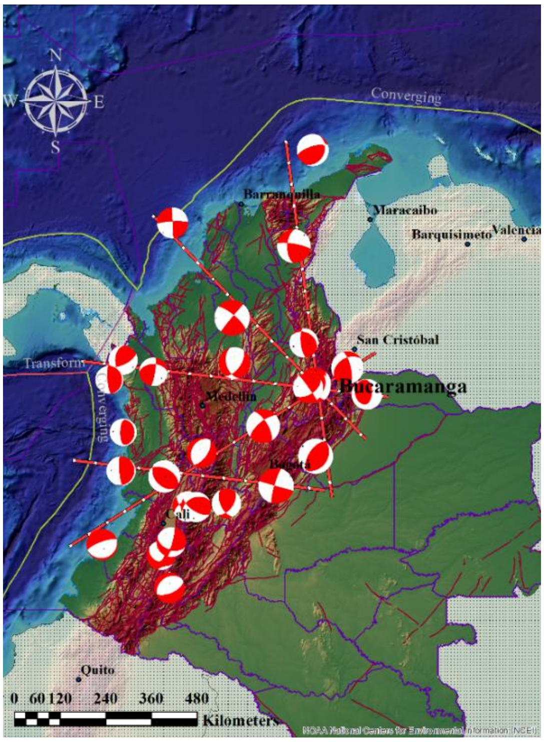

Fig. 7. Location of focal mechanisms

Using these focal mechanisms, they were located to their corresponded lines on the Benioff Zones, as they can be seen on the next figures (From Fig. 8 to Fig. 12).

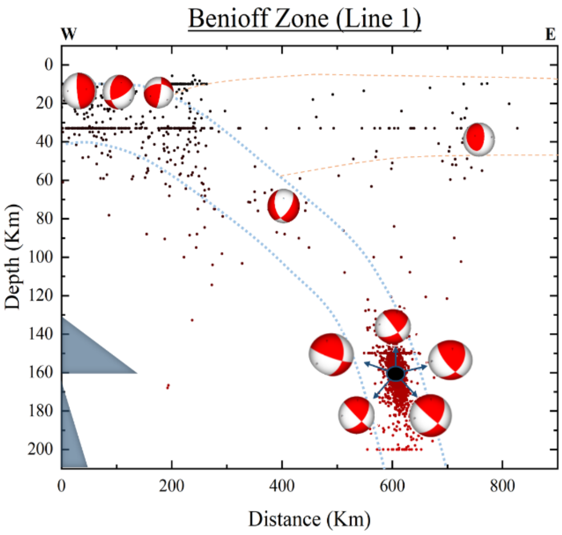

Fig. 8. Benioff Zone (Line 1)

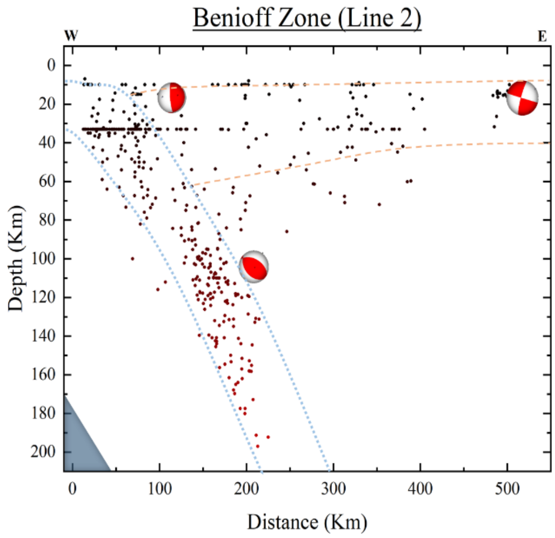

Fig. 9. Benioff Zone (Line 2)

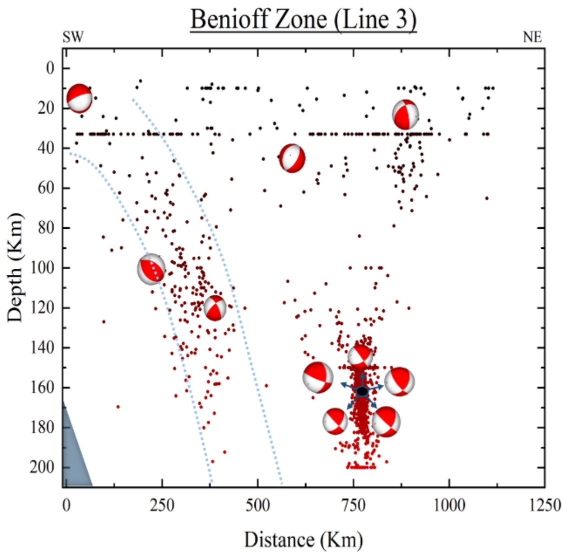

Fig. 10. Benioff Zone (Line 3)

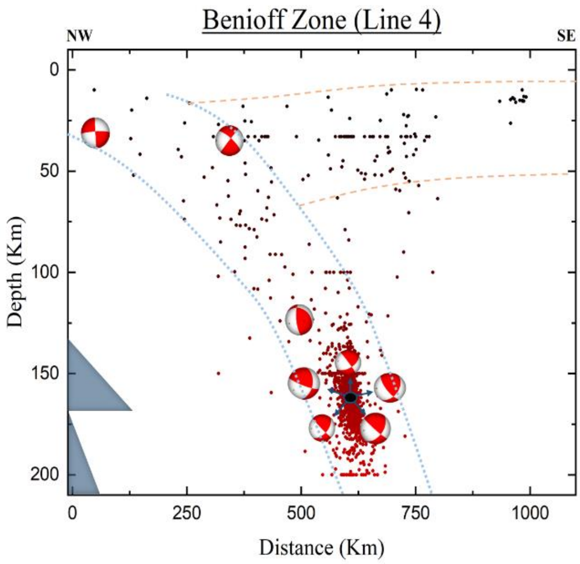

Fig. 11. Benioff Zone (Line 4)

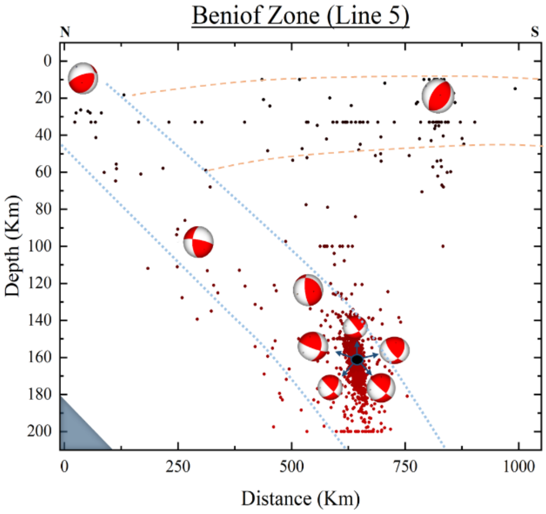

Fig. 12. Benioff Zone (Line 5)

Noticing the Benioff Zones, it is clearly shown The Bucaramanga Nest due to a cluster at an approximately depth of 160 Km (Lines 1, 3, 4 & 5), where are localized five focal mechanisms (Fig. *14*), which correspond to oblique faults, specifically, reverse faults with a strike-slip component, with a fault plane around 15-40º. Besides, at the same time, this fault system is saying that The Bucaramanga Nest is a stressed region with it is receiving an external force.
From the slabs gotten on Benioff zones, it was calculated the different angle of subduction (Table 2) which they are symbolized by a blue triangle. It is remarkable saying that the lines 1 and 4, two angles of subduction were calculated means of it changed before arriving to The Bucaramanga Nest.

Table 2. Subduction angles in the lines

	Line 1	Line 2	Line 3	Line 4	Line 5
Angle	13.5	36	25	14.5	14
(º)	42	-	-	27	-

From the table of angles and knowing the configuration of tectonic plates (Nazca Plate: Lines 1, 2 & 3; Caribbean Plate: Lines 4 & 5) it is noticed that The Nazca Plate is reducing its angle of subduction from south to north. On the other hand, The Caribbean Plate it is consisted with its angle.

4.3 Mapping the subduction zone

With the depth of every earthquake, it was possible to make a contour map to observe an approximation of how the subduction is in Colombia and how it can be seen on The Bucaramanga Nest.

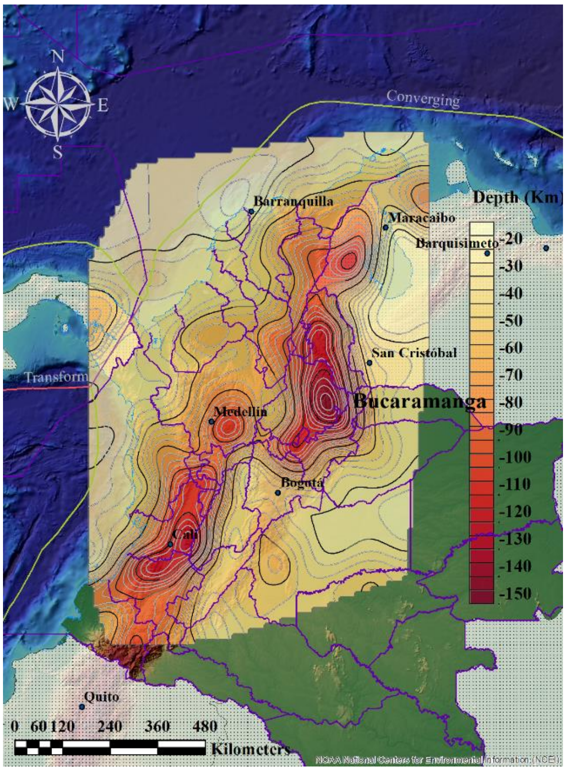

Fig. 13. Earthquake depth contour map

It is clearly well-defined the tendency of subduction and the depth around The Bucaramanga Nest. Another thing is that deepest areas are where the cordilleras are located.

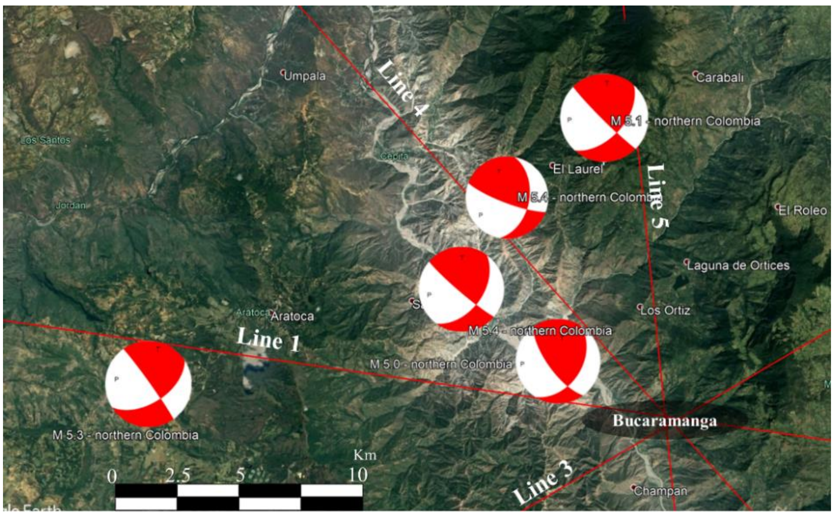

Fig. 14. Focal mechanisms on Bucaramanga Nest

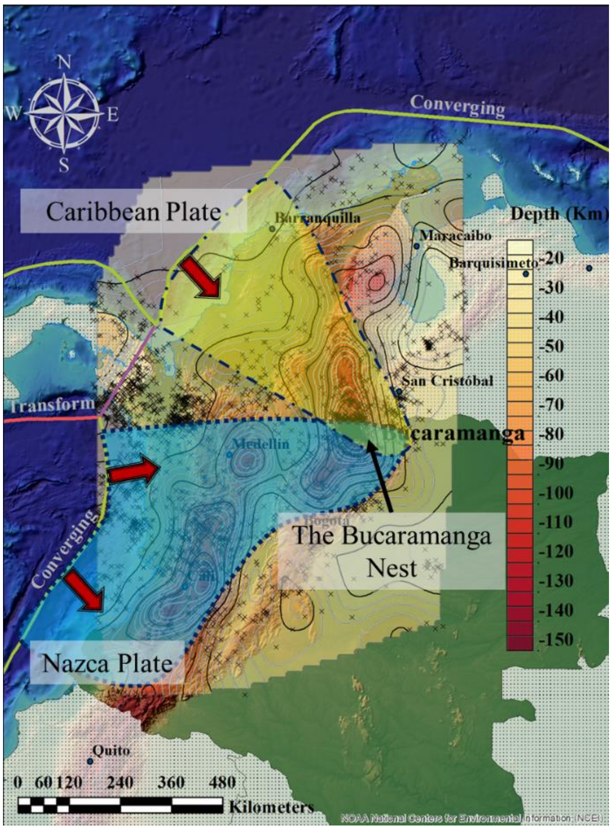

Fig. 15. Slab geometry

5. Discussions

After noticing all the gotten results it was able to design the plate subduction structures (Fig. 15) that lets to know why The Bucaramanga Nest happens.

Observing the subduction geometry for the tectonic plates, the supposed theory is that there is a collision between The Caribbean Plate and The Nazca Plate, nonetheless, this collision occurs obliquely due to they have an angle of contact, being that, as is it shown on Fig. 15, there is a place on the west which no plate is subducting. Besides, means of the angle of subductions of every plate, mentioned on Table 2, and the oblique contact, these plates only have this kind of contact and after that, they continue their subduction. On the other hand, from the Benioff zones it was possible to get the contact surface (Fig. 16).

6. Conclusions

Bucaramanga is a complex area, difficult to define, nevertheless in this work it was able to find a possible answer which could explain how The Bucaramanga Nest happens, due to a collision between the two slabs, being that, the Nazca Plate changes is subduction angle at north, letting it reach the Caribbean plate path.

On the other hand, the tectonic configuration in Colombia should be more studied, first to define better the plate limits and also to reach an answer more agreed upon The Bucaramanga Nest.

7. Acknowledgement

Thanks to the USGS platform which has available seismic data to download without any kind of payment, being, in this way really, important to do this paper.

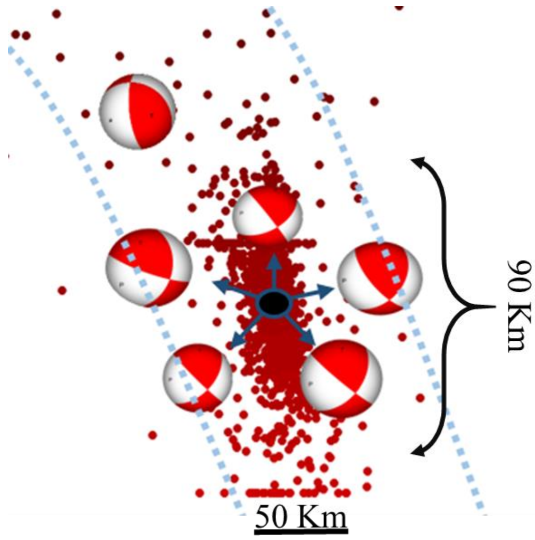

Fig. 16. Colition contact Surface

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