Costa Rica-Panama border 6.4 magnitude earthquake and aftershocks: distribution of sources, nature of faulting and tectonic significance

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Abstract

Costa Rica is a country that is characterized by having high seismicity due to its complex tectonic setting. This complexity becomes less understood in the Southern region of Costa Rica. The tectonic setting of Southern Costa Rica consists of the Caribbean Plate, the subducting Cocos Plate and Cocos Ridge, the subducting Nazca Plate, the Panama Microplate, and the Panama Fracture Zone.

Understanding the factors for the current local seismicity is of high importance for general public awareness, the government, and seismologists. We used earthquake data as a tool to understand and describe crustal deformation patterns at the source zones of a series of 52 aftershocks that followed a 6.4 magnitude earthquake at the Costa Rica-Panama border on June 26th, 2019. The series of earthquakes could be a result of the interaction between the subducting Cocos plate, the overriding Panama Microplate, and the Panama Fracture Zone. For the purpose of improving the accuracy of the preliminary earthquake data, we used the seismic processing software SEISAN to select P-waves, S-waves and polarities directly from earthquake waveforms. Our earthquake data analysis shows that the series of earthquakes are not associated directly with the subduction zone or the right-lateral slip of the Panama Fracture Zone, but rather triggered by a newly activated NW-SE striking fault zone and other minor faults in the overriding plate.

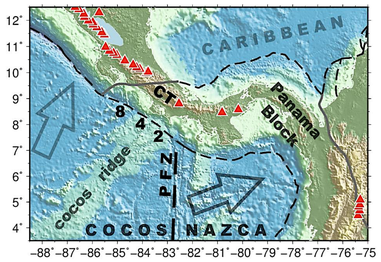


Figure 1. Tectonics of Costa Rica displaying Cocos plate, Caribbean and Nazca plates, the Panama Block, Cocos Ridge and Panama Fracture Zone (PFZ)

Figure 2. Map showing epicenter of 6.4 magnitude earthquake in Puerto Armuelles, Costa Rica. Credits: RSN website.

Background

Plates and Fracture Zones involved in Costa Rica's tectonism:

- Cocos Plate
- Caribbean Plate
- Nazca Plate
- Panama Microplate
- Panama Fracture Zone

The Cocos Plate subducts with a convergence direction of N25º – N30ºE with respect to the overriding Caribbean Plate. The Panama Fracture Zone marks the boundary between the Cocos Plate and Nazca Plate and forms a triple junction between the Cocos, Nazca and Caribbean Plates. The current motion of the Panama block is 11mm/yr. to the north with respect to the Caribbean Plate.

Main Earthquake Preliminary Data

- Time : June 25,2019 at 11:23pm
- Location: Panamanian Territory 11 km northeast of Puerto Armuelles
- Preliminary Depth: 29 km
- Magnitude: 6.4
- Source: Interaction between the subduction of the Cocos Plate under the Panama Microplate accompanied by the presence of the Panama Fracture Zone
- 260 aftershocks occurred between June 2019 and July 2019

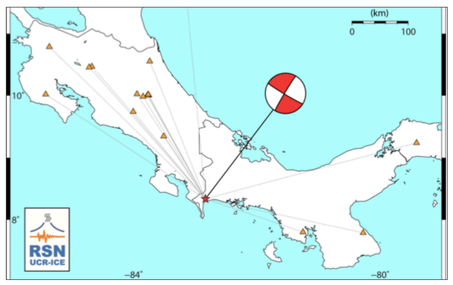


Figure 3. Map showing epicenter and focal mechanism of mainshock relative to a few seismic stations in Costa Rica and Panama. Credits: RSN Website

Since July 2019, the earthquake sequence increased from a total of 260 events to 465. The number of events is based on threshold parameters selected by the RSN. One of the parameters is that all the 465 events are of magnitude 2.5 or higher. The highest magnitude for an aftershock was 5.2, which occurred in December 2019.

Methods

Understanding the seismic network of Costa Rica

Above are images of field work in Costa Rica. Our team's fieldwork consisted of servicing seismic stations in different regions of the country. This task required a thorough checkup of each seismic station's system, software updates, and replacement of memory cards. The SD memory cards are changed once the system's memory reaches capacity for recording many seismic events.

Utilizing the seismic analysis software SEISAN

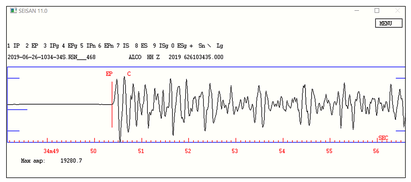
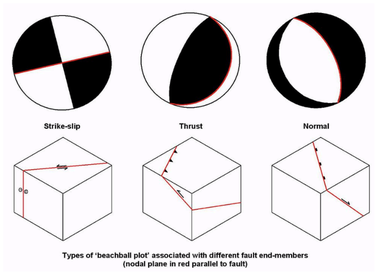


Figure 4. Seisan interactive screen displaying the waveform of an event

- Revising waveform data of the 6.4 magnitude earthquake sequence.
- Picking first wave arrivals of aftershocks with magnitudes larger than 3.5 and coverage gap of <220 degrees (52 events out of 260 events that occurred between June 25, 2019 and July 25, 2019).

Determining focal mechanisms for aftershocks from P-wave arrival patterns



The focal mechanism of an earthquake describes the deformation in the source region that generates the seismic waves. The focal mechanism can be derived from observing the pattern of "first motions" when the arriving P wave breaks up or down.

Figure 5. "Beachball plots" that represent the type of deformation associated with a seismic event

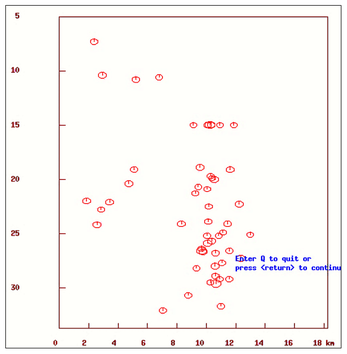


Figure 6. Cross-section displaying various depths for 52 events; corresponds to yellow trend on map.

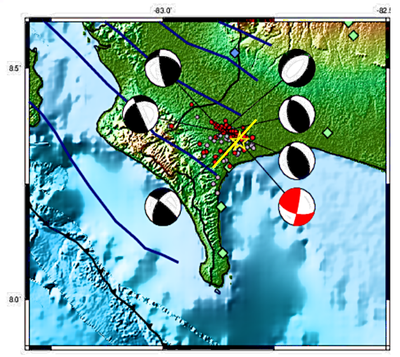
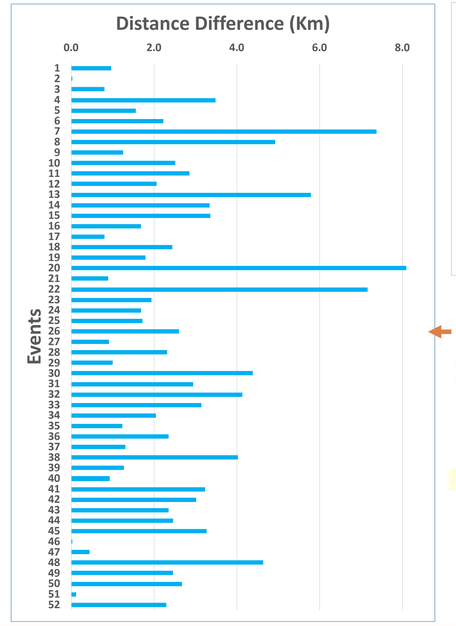


Figure 7 . Map of study region and a few focal mechanisms for events. The main shock represented with red colored "beach ball". Blue lines are 10 km interval contour lines for depth to the top of the Cocos Plate.

Discussion

Determining distance changes from preliminary locations and errors (rms) changes



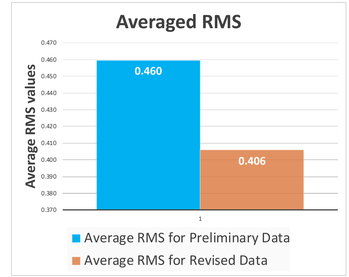


Figure 8. RMS values that correspond to preliminary (Blue) and revised data (Orange).

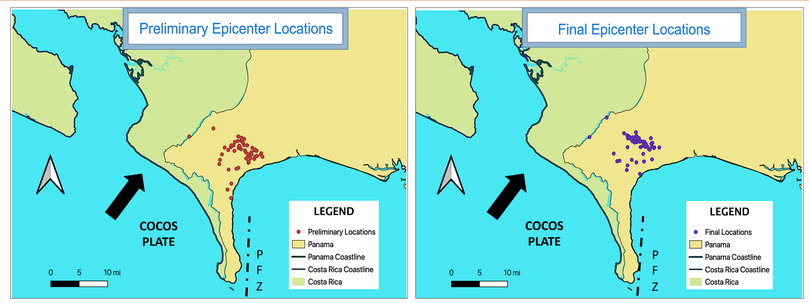
Figure 9. Distance Change Graph shows how much the epicenter has changed from the preliminary locations based on their respective measurements of latitude and longitude. The Great Circle Distance Formula is used to obtain the distance difference, which takes into consideration the radius of Earth and previous and new values of latitude and longitude

The Great Circle Distance Formula:

$$D = \arccos\left(\sin(lat_S)\cdot\sin(lat_M) + \cos(lat_S)\cdot\cos(lat_M)\cdot\cos(\Delta lon)\right)\cdot R$$

Where:

D = Distance Difference (km)
R = Radius of Earth
Lat_S = start point latitude (in radians)
Lat_M = measured latitude (in radians)
Δlon = Difference in longitude between start point and measured point (in radians)



Figures 10,11. Maps showing preliminary and final locations after revision task with seismic analysis software SEISAN.

After revision of first wave arrivals, the cluster of earthquakes showed a more definite trend. The final hypocenter locations are aligned in a trend NW-SE that is different than what was expected based on the subduction direction of the Cocos Ridge (NE).

Conclusions

Based on the depth and focal mechanisms analysis, the team concluded that the possible sources responsible for the seismicity of the Armuelles Earthquake sequence can be associated with:

- A fault striking NW-SE within the Cocos Plate
- Subduction of the Cocos Plate beneath the Panama Microplate
- Minor faults in the overriding Panama Microplate

Acknowledgments

This research project was funded by the National Science Foundation. I would like to thank my mentors Dr. Ivonne Arroyo, Dr. Vadim Levin and the RSN team for their support and guidance throughout this project.

References

- The RSN (National Seismological Network of Costa Rica) website.