

PROCEEDINGS OF THE TWENTY-SEVENTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

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PREMONITORY SEISMICITY BEFORE THE SEPTEMBER 5, 2012, MW 7.6 NICOYA EARTHQUAKE, COSTA RICA: RELATIONSHIP WITH MAINSHOCK RUPTURE AND AFTERSHOCK ZONE

ANTHONY MURILLO GUTIÉRREZ, Universidad Nacional de Costa Rica (UNA)

Research Advisor: Marino Protti

INTRODUCTION

The Nicoya Peninsula is located in NW Costa Rica where the oceanic Cocos plate subducts beneath the Caribbean plate. The subduction zone along the southern Pacific margin of Central America has been divided into five segments (Protti et al., 2001): 1) Nicaragua-Papagayo, 2) Nicoya, 3) Cóbano-Herradura, 4) Quepos-Sierpe y 5) Osa-Burica. Two of these segments, Nicoya and Osa-Burica, have a strong seismic coupling, capable of breaking with earthquakes of magnitude above $M_w=7.0$.

Under the Nicoya peninsula there have been large earthquakes in 1853, 1900, 1950 and 2012, with a recurrence interval of 50 to 60 years. The rupture zone of the most recent event, $M_w=7.6$ on September 5th, 2012, extended from 20 to 30 km in depth, under the

western and central portions of the peninsula (Fig. 1). This earthquake represents a partial rupture of what was defined by Protti et al. (2001) as the Nicoya Seismic Gap, with potential to generate an earthquake with magnitude as large as $M_w 7.9$.

In order to document the rupture process after the 2012 Nicoya Earthquake, and to learn seismologic research techniques, including field instrumentation and seismic data processing, I took part in a Keck Geology Consortium field project on the Nicoya Peninsula, Costa Rica, from 23 June to 20 July 2013. This project involved 10 student participants, 9 from the US, and me from Costa Rica. There were 6 students working on coastal geomorphology and 4 in geophysics. The students were supervised in the field by 3 faculty members and 1 graduate teaching assistant.

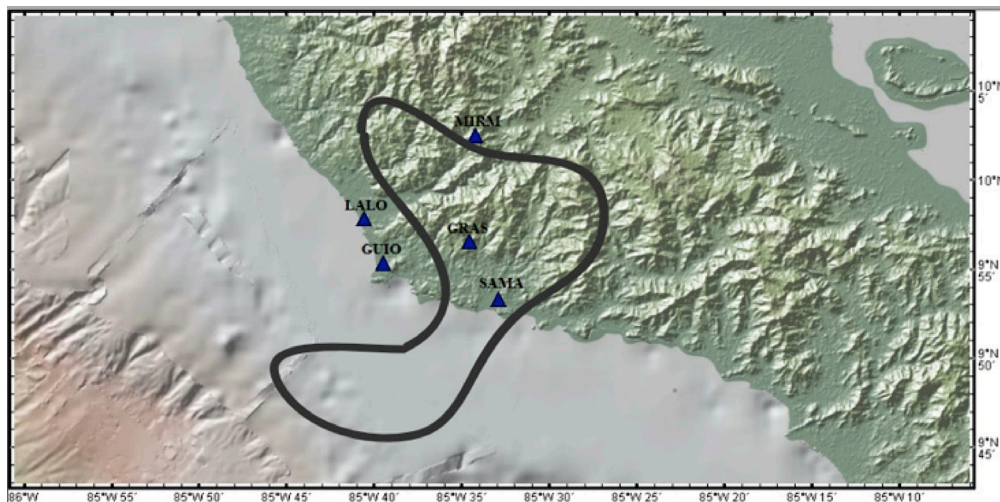


Figure 1. Digital Elevation Model (DEM) of the Nicoya Peninsula showing locations of the KECK Network seismic and geodetic stations (blue triangles) and the approximate rupture zone of the 5 September 2012 Mw 7.6 Nicoya Earthquake (black line, after Yue et al, 2013).

Fieldwork

As part of the geophysical team we installed a dense network (the KECK network) consisting of 5 Nanometrics seismic stations Taurus with Trillium-compact seismometers. The sensors were buried 30 to 50 cm deep and stations were 5 to 15 km apart (Fig. 1). This KECK network recorded from July 1st, to July 18, 2013. In addition to this seismic instrumentation, we co- installed campaign style GPS stations (Trimble 5700 receivers with Zephyr antennae) at three of the seismic stations. Also as part of this learning experience, we serviced and downloaded data from several stations of the Nicoya permanent geodynamic network, located at sites around and KECK network.

Base camp work

At our base camp we learned the use of seismic analysis tools such as SEISAN and processed some of the data we were collecting in the field. We had lectures on seismology, geodesy and tectonics. After returning to my university, I also learned the use of Antelope, another software package for earthquake data processing, for the location of earthquakes during the month prior to the Nicoya 2012 mainshock, located by both the Nicoya and OVSICORI permanent networks.

RESULTS

For this work I processed seismic data from three time windows: 1) from August 1st to September 5th, 2012, using data collected by the Nicoya and OVSICORI networks; 2) from June 23th to July 1st, 2013, registered also by these same networks; and 3) from July 1st to July 18th, 2013, using records from the Nicoya and OVSICORI networks, complemented by the dense KECK network.

For the first time interval (Fig. 2), 63 earthquakes were located, using Antelope, from regions in and around the Nicoya peninsula. Seismicity during August 2012 was disperse across the country and does not show any anomalous clustering which could be an indicative of an impending large earthquake. The first five days of September to just 30 minutes before the earthquake the pattern remained the same with sparse seismicity in and around the Nicoya peninsula. From 14:07 to 14:39 UTC on September 5, 2012, 10 earthquakes, with magnitudes between 1.3 and 2.9 occurred up-dip of the mainshock at 14:42 UTC. Even the main rupture nucleated with two small events 2 and 3 seconds before. All these foreshocks located in the shallow portion of the rupture zone inverted by Yue et al., 2013, using high-rate GPS, strong motion data and local and teleseismic broadband data.

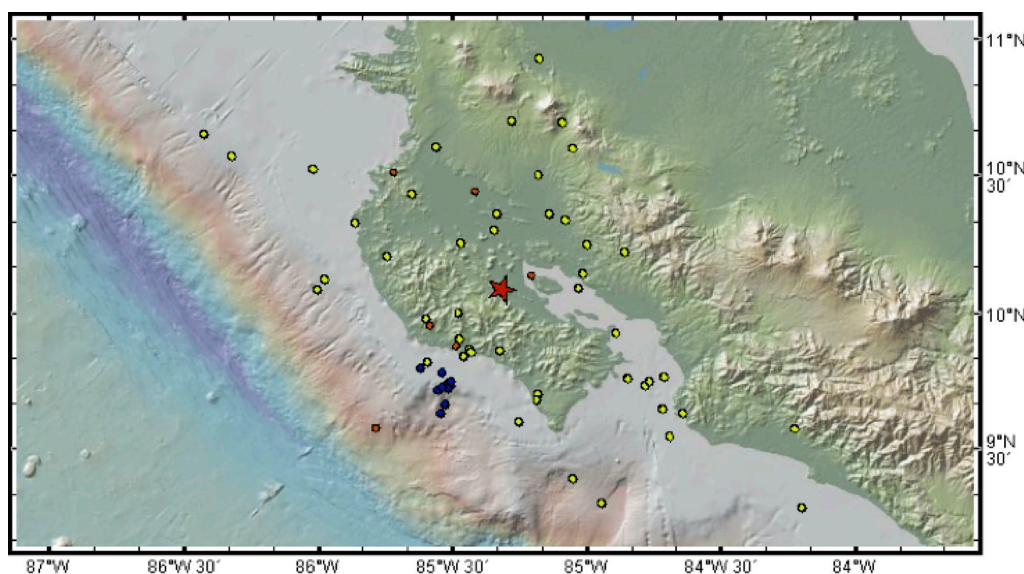


Figure 2. DEM of northwestern Costa Rica and the Nicoya Peninsula showing locations of the 5 September 2012 Mw7.6 Nicoya Earthquake mainshock (red star), August 2012 seismicity (yellow dots), September 1-5 2012 seismicity (orange dots), and 5 September 2012 premonitory earthquakes occurring within 30 minutes prior and up-dip of the mainshock (blue dots).

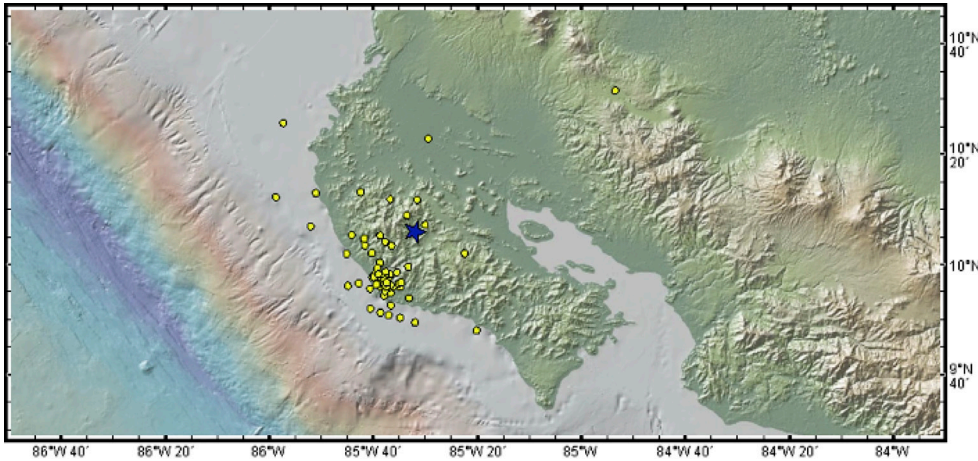


Figure 3. DEM of northwestern Costa Rica and the Nicoya Peninsula showing locations of the 23 June 2013 M 5.4 aftershock (blue star) and seismicity that followed (yellow dots).

The second time interval (Fig. 3), in late June 2013, included the occurrence of the most recent aftershock of magnitude above 5.0. That aftershock ($M_w=5.4$) occurred on June 23, 2013, the same day that the Keck project students arrived in Costa Rica. A total of 93 background aftershocks of the 2012 earthquake and of this latest aftershock were located. Most of these events locate between Nosara and Sámara and from the coastline to under station MIRM, coincident with the area of maximum slip of the 2012 mainshock.

For the third period (Fig. 4), the first three weeks of July 2013, while we were in the field, we used data recorded by the KECK network (Fig. 1), designed precisely to cover the rupture zone of the September 5, 2012 $M_w 7.6$ main event (Yue et al., 2013), and the location of the June 23, 2013 aftershock. We located 163 events with magnitudes between -0.1 and 2.9. Most of the events located right under the network and along the rupture zone of the September 2012 and June 2013 events (Fig. 4), indicating that slip still occurs along the plate interface in that region, mainly through very small events ($m_l < 1.9$). This

might indicate that what did not slip in 2012 could be still slipping, but the energy released by these tiny aftershocks is insignificant. The occurrence of so few aftershocks with $M_w > 5$, following a $M_w=7.6$ mainshock, confirms that the plate interface remains partially locked.

CONCLUSIONS

Seismicity occurring in the month prior to the September 5, 2012 earthquake did not show any anomalous behavior that could indicate the occurrence of an imminent large earthquake. Foreshocks only occurred 30 minutes before the main rupture but, with the exception of their location, there is nothing in the waveform of these events that differentiates them from regular background seismicity. The design of the KECK network allowed us to located events from the main rupture zone with magnitudes as low as -0.1. Continuous seismicity of low and very low magnitude still occurs along the plate interface, but are too small to unlock portions of the plate interface that did not rupture with the 2012 $M_w 7.6$ Nicoya Earthquake.

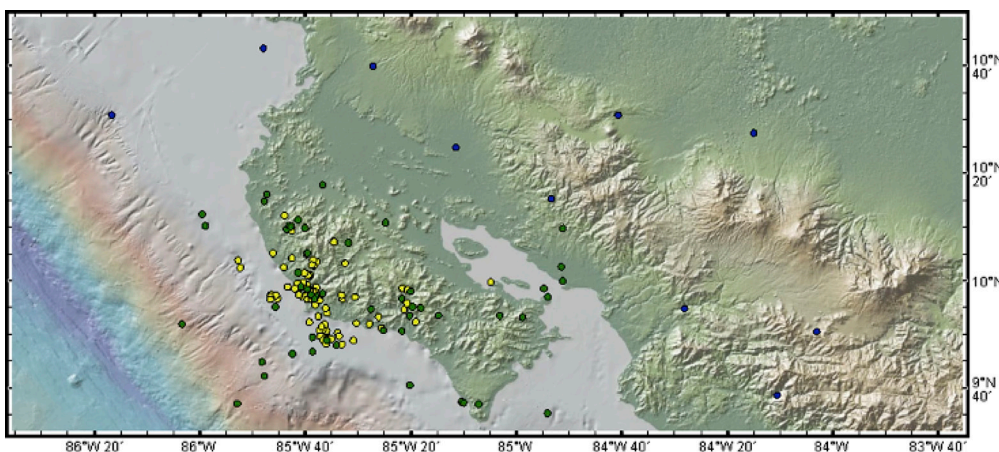


Figure 4. DEM of northwestern Costa Rica and the Nicoya Peninsula showing locations of all seismicity located with the KECK Network: $M -0.1$ to 0.9 (yellow dots), $M 1.0$ to 1.9 (green dots), $M 2.0$ to 2.9 (blue dots).

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