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

April 2014
Mt. Holyoke College, South Hadley, MA

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ISSN# 1528-7491

The Consortium Colleges   The National Science Foundation   ExxonMobil Corporation

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

ISSN# 1528-7491

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The National Science Foundation Grant NSF-REU 1062720
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Funding Provided by:
Keck Geology Consortium Member Institutions
The National Science Foundation Grant NSF-REU 1062720
ExxonMobil Corporation

Learning Science Through Research
Published by Keck Geology Consortium

Short Contributions
27th Annual Keck Symposium Volume
26 April, 2014
ISBN: 1528-7491

ANALYSIS OF AFTERSHOCKS FOLLOWING THE SEPTEMBER 5, 2012 NICOYA, COSTA RICA M_W 7.6 EARTHQUAKE

SHANNON FASOLA, St. Norbert College
Research Advisor: Nelson Ham

INTRODUCTION

The seismogenic zone in convergent margins is the seismically-active portion of the thrust interface between subducting and overriding plates (Newman et al., 2002). Generally, this seismogenic zone lies about 100 km offshore. However, the Nicoya Peninsula, on the Pacific coast of Costa Rica, sits directly above the seismogenic zone of the Caribbean and Cocos plates allowing for a better understanding of its processes. Because of its proximity to the seismogenic zone, the Nicoya Peninsula provides an unusual opportunity to place seismic and geodetic stations on land, in the near field right above the seismogenic zone (Yue et al., 2013; Protti et al., 2014). The Nicoya Peninsula was a recognized seismic gap with a recurrence interval of approximately 50 years (Protti et al., 2001; DeShon et al., 2003). Due to an increasing seismic risk, numerous seismic stations have been installed covering all of the Nicoya Peninsula over the last two decades. The goal of these deployments was to study the long-term deformation prior to a megathrust event (Feng et al., 2012).

The September 5, 2012 megathrust earthquake (M_w 7.6) that partially ruptured the Nicoya Seismic Gap provided valuable data prior to, during, and after the event. Since then, there have been only five aftershocks with magnitude above a 5.0, with the most recent occurring on June 23, 2013. Aftershocks for the 2012 event have not yet been looked at in great detail. The goal of this project is to analyze aftershocks ten months after the 2012 Nicoya earthquake. In doing so, a small seismic array was installed over the rupture zone of the main shock. The importance of installing a small array is to locate local, small-magnitude earthquakes (as small as 0.2 in magnitude) otherwise not registered by the larger Nicoya and OVSICORI seismic networks. With small-magnitude earthquakes, the rupture zone of the most recent aftershock can be better mapped and compared to the rupture zone of the main shock.

The June 23, 2013 aftershock (M_w 5.4) occurred eight days before the network was installed. The aftershock located right beneath the network soon to be installed. This large aftershock and the aftershocks that followed, provide valuable data to better study the 2012 Nicoya earthquake.

FIELD METHODS

For this study, a dense, temporary, broadband seismic array was installed above the 2012 Nicoya earthquake rupture zone, which was called the Keck Network. The network consisted of five Trillium compact seismometers and Taurus digitizers from Nanometrics, operating from July 2 to July 17, 2013. In order to provide for best coverage of events, the stations were spaced approximately 10 to 20 km apart, approximately the same distance as the vertical distance from surface to plate interface. Stations formed a triangle with one base lying parallel to the Middle American Trench. Within the Keck Network, there were two permanent stations of the Nicoya broadband network. Two stations of the OVSICORI Network and two other stations of the Nicoya Network are located on the northern part of the peninsula close enough to be of value to the Keck Network. Stations of the Nicoya and OVSICORI Networks were used to more accurately locate earthquakes. With the addition of part of the Nicoya and OVSICORI Networks, data was able to be gathered from right before the June 23 large aftershock until July 18, the end of the Keck Network.

ANALYSIS

The earthquake analyzing software, SEISAN (Ottemoller et al., 1999), was used to convert the files gathered from the digitizers and to read the seismic waveforms. Phase readings were manually picked with a cursor to locate events. Initially, 163 earthquakes were located from July 2 to July 18 using the Keck, OVSICORI, and Nicoya Networks. Another 213 earthquakes were located from June 23 to July 1 using only the Nicoya and OVSICORI Networks, yielding a total of 376 earthquakes over a span of 3.5 weeks.

Using the arrival times, Hypoinverse, a location program within SEISAN (Ottemoller et al., 1999), located the events. Earthquake data, including time, location, depth, and magnitude, were transferred to an Excel file to be read by mapping programs and to create histograms. Maps were made using GeoMapApp (Geoscience Data System, 2009; Ryan et al., 2009). The events were plotted in Global Mapper (Blue Marble Geographics, 2002) to be viewed in 3D to visualize the cross sections parallel and perpendicular to the Middle American Trench. A cluster of shallow events was noticed about 4 km in depth. It was determined that the shallow cluster was due to an inadequate amount of arrival times. The events were relocated in SEISAN (Ottemoller et al., 1999) by re-picking arrival times for events with a RMS value greater than 0.10 seconds to reduce the error in location and depth. A total 69 events with too few arrival times and a large RMS value were removed from the dataset.

Of the 69 events, 47 with less than 3 adequate and/or distinguishable arrival times were removed. Locations generated by too few arrival times are considered unstable. The depths of these events are fixed by the location software in SEISAN (Ottemoller et al., 1999), because the software only had phases from two useful stations. This was the reason for the cluster of shallow events. The events removed were too small in magnitude to be detected clearly on three separate stations.

The remaining 22 events were removed due to a RMS value greater than 0.15 seconds. These were regional events with poor coverage as a result of their location far from the Keck, Nicoya, and OVSICORI Networks. Events closest to the Keck, Nicoya, and OVSICORI Networks had the least amount of error, since they had the greatest coverage. A majority of the events had a RMS value less than 0.10 seconds.

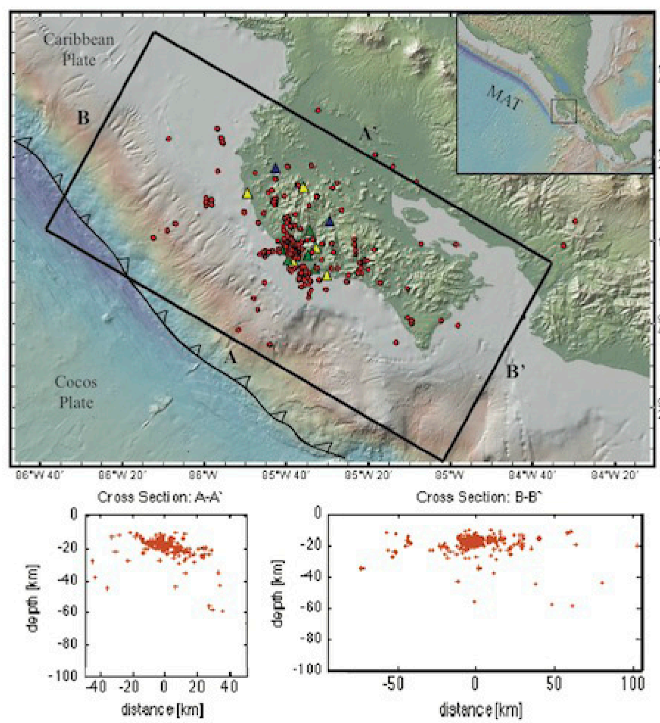

Figure 1. Map of the study area with a barbed solid line representing where the Cocos plate starts to subduct under the Caribbean plate. Inset shows location of the Nicoya Peninsula to Central America and the Middle American Trench (MAT). Shown are all of the earthquakes (red dots) located from June 23 to July 18, 2013 from the Keck (green triangles), Nicoya (yellow triangles), and OVSICORI (blue triangles) Networks. Black box outlines cross-sections perpendicular (A-A') and parallel (B-B') to the MAT.

After removing the unstable events, there were 307 events left in the dataset. The new dataset was remapped. A more precise and less scattered map and cross sections were produced (Fig. 1). The rupture model from Yue et al., (2013) of the 2012 Nicoya earthquake was superimposed on Figure 1, the map of aftershocks from June 23 to July 18, to compare locations.

RESULTS AND DISCUSSION

From the three and a half weeks, 307 small-magnitude earthquakes from the Keck, Nicoya, and OVSICORI Networks were useful in the analysis (Fig. 1). The Keck, Nicoya, and OVSICORI Networks registered 144 events from July 2 to July 18. Prior to the installation of the Keck Network, the Nicoya and OVSICORI Networks registered 163 similar events from June 23 to July 1. Of the 163 events, 97 occurred within 24 hours of the June 23 aftershock. The magnitudes range from 0.2 to 3.9. Figure 2a shows a majority of the events ranging between 0.5 and 1.0 in magnitude, which is about 68% of the total. The earthquakes are located within a large range of depths from 10 to 133 km. A majority of the earthquakes are located between 10 and 25 km in depth (Fig. 2b). This range of depths lies within the seismogenic zone along the plate interface of the subduction zone, which is consistent with locations from previous data. Events with greater depths are located farther downdip from the seismogenic zone.

There appears to be a pattern in the depths when looking at the events in cross section parallel to the Middle American Trench (Fig. 1 – Cross-section B-B'). Generally, the events lie along a horizontal line with events south of the bend in the peninsula being slightly shallower in depth than the events to the north, which is consistent with findings from Newman et al., (2002). There is a difference in depth because of the change in the updip limit of the seismogenic zone beneath the peninsula. The change is caused by the variance of temperatures of the incoming crust. The incoming crust under the southern portion of the peninsula originates from the warmer Cocos-Nazcas Spreading Center, whereas the incoming crust under the northern portion originates from the colder East Pacific Rise. Since both crusts are of about the same age, it is the temperature difference that causes the updip limit to be shallower in the south (~10km) than in the north (~20km) (Newman et al., 2002).

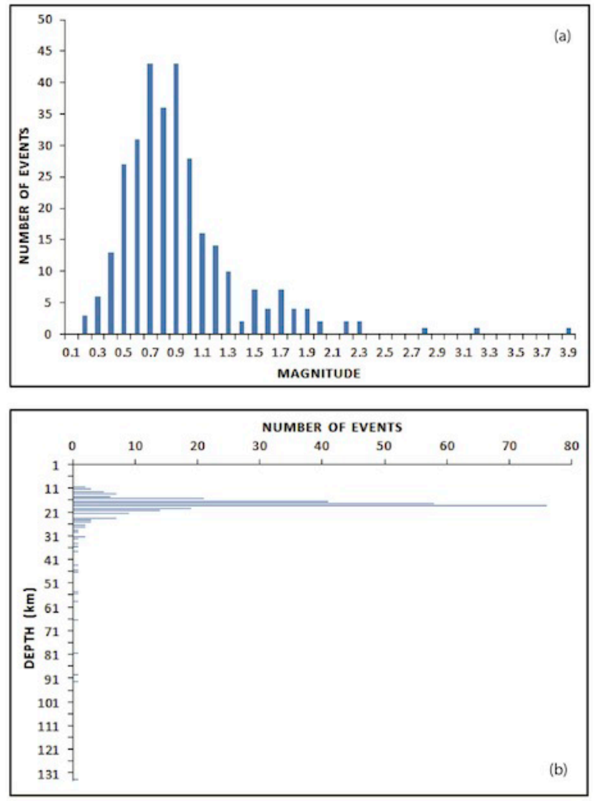

Figure 2. Histograms of number of events versus (a) magnitude and (b) depth.

The locations of the events are consistent with recent studies on the 2012 Nicoya earthquake (Fig. 3). Yue et al. (2013) report a rupture area determined by inversion of high-rate GPS, seismic and strong motion data. Figure 3 shows this co-seismic slip area (yellow lines) and the prior slip-deficient area determined by Feng et al. (2012) (black lines). The area outlined with a thick yellow line is where there was co-seismic slip greater than 2.0 m. Areas with greater than 1.2 m of co-seismic slip are outlined with a thin yellow line. The regions outlined in black represent the prior interseismic locking pattern showing 100% and greater than 80% locking. As is shown in Figure 3, the aftershocks (red dots) ten months after the main shock are located within the greater-than-80%-locked segment and in between the 100% locked segments of the Nicoya Seismic Gap, outlined by thin and thick

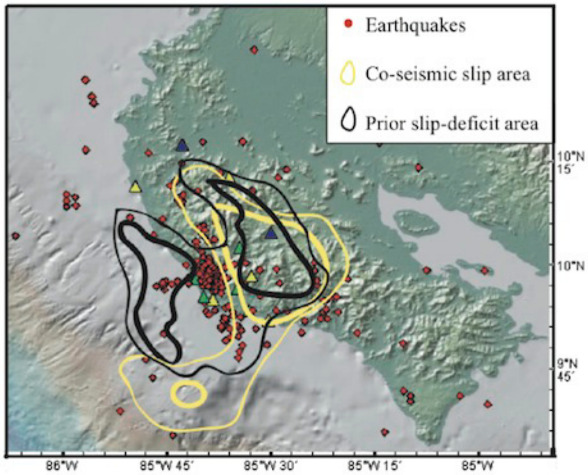

Figure 3. Map of the 2012 Nicoya, Costa Rica rupture model (black and yellow lines) and aftershocks (red dots – from Figure 1) ten months after the main shock. Black and yellow contours were retrieved from Yue et al., (2013). The regions of co-seismic slip-greater-than-1.2 m and greater-than-2.0 m are represented by thin and thick yellow contours, respectively. The interseimic locked region is outlined in thin and thick black contours for greater-than-80% and 100% slip deficit (Feng et al., 2012), respectively.

black lines, respectively. The aftershocks ten months later are consistent with the 2012 Nicoya rupture zone. Very few aftershocks were located within the 100% locked patch located offshore, which we interpret as due to the fact that this offshore patch is still locked.

CONCLUSIONS

Aftershocks ten months following the 2012 Nicoya earthquake possess similar characteristics to earthquakes beneath the Nicoya Peninsula in previous studies. When looking at these aftershocks in cross section parallel to the Middle American Trench, there is a slight change in the updip limit of the seismogenic zone. This change is interpreted as caused by the change in temperature of the incoming crust. Most of the aftershocks located in this study are located within the greater-than-80%-locked region of the Nicoya Seismic Gap of Feng et al. (2012). Without the installation of the small seismic array, the small-magnitude earthquakes associated with the June 23 large aftershock would not have been adequately located. More data can be obtained from earlier large aftershocks to better compare them with the main shock and to better understand the geometry of the seismogenic zone.

ACKNOWLEDGMENTS

Thank you to my on campus advisor Nelson Ham, to my project advisors Jeff Marshall, Tom Gardner and especially Marino Protti who served as my geophysics project advisor, and to my project teammates for all their help, advice, and guidance. I would also like to thank Keck Geology Consortium for making this experience possible.

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