

# Characterization of VLF earthquakes in the Colombian Pacific subduction zone

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Colombia located in the northwestern corner of South America is tectonically and seismically active due to the convergence of the Nazca and Caribbean plates as well as the movement of the Choco-Panama and North Andean blocks. Two large earthquakes, the Ecuador-Colombia earthquake in 1906 (Mw 8.4) and the Tumaco earthquake in 1979 (Mw 8.2), occurred in the Colombian subduction zone between the Nazca and South American plates.

Earthquake monitoring in Colombia has been performed using the network of broadband seismometers deployed and maintained by the Colombian Geological Survey (SGC). Very low frequency (VLF) earthquakes, which have been reported in various subduction zones around the world such as Nankai, Cascadia, and Mexico, are important to understand rupture processes in subduction regions because they might increase the stress on faults that are capable of generating large, damaging earthquakes. VLF earthquakes, however, have not been found in the Colombian subduction zone.

In this study, we used continuous data from the broadband seismometer networks in Colombia and Ecuador. Continuous seismograms were filtered in low and high frequency bands of 0.02-0.05 and 2.0-8.0 Hz, respectively, to visually find VLF waveforms in time windows of 40 min. We found a VLF earthquake on February 10 2016, which was characterized by a distinct phase in the low frequency band without visible phases in the high frequency band. The waveforms of this VLF earthquake were used as the template to detect other VLF events in a systematic process using the matched filter technique for continuous data between January 2016 to June 2017. Several events were detected in this procedure and we confirmed that these events are not local ordinary or teleseismic earthquakes by checking the bulletins of SGC, Geophysics Institute of Ecuador, and US Geological Survey.

Power spectral densities of the VLF earthquakes showed higher energy contents in a frequency band of 0.02-0.05 Hz, which corresponds to the dominant frequency band of VLF earthquakes reported by Ito et al. (Science, 2007). We found that the VLF waves propagated from a region near Tumaco in the southwest of Colombia. We performed waveform inversion of five relatively large VLF earthquakes using the SWIFT method (Nakano et al., GJI, 2008) and assuming an initial source location off Tumaco. Our waveform inversion results indicate that these VLF earthquakes were located in the southern Colombian Pacific subduction zone, which corresponds to the source region of the Tumaco earthquake in 1979. Our estimated source depths and moment magnitudes ranged between 5 and 45 km and 3.6 and 4.5, respectively, although the accuracy of the depth estimates may not be good. Since we could use data from only a few stations for our inversion, our estimated focal mechanisms were not stable. However, the estimated depth and magnitude ranges and the VLF waveform features are similar to those of VLF earthquakes in Cascadia, Nankai, and Guerrero subduction zones, and the VLF earthquakes found in this study may be generated by Nazca plate subduction processes along the Colombia subduction zone.

Keywords: VLF earthquakes, Colombian Pacific subduction zone