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Seismogenesis in a Long-Feared Gap: A Sway of Slow and Fast Slip

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in collaboration with dozens of Mexican and Japanese colleagues

In the last seven years, the arduous and sustained scientific collaboration between DPRI and UNAM has led to unexpectedly valuable achievements, both in the understanding of seismogenic physics and the effective prevention of future earthquake and tsunami disasters. The generation and transfer of knowledge between experts from both countries has led us to raise new questions at the frontier of knowledge. In this seminar I will deepen some of them related to unprecedented ocean bottom observations related to silent (slow slip events, SSEs) and devastating earthquakes inside and outside the Guerrero Seismic Gap, Mexico. The data acquired aboard the UNAM R/V El Puma in seven oceanographic campaigns together with the observations yielded by the seismogeodetic network we installed onshore, represent an observational treasure that we have not finished understanding despite the novel models and methods we have developed. However, as I describe below, some conclusions of general interest are already emerging.

The great Mw8.2 intra-slab Tehuantepec earthquake of September 8, 2017, the largest ever recorded in Mexico, caused an unprecedented disruption in the regional seismotectonics. As they propagated through Mexican territory, the seismic waves of the event transiently changed (for at least two years) the mechanical properties of the rocks at the contact between the subducting Cocos and the overriding North American plates, causing an unprecedented (since 1997, when initiates the continuous geodetic record) sequence of slow and devastating earthquakes over the 750 kilometers spanning the states of Guerrero and Oaxaca. To illustrate this, simply consider the precise recurrence period of 3.5 years of the long-term SSEs in Guerrero (Mw~7.5) during the 20 years prior to the great earthquake, and the recurrence periods of the following two SSEs in Guerrero of 0.25 and 0.5 years (Mw~7.0), occurred in 2018 and 2019. In addition, bidirectional causality (quasi-static and dynamic) was demonstrated between the Tehuantepec rupture, several SSEs and both the Puebla-Morelos (Mw7.1 on September 19, 2017) and Pinotepa (Mw7.2 on February 16, 2018) earthquakes, which devastated Mexico City and coastal localities in the state of Oaxaca, respectively. It is worth noting that the last six Mw7+ earthquakes in Guerrero and Oaxaca, which occurred between 2012 and 2021, were preceded by an SSE in the hypocentral vicinity.

Exactly four years after the Tehuantepec rupture, on September 8, 2021, a Mw7.0 thrust earthquake took place beneath Acapulco, Mexico, causing significant local damage and triggering the public early warning system in Mexico City, located 280 km north of the epicenter. The earthquake occurred in the heart of the Guerrero seismic gap and is a repetition of the May 11, 1962 event (Mw7.1) that was followed by a doublet nine days later (Mw7.0) next to the large rupture of 1957 (Mw7.7), which toppled the Angel of Independence, an emblematic historical monument of the country's capital, and gave birth to earthquake engineering in Mexico.

In May 2021, four months before the Acapulco earthquake, a slow slip event was initiating to the east, in Oaxaca, and propagated to the Costa Chica of Guerrero over the deep segment of the plate interface (i.e., between 25 and 50 km depth). Dense GNSS data and unprecedented seafloor geodetic observations revealed that another one, this time shallow SSE (Mw6.6) initiated one month before (in April 2021) at the oceanic trench of the seismic gap, first observed in Mexico, and propagated downdip towards the earthquake hypocentral region during the five months prior to rupture. This SSE as well as the mainshock were recorded offshore either by seafloor hydrostatic pressure sensors (vertical displacement) and/or collocated tiltmeters (two component rotations). The earthquake and its postseismic relaxation produced a Mw7.3 long-term SSE deeper in Guerrero to the northwest (between October 2021 and April 2022) significantly increasing the seismicity of the region, particularly around the 1957 rupture zone where most of the aftershocks concentrated. Offshore earthquake clustering and continuous geodetic observations, last acquired at sea in March 2023, revealed that a new short-term shallow SSE (5-15 km depth) took place offshore Acapulco (preliminary Mw6.5) starting around January 2022. Additional offshore SSE have been identified since November 2017 and are being analyzed from the 5.5 years of continuous seafloor pressure and tilt data we acquired.

Another surprising observation unveiled by four seafloor tiltmeters emerged just after the 2018 Pinotepa (Mw7.2) and 2022 Michoacán (Mw7.8) earthquakes, both events with epicentral distance larger than 250 km, when all instruments (inter-station spacing from 25 to 55 km, with two instruments on both sides of the oceanic trench only ~10 km from it) experienced a several-month-long fast-tilting deceleration phase (typical rates of ~3 μrad/yr), suggesting that regional seismic waves from Mw7+ earthquakes may play a major role in the accommodation of the subducting plate beneath the continents and thus in the seismic cycle. All these observations along with dozens of joint inversions of GNSS, pressure and tilt data suggest that the genesis of potentially devastating earthquakes in the Guerrero seismic gap is controlled by the sway of slow slip transients (either triggered or spontaneously initiated) interacting from the trench to 50 km depth that eventually break up locked asperities interposed at seismogenic depths, phenomenology that may have important dynamic implications for the origin of large subduction earthquakes in the globe.