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The first since 1960: A large event in the Valdivia segment of the Chilean Subduction Zone, the 2016 M7.6 Melinka earthquake

Diego Melgar [a,*], Sebastian Riquelme [b], Xiaohua Xu [c], Juan Carlos Baez [b], Jianghui Geng [d], Marcos Moreno [e]

[a] *Seismological Laboratory, University of California Berkeley, Berkeley, USA*
[b] *Centro Simológico Nacional, Universidad de Chile, Santiago, Chile*
[c] *Scripps Institution of Oceanography, UC San Diego, San Diego, USA*
[d] *GNSS Center, Wuhan University, Wuhan, China*
[e] *GeoForschungsZentrum, Potsdam, Germany*

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A B S T R A C T

We present results for joint kinematic inversion of high-rate GPS, strong motion and InSAR data for the 2016 M7.6 Melinka earthquake. We show that the source is a compact 35 s long rupture with 5.0 ± 0.15 m of peak slip. We find the Melinka earthquake occurs inside the slip region for the 1960 M9.5 Valdivia earthquake and within the highly locked portion of the megathrust inferred from inter-seismic velocity analysis. We show that there is very modest post-seismic deformation at a nearby GPS site QLLN and argue that this indicates the Melinka earthquake ruptures within the intermediate portion of the megathrust and is an isolated asperity surrounded by locked velocity weakening material. Further we find that the peak slip observed during this earthquake is larger than what has been accumulated in the intervening 57 years since the 1960 rupture and conclude that, at least in the area of the Melinka earthquake, this is indicates that the 1960 Valdivia event might not have used all the slip deficit available on the megathrust.

1. Background

The 1960 M9.5 Valdivia, Chile earthquake is the largest event recorded in the time of modern instrumental seismology (Benioff et al., 1961; Barrientos and Ward, 1990). It ruptured a 1000 km long segment of the Chilean megathrust with an average slip of 20 m (Fig. 1), and tts geographic extent defines what we refer to as the Valdivia segment of the subduction zone (roughly from −37° to −46° latitude) (Plafker and Savage, 1969). In modern seismicity catalogs of large events, such as the Global CMT catalog, which spans the dates 1976–2017, moment release in most of the Valdivia segment has been comparatively modest (Fig. 1). This is perhaps unsurprising considering the large amount of slip during the 1960 event that potentially accounts for most, if not the entire, slip deficit accumulated prior to 1960. To the north of the Valdivia segment there is more recent activity. The 2010 M8.8 Maule earthquake (Tong et al., 2010; Lorito et al., 2011; Koper et al., 2012) had an average of 10 m of slip over a 500 km expanse of the subduction zone and had some limited overlap with the rupture are of the 1960 Valdivia earthquake (Fig. 1). The Maule event had vigorous aftershock sequence with megathrust events as large as M7.2. The coseismic slip of the Maule earthquake and its aftershock sequence account for a substantial portion of moment release in the northern section of the Valdivia segment (Fig. 1) since 1960. We note, however, that in the central and southern portions of the Valdivia segment seismicity, at least since 1976, has been of only limited productivity with no significant event since the beginning of the Global CMT catalog and none reported in the instrumental catalog of the National Seismological Center (CSN) of Chile.

Thus this apparent quiescence of at least two thirds of the Valdivia segment of the Chilean subduction zone is of fundamental interest. It illustrates the long-lived effects of large megathrust ruptures and their impacts on hazards. The reduced earthquake productivity suggests that large slip events such as the 1960 Valdivia earthquake temporarily diminish the hazard for large segments of the subduction system. Continued monitoring of large events such as the 2004 M9.1 Sumatra, 2010 M8.8 Maule and 2011 M9.0 Tohoku-oki earthquakes will allow for a better understanding of this temporal dependence of hazard and its evolution. If indeed these large slip events diminish the slip budget to the point where

* Corresponding author.
E-mail address: dmelgar@berkeley.edu (D. Melgar).

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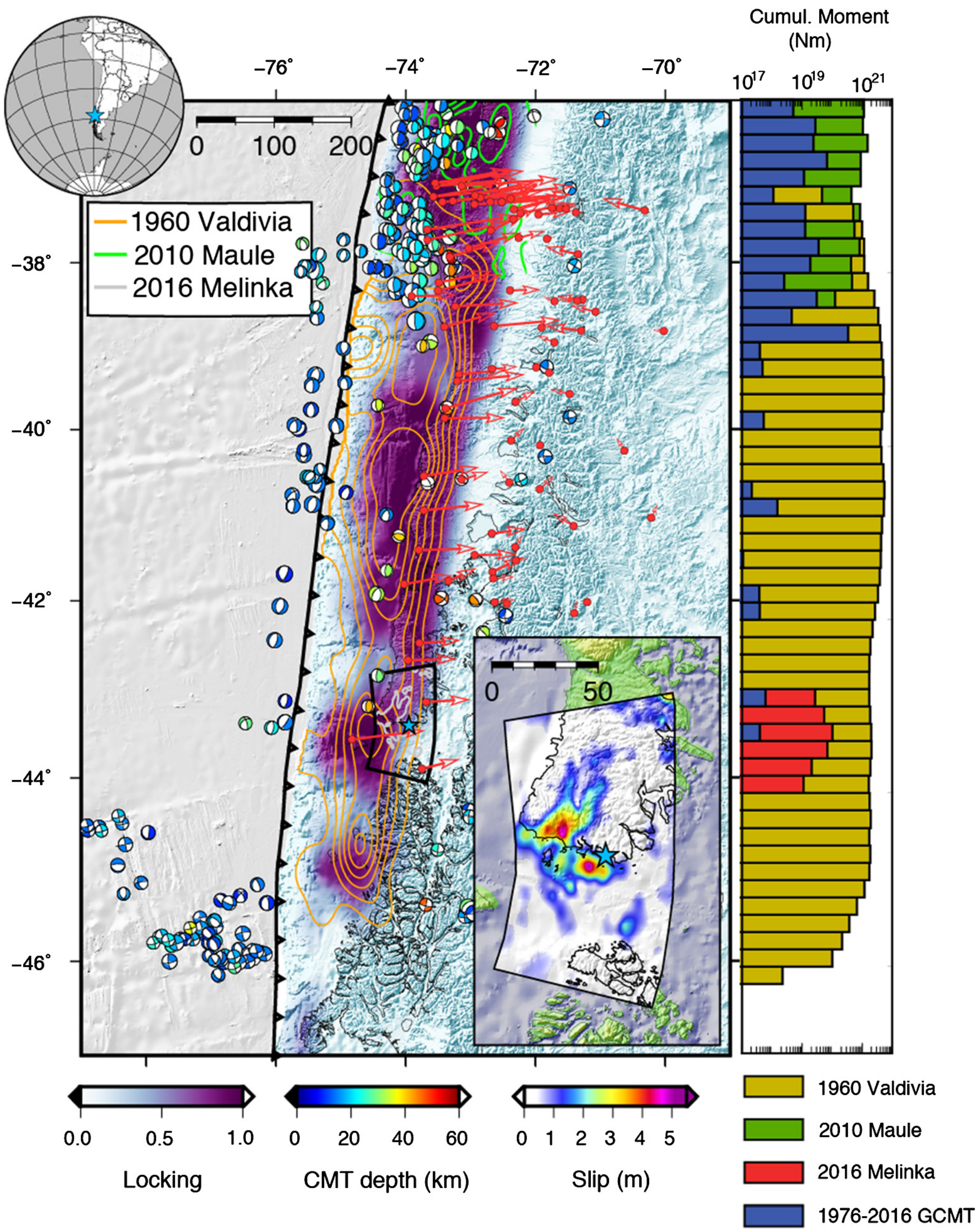

Fig. 1. Locking map for the Chilean subduction zone from Moreno et al. (2011). The Contours are the slip for the 1960 M9.5 Valdivia (4 m intervals), 2010 M8.8 Maule (4 m intervals), and 2016 M7.6 Melinka (1.5 m intervals) earthquakes from Moreno et al. (2009), Melgar et al. (2016), and this study respectively. Moment tensor solution for the time period 1976–2016 (excluding the Valdivia and Maule mainshocks) are from the Global CMT catalog. Red arrows are interseismic velocities reported by Moreno et al. (2011). The blue star is the hypocenter for the 2016 M7.6 Melinka earthquake and the inset is the slip inversion from this paper for that event. The bar graph is the cumulative moment release in 0.2 degree bins on the megathrust disregarding outer rise normal faulting and upper crustal events. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

damaging events are precluded for a period of time, potentially for decades, then an important question arises, how fast do megathrusts heal? In this context we understand "healing" to refer to the ability of the fault to once again produce large events of consequence for society and for the built environment. It is likely that the timescales of this process depend on the viscoelastic properties of the shallow subduction system. Wang et al. (2012) argue that the opposing interseismic motions in Southern Chile (Fig. 1), where coastal sites are moving landward while inland sites over the Andes and in Argentina are moving oceanward can be explained by considering viscoelasticity. Coastal site velocities show relocking of the megathrust while inland sites reflect bulk viscoelastic relaxation of the upper mantle, produced by the large coseismic slip pattern of the 1960 earthquake. This is in contrast to the Cascadia subduction zone, for example, where 317 years after the last M9 event all stations are moving landward, indicative of a system very late in the seismic cycle. Indeed after accounting for post-seismic effects Moreno et al. (2011), by analyzing these inter-seismic velocities from permanent and campaign GPS measurements, found that most of the Valdivia segment exhibits a high degree of locking (Fig. 1).

Within this framework the 2016 M7.6 Melinka earthquake occurred on December 25th. Here we will present results of a detailed analysis of the source characteristics of this earthquake and discuss its importance within the broader seismotectonics of the region and the implications based on its occurrence well within the rupture area of the 1960 Valdivia earthquake.