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Shallow seismicity patterns in the northwestern section of the Mexico Subduction Zone

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ABSTRACT

This study characterizes subduction related seismicity with local deployments along the northwestern section of the Mexico Subduction Zone where 4 portions of the plate interface have ruptured in 1973, 1985, 1995, and 2003. It has been proposed that the subducted boundary between the Cocos and Rivera plates occurs beneath this region, as indicated by inland volcanic activity, a gap in tectonic tremor, and the Manzanillo Trough and Colima Graben, which are depressions thought to be associated with the splitting of the two plates after subduction. Data from 50 broadband stations that comprised the MARS seismic array, deployed from January 2006 to June 2007, were processed with the software program Antelope and its generalized source location algorithm, genloc, to detect and locate earthquakes within the network. Slab surface depth contours from the resulting catalog indicate a change in subduction trajectory between the Rivera and Cocos plates. The earthquake locations are spatially anti-correlated with tectonic tremor, supporting the idea that they represent different types of fault slip. Hypocentral patterns also reveal areas of more intense seismic activity (clusters) that appear to be associated with the 2003 and 1973 megathrust rupture regions. Seismicity concentrated inland of the 2003 rupture is consistent with slip on a shallowly dipping trajectory for the Rivera plate interface as opposed to crustal faulting in the overriding North American plate. A prominent cluster of seismicity within the suspected 1973 rupture zone appears to be a commonly active portion of the megathrust as it has been active during three previous deployments. We support these interpretations by determining focal mechanisms and detailed relocations of the largest events within the 1973 and inland 2003 clusters, which indicate primarily thrust mechanisms near the plate interface.

1. Introduction

The theoretical downdip limit of a plate interface seismogenic zone is marked by a transition from stick-slip to stable sliding behavior (Scholz, 2002). While there are some indications this transition in behavior can be influenced by the rheological brittle–ductile transition of crust or mantle rocks, ultimately the change in behavior is due to a change in frictional stability. This characterization of the seismogenic zone is particularly important in subduction zones where sudden slip in the locked zone produces the largest and most devastating earthquakes. While seismic behavior of subduction zones is variable, it is thought that the age and mechanics of the subducting plate has a large influence on the behavior of the seismogenic zone. The Mexico Subduction Zone (MSZ) can be strongly characterized by the along-strike variation in subduction geometry, ranging from more steeply dipping segments near the Rivera-Cocos plate boundary to subhorizontal segments. Though they are not well understood, flat slab regions are not uncommon globally, occurring in 10% of modern convergent margins including Guerrero and Oaxaca to the southeast of our study region (Gutscher et al., 2000; Husker and Davis, 2009; Kim et al., 2010; Pérez-Campos et al., 2008). This portion of the MSZ at the Rivera-Cocos plate boundary provides a unique opportunity to examine the seismic behavior during subduction of young lithosphere under active microplate fragmentation and with variable geometry that has occurred repeatedly through time along this subduction zone (Dougherty et al., 2012). Here, the young Rivera and Cocos plates are subducting beneath North America, contributing to an

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environment with a wide range of seismic activity including frequent large to great earthquakes, abundant microseismicity, prominent earthquake afterslip, and tectonic tremor (e.g., Schmitt et al., 2007; Schlanser et al., 2010). Despite the fact that each of these different fault behaviors could largely be influenced by slab geometry and/or controlled by stress on the plate interface, no reliable relationship has been found between these phenomena as of yet. This uncertainty fuels significant discussion around the characterization of and tectonic interactions between the subducting Rivera and Cocos plates, warranting further investigation.

In this region, the Manzanillo Trough and Colima Graben appear to occur above the boundary between the subducting Rivera and Cocos plates, adding to the intrigue of this tectonic region. Both plates consist of young (<11 Myr) oceanic lithosphere, though the Rivera microplate separated from the Cocos plate 5–10 Ma (DeMets and Traylen, 2000; Dougherty et al., 2012). The boundary between the two plates is still difficult to discern or interpret (DeMets and Wilson, 1997; Bandy et al., 1999; Suarez et al., 1999; Peláez Gaviria et al., 2013). The Rivera plate is subducting at ~30–50 mm/yr nearly perpendicular to the trench beneath Colima though the rate slows to ~15 mm/yr as the trajectory becomes increasingly oblique to the northwest (Kostoglodov and Bandy, 1995; DeMets and Wilson, 1997). The Cocos plate subducts at ~50 mm/yr suggesting that motion occurs between the Cocos and Rivera plates beneath the continental margin as well. The Colima Graben (5 Ma) is a generally north–south linear depression characterized by active faulting and abundant volcanism, and has been proposed to be the surface manifestation of the boundary between the Rivera and Cocos plates, marking the eastern extent of the high elevation associated with the Jalisco crustal Block (Singh et al., 1985; Bandy et al., 1995; Rosas-Elguera et al., 1996; Peláez Gaviria et al., 2013). Although much geodetic, petrologic, structural, and paleomagnetic work as been done there has been no detailed study of the subduction interface so not much is known about how subduction of young lithosphere under active microplate fragmentation influences the interaction between the subducting and overriding plates.

There have been several megathrust earthquakes in this region during modern instrumental recording. The first was the 1973 January 30 (Mw 7.6) Colima earthquake that occurred just southeast of the Manzanillo Trough and Colima Graben. It is considered a megathrust event based on a shallow thrust focal mechanism and the rupture extent has been estimated from the distribution of aftershocks (Reyes et al., 1979). The 1995 October 9 (Mw 8.0) Colima–Jalisco earthquake occurred northwest of the Manzanillo Trough, the first event to occur in this region since the 1932 June 3 (Mw ~8.2) and 1932 June 18 (Mw ~7.8) earthquakes (Singh et al., 1985; Pacheco et al., 1997) which are thought to have ruptured this area as well. Focal mechanisms for this event are consistent with shallow thrusting (Dziewonski et al., 1997; Escobedo et al., 1998) as well. The 1995 earthquake was also one of the first earthquakes to occur close enough to a GPS geodetic network to be able to study the coseismic and near-term post-seismic behavior of the subduction interface. Geodetic and seismologic results concur that slip was primarily above 20 km depth along a ~150 km segment extending northwest from the Manzanillo Trough (Courboulex et al., 1997; Melbourne et al., 1997; Mendoza and Hartzell, 1999; Hutton et al., 2001). The most recent megathrust event to occur in this region was the 2003 January 22 (Mw 7.2) Tecomán earthquake off shore from Colima. Focal mechanisms indicate shallow interplate thrusting (Yagi et al., 2004; Ekström et al., 2005) while seismic and geodetic inversions signify that the large majority of the coseismic slip was limited to an 80 km along-strike region bounded by the Manzanillo Trough and southernmost Colima Graben (Yagi et al., 2004; Schmitt et al., 2007). The coincidence of the 1932, 1973, 1995, and 2003 rupture edges with the Manzanillo Trough and Colima Graben may indicate that these features represent a mechanical barrier to along-strike rupture propagation.

In addition to earthquakes, episodic slow slip and tectonic tremor have been observed along the southern coast of Mexico, including some of the largest (Mw 7.5) episodic transient slip events which have been produced in the Guerrero and Oaxaca regions to the southeast of the study region (Larson et al., 2007; Brudzinski et al., 2007, 2010; Payero et al., 2008; Kostoglodov et al., 2010). Large slow slip recurs 1–4 years on average in Guerrero and Oaxaca, but no evidence for slow slip has been reported yet in our study region. Patches of tremor in Oaxaca and Guerrero occur more frequently, with epicenters shifted inland from slow slip between the 30–50 km plate interface contours. Tremor has been found in our study region (Schlanser et al., 2010), using the same seismic network as this study and with an approach similar to that utilized in the Oaxaca region (Brudzinski et al., 2010). The results of that study are similar to that of Ide (2012), with tremor located in a trench-parallel band with a distinct gap at the western edge of the Colima Graben.

The Mapping the Rivera Subduction Zone (MARS) deployment has provided a new opportunity to reevaluate ideas regarding this region specifically. This study seeks to further analyze the shallow (0–80 km) earthquakes captured by the recent seismic recording in this region in the context of results from previous seismic deployments to improve our understanding of the configuration and complicated tectonic interactions between two subducting plates in the westernmost section of the MSZ.

2. Data and methods

The MARS (Mapping the Rivera Subduction Zone) experiment, composed of 50 temporary broadband seismic stations in a two dimensional grid, was an IRIS-PASSCAL deployment in southwestern Mexico from January 2006 to June 2007 (Fig. 1). This 18-month experiment involved the University of Texas at Austin and New Mexico State University in collaboration with colleagues at Centro De Geociencias, UNAM, and the Volcanic Observatory at the Universidad de Colima in Mexico. The overall goals of the MARS experiment were to gain a better understanding of the forces controlling the unusual tectonics of the Jalisco block and the behavior of the Rivera and Cocos plates (Soto et al., 2009; Yang et al., 2009). The deployment configuration is ideally situated to examine a ~400-km along-strike section of the seismogenic and transition zone of the plate interface. We use this dataset to establish the shallow microseismicity patterns across this unique subduction boundary, comparing to patterns observed during previous temporary deployments, as well as patterns in megathrust earthquakes, afterslip, and tectonic tremor.

In order to locate shallow seismicity, the data used in this study have been organized and analyzed using the Antelope software package (version 4.11). Processing begins by applying a multi-frequency STA/LTA detector (dbdetect) on all vertical component waveforms. We use the default Antelope parameters, including an overall SNR detection threshold of 5 and short/long window lengths of 5 s/50 s, 2 s/20 s, and 1 s/10 s for filters of 0.5–1.2 Hz, 0.8–3.0 Hz, and 3.0–3.0 + Hz, respectively. Detections are then investigated using the spatial grid search based associator and event locator (dbgrassoc). Nearly all default parameters are employed, including the use of the iasp91 velocity model, a 500 s time window, the taup phase predictor, and residual thresholds for association of P and S waves at 10 and 20 s, respectively. The lone exception to our use of default parameters is that the minimum allowable number of stations is lowered to 4 at this stage in