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Present-day crustal deformation along the El Salvador Fault Zone from ZFESNet GPS network

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A B S T R A C T

This paper presents the results and conclusions obtained from new GPS data compiled along the El Salvador Fault Zone (ESFZ). We calculated a GPS-derived horizontal velocity field representing the present-day crustal deformation rates in the ESFZ based on the analysis of 30 GPS campaign stations of the ZFESNet network, measured over a 4.5 year period from 2007 to 2012. The velocity field and subsequent strain rate analysis clearly indicate dextral strike–slip tectonics with extensional component throughout the ESFZ. Our results suggest that the boundary between the Salvadoran forearc and Caribbean blocks is a deformation zone which varies along the fault zone. We estimate that the movement between the two blocks is at least ~12 mm yr^{-1}. From west to east, this movement is variably distributed between faults or segments of the ESFZ. We propose a kinematic model with three main blocks; the Western, Central and Eastern blocks delimited by major faults. For the first time, we were able to provide a quantitative measure of the present-day horizontal geodetic slip rate of the main segments of ESFZ, ranging from ~2 mm yr^{-1} in the east segment to ~8 mm yr^{-1}, in the west and central segments. This study contributes new kinematic and slip rate data that should be used to update and improve the seismic hazard assessments in northern Central America.

1. Introduction

El Salvador is located in northern Central America, at the Pacific Ocean margin of the Caribbean plate, in the western margin of the Chortis block (Rogers et al., 2007) (Fig. 1). Along the El Salvador Pacific coast, convergence between the Cocos and Caribbean plates is accommodated by a combination of 73 mm yr^{-1} of northeast-directed Cocos Plate subduction (DeMets et al., 2010) and ~14 mm yr^{-1} of northwestward trench-parallel motion of the Central American forearc (CAFA) (Fig. 1) (Turner et al., 2007; LaFemina et al., 2009; Correa-Mora et al., 2009; Alvarado et al., 2011; Franco et al., 2012; Kobayashi et al., 2014). This process works under a setting of low degree of coupling across the Middle America subduction zone (e.g. Álvarez-Gómez et al., 2008; Correa-Mora et al., 2009; LaFemina et al., 2009; Franco et al., 2012; Geirsson et al., 2015). Therefore, the causes of the northwestward trench-parallel motion of the CAFA are nowadays a topic of discussion. There are three main driving forces suggested in the literature for CAFA motion: (1) oblique convergence between the Cocos and Caribbean plates (DeMets, 2001); (2) Cocos Ridge collision offshore Costa Rica (LaFemina et al., 2009), which forces the northwestward lateral escape of the CAFA, driving the Nicaraguan forearc to the northwest which pushes the Salvadoran forearc; (3) pull on the CAFA western edge, caused by the pinning of the CAFA with the North American plate at the diffuse triple junction (Lyon-Caen et al., 2006; Álvarez-Gómez et al., 2008; Franco et al., 2012), which would cause the westward dragging of the CAFA due to North American plate motion. This idea highlights the importance of the weakness area along the volcanic arc in the geodynamic evolution of the Chortis block (Burkart and Self, 1985; Malfait and Dinkelman, 1972; Rogers et al., 2007), explaining the extensional structures formed in both the Salvadoran and Nicaraguan forearcs (e.g. Álvarez-Gómez et al., 2008).

Associated with these processes, destructive earthquakes within the Salvadoran volcanic arc have occurred periodically over the past century (White, 1991; White and Harlow, 1993) and offshore along the Cocos Plate subduction interface (e.g. Benito et al., 2004; Geirsson et al., 2015) (Fig. 2). In the last 100 years El Salvador has suffered at least 11

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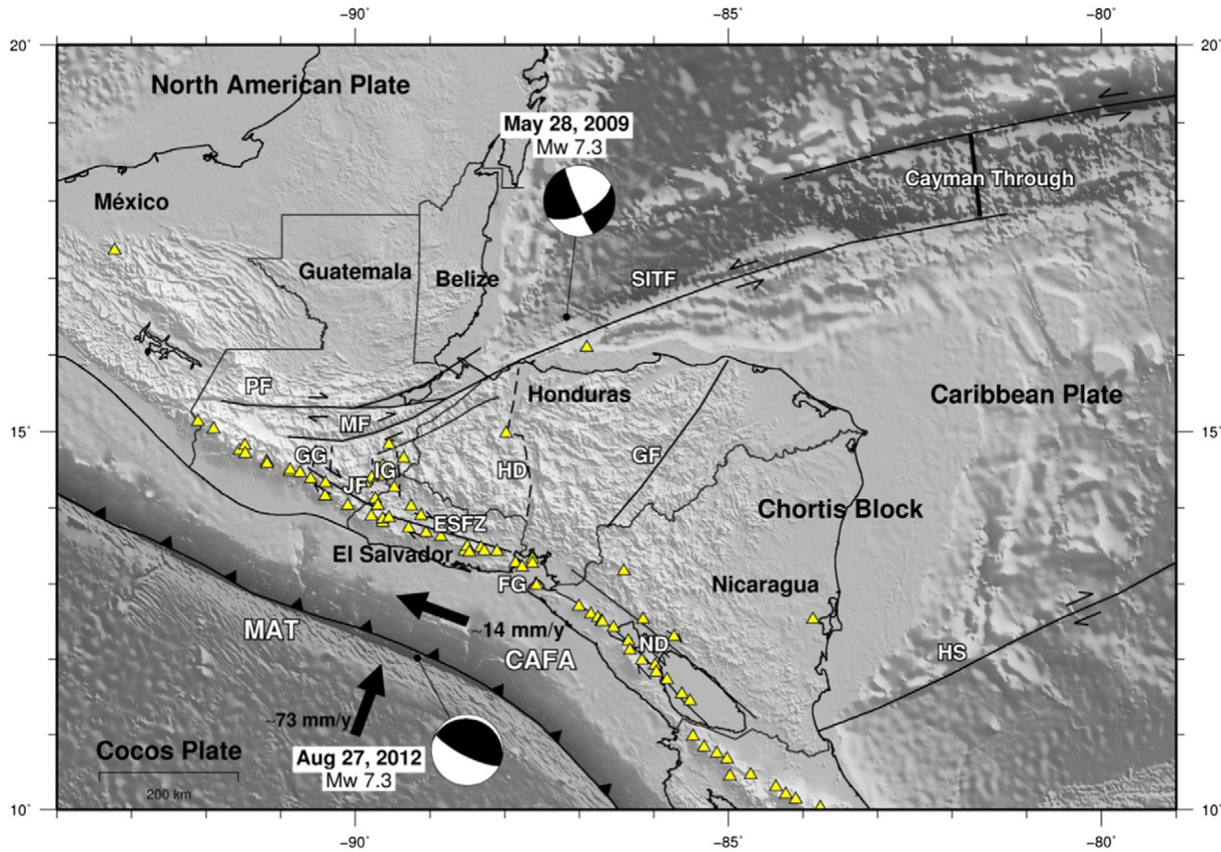

Fig. 1. Tectonic setting of northern Central America. Black vectors indicate relative rate and azimuth between Cocos and Caribbean plates (DeMets et al. 2010) and CAFA motion relative to Caribbean plate. Orange triangles show the position of volcanoes. Focal mechanisms and earthquake locations are for the 2009 May 28 and 2012 August 27 earthquakes from the Global CMT catalogue (Dziewonski et al., 1981). Abbreviations: CAFA — Central American forearc, GG — Guatemala Graben, IG — Ipala Graben JF — Jalpatagua Fault, ESFZ — El Salvador Fault Zone, HD — Honduras Depression, ND — Nicaraguan Depression, FG — Gulf of Fonseca, SITF — Swan Islands Transform Fault, PF — Polochic Fault, MF — Motagua Fault, HS — Hess Scarpment, GF — Guayapé Fault, MAT — Mid-American Trench.

destructive earthquakes that have caused more than 3,000 victims (Bommer et al., 2002), underlining the importance of better understanding their sources and causes.

According to Canora et al., 2010, the last destructive earthquake in El Salvador, the 13 February 2001, Mw 6.6 earthquake (Fig. 2), was caused by a tectonic rupture on one of the segments of the El Salvador Fault Zone (ESFZ) (Martínez-Díaz et al., 2004; Corti et al., 2005). The ESFZ is thought to be responsible for frequent damaging earthquakes (e.g. 1951, M_s 5.9; 1965, M_s 6.3; 1986, M_s 5.4;) in El Salvador (Martínez-Díaz et al., 2004; Canora et al., 2010). Some authors (e.g. Álvarez-Gómez, 2009; Alvarado et al., 2011; Franco et al., 2012) suggest that this fault system could be accommodating the ~14 mm yr^{-1} trench-parallel strike–slip displacements due to the eastward movement of the CAFA relative to the Caribbean plate.

In the recent decades, several studies have tried to quantify the kinematics of the principal structures in Central America that are accommodating active deformation, as well as to understand the factors and tectonic forces that control this deformation (e.g. DeMets, 2001; DeMets et al., 2007; Álvarez-Gómez et al., 2008; Correa-Mora et al., 2009; LaFemina et al., 2009; Alvarado et al., 2011; Franco et al., 2012; Kobayashi et al., 2014; Alonso-Henar et al., 2015).

So far, geodetic studies carried out in northern Central America (Lyon-Caen et al., 2006; DeMets et al., 2007; Turner et al., 2007; LaFemina et al., 2009; Alvarado et al., 2011; Franco et al., 2012; Kobayashi et al., 2014) have mainly focused on understanding the regional tectonics of this region. The existing geodetic data in El Salvador did not allow the carrying out a detailed analysis of the kinematics of the active faults associated with the Salvadoran volcanic arc. In consequence, in this paper we show the first detailed results of a new geodetic GPS network established in El Salvador that allows us not only to refine previous results but also to complement the data set in El Salvador. From the obtained GPS velocity field, we quantify current crustal deformation rates in the area in order to estimate the current activity and behavior of the different segments of the El Salvador Fault Zone (ESFZ) (Fig. 2). These new data will be very useful for improving the seismic hazard assessments in the region.

2. Seismotectonic setting

2.1. Active faults — the ESFZ structure

The El Salvador Fault Zone (ESFZ) is an active, c. 150 km long and 20 km wide, dextral strike–slip fault zone within the El Salvador Volcanic Arc striking N90°–100°E (Martínez-Díaz et al., 2004; Corti et al., 2005). It is composed of several larger E–W to ESE–WSW strike–slip faults with lengths ranging 20–30 km and secondary N–S and NNW–SSE normal and oblique-slip faults that accommodate deformation between larger faults. No evidence of pure strike slip movements is observed in these faults. The ESFZ has been divided into five segments according to structural, geometric and kinematic criteria which are, from west to east: the Western, San Vicente, Lempa, Berlin and San Miguel segments (Canora et al., 2012 and Fig. 2).

The main faults of the ESFZ have strikes ranging N90°–110°E and dips of 70°. These faults are interpreted as part of several inherit graben structures formed during a previous extensional phase, that are reactivated under a younger strike slip regime (Canora et al., 2014b;