Journal of Asian Earth Sciences 65 (2013) 64–74

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

journal homepage: www.elsevier.com/locate/jseaes

Present-day crustal deformation along the Philippine Fault in Luzon, Philippines

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ARTICLE INFO

Article history:
Available online 26 January 2011

Keywords:
Philippine Fault
GPS velocity
Crustal strain
Interseismic deformation
Dislocation model

ABSTRACT

The Philippine Fault results from the oblique convergence between the Philippine Sea Plate and the Sunda Block/Eurasian Plate. The fault exhibits left-lateral slip and transects the Philippine archipelago from the northwest corner of Luzon to the southeast end of Mindanao for about 1200 km. To better understand fault slip behavior along the Philippine Fault, eight GPS surveys were conducted from 1996 to 2008 in the Luzon region. We combine the 12-yr survey-mode GPS data in the Luzon region and continuous GPS data in Taiwan, along with additional 15 International GNSS Service sites in the Asia-Pacific region, and use the GAMIT/GLOBK software to calculate site coordinates. We then estimate the site velocity from position time series by linear regression. Our results show that the horizontal velocities with respect to the Sunda Block gradually decrease from north to south along the western Luzon at rates of 85–49 mm/yr in the west–northwest direction. This feature also implies a southward decrease of convergence rate along the Manila Trench. Significant internal deformation is observed near the Philippine Fault. Using a two dimensional elastic dislocation model and GPS velocities, we invert for fault geometries and back-slip rates of the Philippine Fault. The results indicate that the back-slip rates on the Philippine Fault increase from north to south, with the rates of 22, 37 and 40 mm/yr, respectively, on the northern, central, and southern segments. The inferred long-term fault slip rates of 24–40 mm/yr are very close to back-slip rates on locked fault segments, suggesting the Philippine Fault is fully locked. The stress tensor inversions from earthquake focal mechanisms indicate a transpressional regime in the Luzon area. Directions of σ_1 axes and maximum horizontal compressive axes are between 90° and 110°, consistent with major tectonic features in the Philippines. The high angle between σ_1 axes and the Philippine Fault in central Luzon suggests a weak fault zone possibly associated with fluid pressure.

1. Introduction

The Philippine archipelago is a deformed orogenic belt resulting from the collage and collision of blocks of oceanic and continental affinities (Karig, 1983). It is wedged between two converging plates: the oceanic northwest-moving Philippine Sea Plate in the east and the Sunda (Sundaland) Block/Eurasian Plate in the west (Fig. 1). The east-dipping Manila Trench forms part of its western boundary and together with the Negros-Sulu-Cotabato Trench, absorbs the convergence along the western side. The northwestward motion of Philippine Sea Plate is absorbed in part, by the subduction of west-dipping Philippine Trench and the East Luzon Trough in the east, and in another by the Philippine Fault. Recent data derived from GPS (Rangin et al., 1999; Simons et al., 1999; Kreemer et al., 2000; Bacolcol et al., 2005) and earthquake slip vectors (Chamot-Rooke and Le Pichon, 1999) showed the Sunda Block to be a distinct entity and rotates clockwise with respect to the Eurasian plate (Chamot-Rooke and Le Pichon, 1999; Michel et al., 2001). Simons et al. (2007) used a decade (1994–2004) of GPS data to characterize the Sunda Block boundaries and derived the rotation pole at 49.0°N–94.2°E, with a clockwise rotation rate of 0.34°/Myr. The convergence rate of about 80–90 mm/yr between the Philippine Sea Plate and the Eurasian Plate has been reported from the plate model (Seno et al., 1993) and Global Positioning System (GPS) (Yu et al., 1999). The oblique convergence between two plates is decomposed into a trench-parallel component of 20–25 mm/yr on the Philippine Fault (Barrier et al., 1991) and a trench-perpendicular component of 40–90 mm/yr on the Philippine and Manila Trench (Megawati et al., 2009).

The Philippine Fault is a sinistral strike-slip fault which transects the Philippine archipelago from north to south for about 1200 km. In spite of its recognition as a major geological structure and sources of destructive earthquakes (M_s 7.5 1973 Ragay Gulf earthquake; M_s 7.9 1990 Luzon earthquake; M_s 6.2 2002 Masbate earthquake), a number of characteristics, e.g., precise fault location,

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doi:10.1016/j.jseaes.2010.12.007

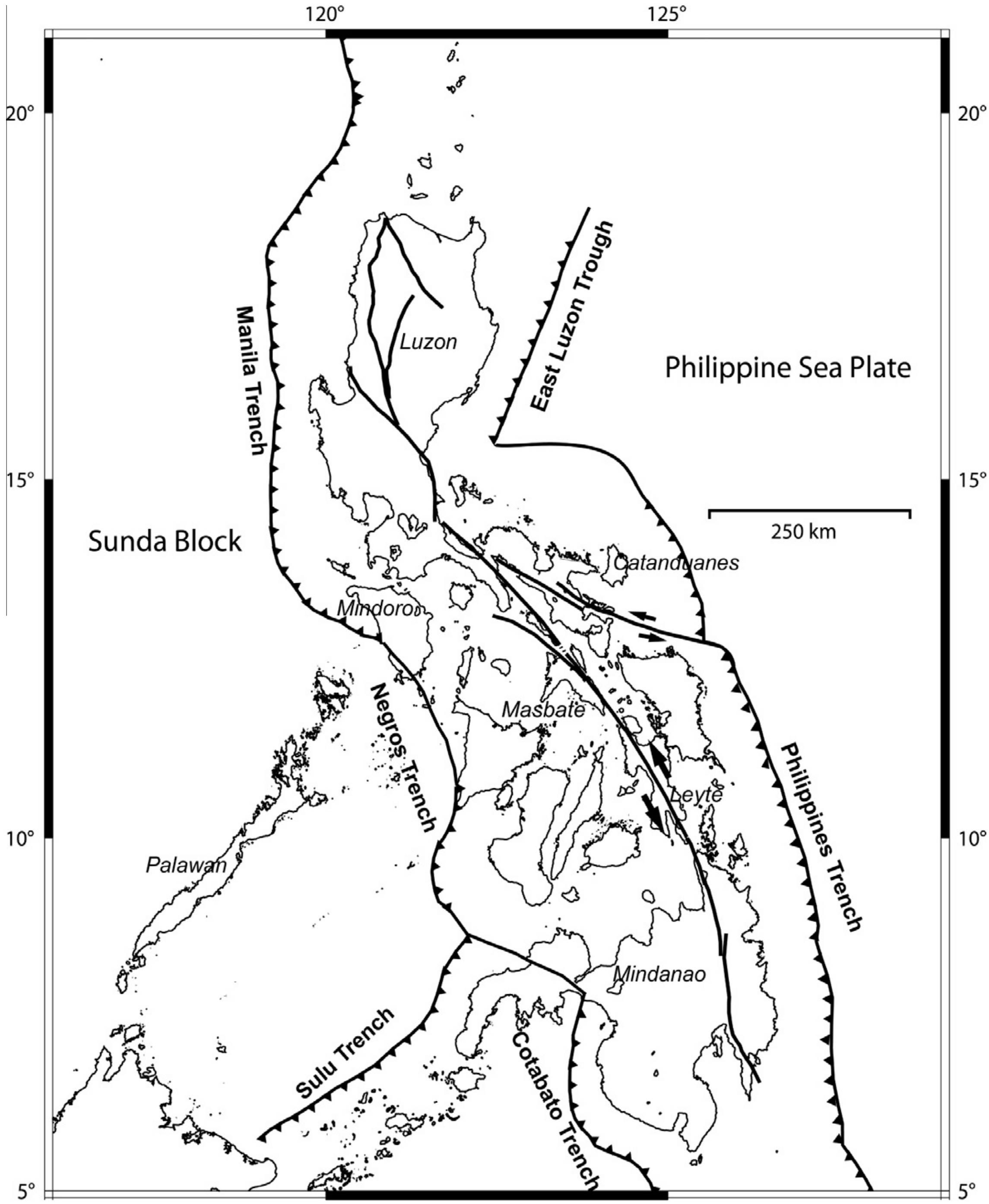

Fig. 1. Tectonic setting in the Philippines. The black barbed lines denote the major trenches. The Philippine Fault (solid line in the middle) transects the Philippine archipelago from the northwest corner of Luzon to the southeast end of Mindanao for about 1200 km.

segmentation, fault slip rates, seismicity, and earthquake recurrence intervals, are poorly understood.

The first quantitative measurement along the Philippine Fault was in Mindanao Island wherein a left-lateral displacement of about 28 km was found (Gervacio, 1971). Since then, studies on the motion of the Philippine Fault have been proposed using various approaches (Acharya, 1980; Karig, 1983; Hirano et al., 1986; Pinet, 1990; Barrier et al., 1991; Aurelio, 1992; Duquesnoy et al., 1994; Galgana et al., 2007). Based on GPS measurements, Duquesnoy et al. (1994) infer the slip rate of 26 ± 0.1 mm/yr on the creeping section of the Philippine Fault near the Leyte Island, consistent with slip rates of 23 and 36 mm/yr found in Masbate and Leyte (Fig. 1), respectively (Bacolcol, 2003; Bacolcol et al., 2005). On the other hand, the slip rate of the Philippine Fault is about 17–31 mm/yr in the Luzon area (Yu et al., 1999). Geological and paleo-seismological investigations indicate that the slip rate on the Philippine Fault near central Luzon is generally between 9 and 17 mm/yr (Daligdig, 1997), which is lower than the value computed from GPS data. This discrepancy will be discussed in Section 5.

The area of interest in this study is the segment of Philippine Fault in the Luzon Island, north of the Philippine archipelago. Luzon is part of the N–S trending Luzon arc, a 1200 km chain of