Tectonophysics 608 (2013) 904–913

Contents lists available at ScienceDirect

Tectonophysics

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

An episodic creep-slip event detected by precise levelling surveys in the central part of the Longitudinal Valley Fault, eastern Taiwan, in 2011–2012

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ARTICLE INFO

Article history:
Received 14 March 2013
Received in revised form 8 July 2013
Accepted 20 July 2013
Available online 31 July 2013

Keywords:
Taiwan
Longitudinal Valley Fault
Precise levelling survey
Fault creep
Episodic creep-slip event

ABSTRACT

Precise levelling surveys were conducted across the central Longitudinal Valley Fault, eastern Taiwan, to understand the deformation of the transition zone between the stable fault creep area and the asperity area. In order to investigate the surface relationship between the fault creep area and the geological condition of the transition zone, we established levelling routes in the Yuli, Chike-san, and Reishuei areas. The Yuli area forms the geological boundary of the Lichi Melange Formation, which is composed of chaotic mudstones containing numerous exotic blocks of various sizes and lithologies. Along the Yuli route, located on the Lichi Melange, an uplift rate of 30 mm/yr was detected during the period 2010–2012, suggesting that aseismic fault creep might be continuing with long-term stability. Along the Chike-san route, a vertical deformation rate of 8 mm/yr was detected in the period 2010–2011. However, a large deformation with an uplift rate of 40 mm/yr was detected in the period 2011–2012. Along the Reisuei route, we detected a deformation of 8 mm/yr in the period 2011–2012.

A two-dimensional single-fault model was developed to discuss the slip distributions in the periods 2010–2011 and 2011–2012. Relatively large slip rates were estimated at two parts of the fault plane—one at a depth of ~1.5 km and another at a depth of ~4 km—in both periods. Because both parts of the fault plane show approximately the same slip distribution, we believe that the detected deformation resulted from an episodic acceleration event of creeping slip.

The northern limit of the stable creep area may be the Yuli area. The episodic creep event occurred in the transition zone between the stable fault creep area and the asperity area. The boundary between the stable creep area and the episodic creep area is consistent with the geological boundary of the Lichi Melange Formation.

1. Introduction

The Longitudinal Valley Fault (LVF) of eastern Taiwan is a plate boundary fault on land. Historically, several M6-class earthquakes have occurred in the northern part of the LVF (e.g., Hsu, 1962; Shyu et al., 2005, 2007), and it was considered to be an asperity area. Several studies have proposed that stable aseismic creep occurs in the southern part of the LVF (e.g., Lee et al., 2003; Yu and Kuo, 2001; Yu et al., 1997). Although fault creep in the southern part of the LVF has been widely researched using deformation data, deformation in the central part of the LVF has not been studied extensively. The central LVF is located in the transition zone between a stable creep area and an asperity area, and hence, there is an urgent need to determine the detailed deformation in the central LVF.

An asperity model was proposed by Lay and Kanamori (1981), Lay and Kanamori (1980) to explain the generating mechanism of interplate earthquakes, which often strike regions located along plate boundaries and cause large seismic disasters. An asperity is a locked area existing during the interseismic period that exhibits large slip when an earthquake occurs. The area surrounding an asperity is a slow-slip area, whereas other more distant regions are considered to be creep areas. The study of the repeated slow-slip and creep events is important for understanding the strain accumulation process at an asperity because strain is transmitted intermittently to the asperity by the repeated slow-slip and creep events.

A precise levelling survey along the surface fault of the LVF can provide detailed information about the deformation caused by fault creep. It is much easier to conduct geomorphological and geological studies of the LVF than it would be to study a submarine fault. The relationship between the distribution of creep and the geological conditions is an important consideration that can be investigated by studying the LVF.

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0040-1951/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.tecto.2013.07.027

Thus, we established levelling routes in and around the northern limit of Lichi Melange distribution in central LVF, as detailed in the next section, to detect deformations. Our survey revealed an episodic acceleration of deformation in the transition zone between the stable fault creep area and the asperity area in the period 2011–2012. Understanding the fault activity of the transition zone will help obtain useful information for assessing the seismic hazard of the LVF.

2. Geological background and geodetic results

We here briefly outline previous geological studies, geodetic studies, and recent activity of the LVF. The LVF, a major eastward-dipping reverse fault in eastern Taiwan, is commonly considered to be the collision boundary between the Eurasian plate and the Philippine Sea plate (Biq, 1973; Bowin et al., 1978; Chai, 1972; Ho, 1986; Teng, 1996). The LVF is located within a narrow 150-km-long valley sandwiched between the Central Range consisting of metamorphic rocks and the Coastal Range consisting of island arc rocks(e.g., Chen, 1988; Ho, 1988) (Fig. 1).

The island arc rocks of the Coastal Range consist of an upper Miocene arc basement with patchy occurrences of limestone at its top, which is overlain by a thick Plio-Pleistocene turbidite sequence with volcanic rocks. In the southwestern part of the Coastal Range, a thin slice of tectonic melange called the Lichi Melange, is exposed along the LVF (Fig. 1). The Lichi Melange Formation is composed of chaotic mudstones that contain numerous exotic blocks of various sizes and lithologies. Some geologists have interpreted that the Lichi Melange formed along the Manila trench by subduction of South China Sea oceanic crust (e.g., Chen, 1997), but others have suggested that it formed by arc–continent collision (Chang et al., 2000). In either case, the Lichi Melange Formation consists of chaotic mudstones with exotic blocks, which include ophiolitic rocks, a few andesites, and various types of sedimentary clasts, and is cut by abundant penetrative shearing (Chang et al., 2000). The stratigraphic relationship between the Lichi Melange Formation and other rock units is not clear. A 1:100,000 geological map (Wang and Chen, 1993) shows most of the details of the boundary between the Lichi Melange Formation and other units in the Yuli area. The northern end of the exposed Lichi Melange (Fig. 1) is located to the north of Yuli and to the south of Chike-san (Wang and Chen, 1993).

Recent large events along the LVF include the appearance of several surface ruptures extending from the southern part of Guangfu to the southern part of Chishang during the 1951 LVF earthquakes (Hsu, 1962; Shyu et al., 2005, 2007). Based on a palaeoseismological trench survey, the recurrence interval of an M7-class earthquake was estimated to be about 150–210 years in the northern part of the LVF (Chen et al., 2007; Yen et al., 2008).

Recent geodetic measurements, including GPS, levelling, and InSAR, show that the deformation pattern in the central and southern parts of the LVF clearly differs from that in the northern part of the LVF (Champenois, 2012; Chen et al., 2007; Peyret et al., 2011). In the northern part of the LVF, the horizontal deformation rate in a direction orthogonal to the LVF decreases gradually from the east coast to the LVF. In contrast, the horizontal deformation rate decreases rapidly close to the surface fault in the southern parts of the LVF (Yu et al., 1997). The rapid change of deformation rate close to the surface fault without remarkable earthquakes strongly suggests that the southern parts of the LVF are creeping aseismically. In addition to the above results, a creep meter installed at Chichang (southern part of the LVF) detected significant shortening without remarkable earthquakes in this area (Lee et al., 2003), and the results of the repetitive levelling survey strongly suggest that fault creep is continuing with constant rate in the southern part of

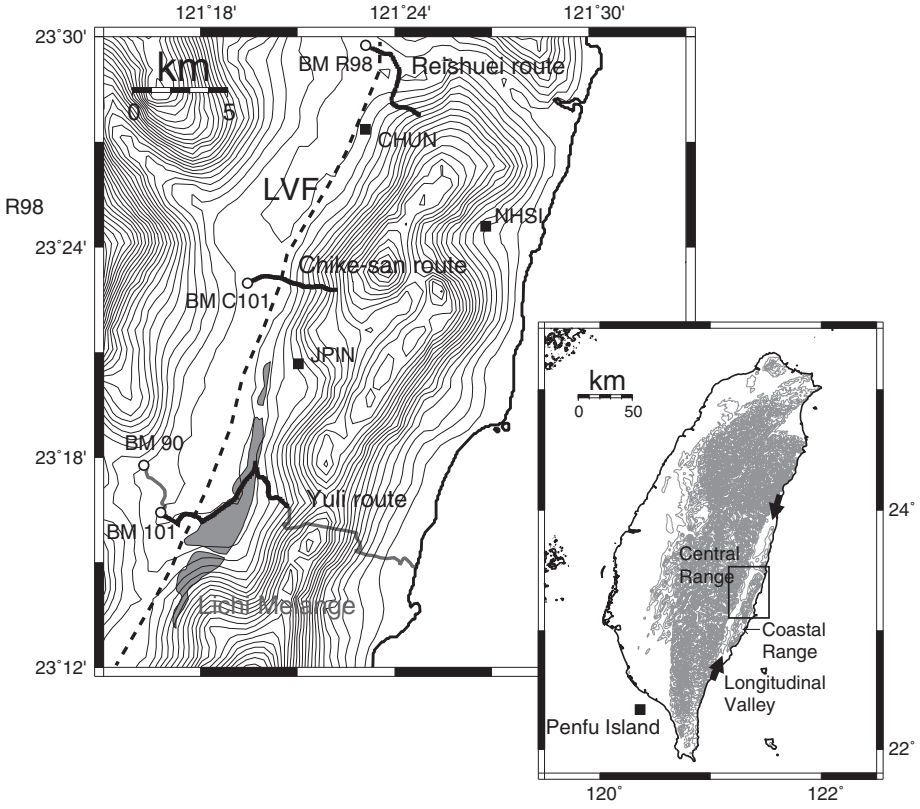

Fig. 1. A location map of the central part of the Longitudinal Valley Fault (LVF) showing the Reishuei, Chike-san, and Yuli levelling routes. The black lines denote the Reishuei, Chike-san, and a part of the Yuli levelling routes. All benchmarks along the black lines as well as the grey line of the Yuli route were observed in 2008, 2009, 2010, and 2012. In 2011, only the central part of Yuli route (black line) was observed. The dashed line denotes the LVF. The grey-coloured areas denote the distribution of the Lichi Melange (Chang et al., 2001). The three solid squares denote continuous GPS stations installed by the Institute of Earth Science, Academia Sinica. (Inset) Location of the Longitudinal Valley in Taiwan. The Longitudinal Valley, marked by the two arrows, is a narrow valley located between the Central Mountain Range and the Coastal Mountain Range. A solid square denotes the reference GPS station at Penfu Island. The rectangle shows the area shown in the location map.