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Seismotectonic characteristics of the northernmost Longitudinal Valley, eastern Taiwan: Structural development of a vanishing suture

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ABSTRACT

The Longitudinal Valley in eastern Taiwan is generally considered as the suture of the collision between the Philippine Sea and the Eurasian plates, and has attracted numerous geologic and seismologic studies. In the northernmost part of the valley, however, constraints on how structures develop as the suture turns into the Ryukyu subduction system offshore are still very limited. Therefore, we analyzed relocated seismicity distributions and focal mechanisms of earthquake sequences, together with tectonic geomorphic investigations to further understand the seismotectonic characteristics of this area. In our seismologic observations, we found two previously unidentified reverse faults in the northernmost part of the Longitudinal Valley suture. One is an E–W striking, south-dipping reverse fault near the Liwu River fan delta, and the other is a N–S striking, east-dipping reverse fault near the eastern Central Range front. Both these structures connect with a detachment at ~10 km deep, and may connect with each other to form a curved structural system. The Meilun fault, a well-known active structure that ruptured in a M7.3 earthquake in October 1951, is not seismically active in the past two decades, and may just be part of a secondary branch of the major structural system. In the northernmost part of the Longitudinal Valley suture, we propose that as the Coastal Range bedrocks subduct northward beneath the Eurasian plate with the Philippine Sea plate, the shallow sediments of the Longitudinal Valley, being a buoyant block, do not subduct, but overthrust northward and westward instead.

1. Introduction

The island of Taiwan is located at the collisional boundary between the Philippine Sea and the Eurasian plates (e.g., Teng 1987, 1990; Shyu et al. 2005a, and references therein; Fig. 1). In eastern Taiwan, the Longitudinal Valley between the Central Range and the Coastal Range is generally considered as the suture of the collision (e.g., York 1976; Teng 1990; Lee et al. 1998, 2001; Shyu et al. 2005b, 2008, 2011). The Ryukyu subduction system, on the other hand, extends southwestward from offshore eastern Taiwan, and intersects with the northernmost Longitudinal Valley suture. As a result, the area of the northernmost Longitudinal Valley is characterized by frequent earthquakes and complex geologic structures (e.g., Bonilla 1975, 1977; Shyu et al. 2005b).

At the northern end of the Longitudinal Valley suture, a small uplifted tableland, the Meilun Tableland, is present (Fig. 2). This distinctive topographic feature is bounded in its west by the Meilun fault, a well-known active fault in eastern Taiwan (e.g., Central Geological Survey 2010). Rupture of this fault produced a M7.3 earthquake in October 1951 (Hsu 1955, 1962). However, due to the relatively short (~100 years) written history of eastern Taiwan, no other fault is known to have ruptured historically in the northernmost Longitudinal Valley. Furthermore, there is very little information about tectonic geomorphic features other than the Meilun Tableland. As a result, how the Longitudinal Valley suture terminates to the north and how it relates with the Ryukyu subduction system remain poorly understood.

In order to further understand this structural transition area, we analyzed the seismologic characteristics of the northernmost Longitudinal Valley with new earthquake data. We then combined the seismologic observations with detailed tectonic geomorphic investigations to identify the general seismotectonic characteristics of this area. Such information enabled us to propose a model for the structural evolution of the vanishing suture at the northernmost Longitudinal Valley.

2. Geologic settings of the northernmost Longitudinal Valley

Taiwan, located at the convergent plate boundary between the Philippine Sea plate and the Eurasian plate, is the product of the ongoing collision between the Eurasian continental margin and the Luzon volcanic island arc, part of the Philippine Sea plate (e.g., Teng 1987, 1990; Shyu et al. 2005a, and references therein). The Coastal Range in eastern Taiwan is the collided and attached part of the Luzon volcanic arc. West of the range is the Longitudinal Valley, a linear valley that is generally considered as the suture between the continental basement and the

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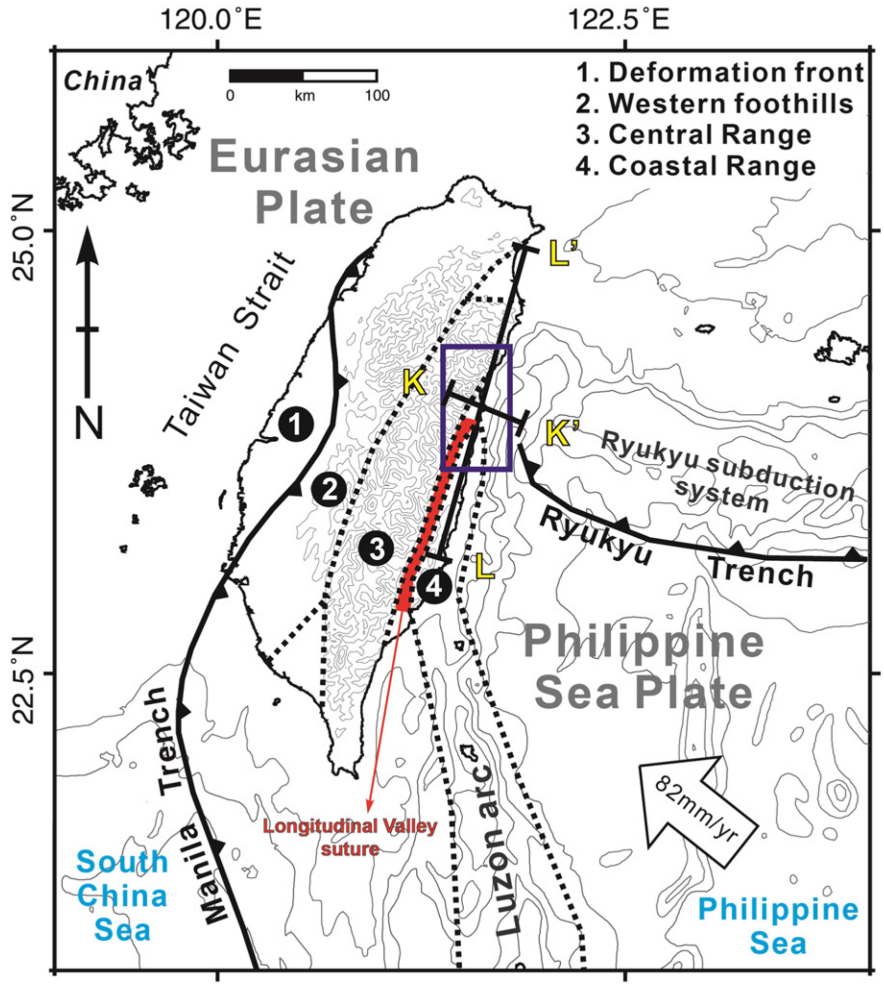

Fig. 1. Tectonic settings of Taiwan and surrounding areas, modified from Shyu et al. (2005a). The dark blue box is the study area. Solid black lines are major structures of Taiwan, and dashed black lines are boundaries of tectonic geomorphic units. The Longitudinal Valley suture is shown in red. K-K′ and L-L′ are two long seismicity profiles shown in Figs. 5 and 7. The short lines perpendicular to the profile traces represent the projection width of each profile.

collided volcanic arc (e.g., York 1976; Teng 1990; Lee et al. 1998, 2001; Shyu et al. 2005b, 2008, 2011; Fig. 1).

As an active collisional plate boundary, the Coastal Range and the Longitudinal Valley is characterized by high rates of deformation and uplift. For example, many lines of evidence suggest that almost the entire Coastal Range is undergoing rapid uplift. These include the results of recent geodetic measurements (e.g., Ching et al. 2011), the presence of widespread river terraces (e.g., Shyu et al. 2006a), and the existence of multiple steps of marine terraces along the coast east of the Coastal Range (e.g., Liew et al. 1990; Hsieh et al. 2004; Yamaguchi and Ota 2004). The deformation and uplift of the range is likely produced by activities of the Longitudinal Valley fault, which is one of the most active structures of Taiwan and crops out along the western edge of the Coastal Range (e.g., Angelier et al. 1997; Shyu et al. 2005b, 2006a, 2007). Holocene slip rate of the fault can be as high as more than 20 mm/year (e.g., Shyu et al. 2006a; Champenois et al. 2012).

The Coastal Range does not extend to the northern end of the Longitudinal Valley, however. Instead, the northernmost part of the valley is bounded in its east by the Meilun Tableland, an uplifted fluvial/marine terrace with the highest point at ~100 m above sea level (Fig. 2). It is generally believed that the uplift of the tableland is due to the activity of the Meilun fault, which crops out along the western edge of the tableland and ruptured in October 1951 (e.g., Hsu 1962). This M7.3 event is the only historical earthquake involving surface ruptures in this area. According to historical documents, co-seismic vertical offsets across the rupture were up to ~1.2 m, and left-lateral offsets were up to ~2 m (e.g., Hsu 1955; Bonilla 1975, 1977). Recent geodetic observations, nonetheless, show that no significant strain is accumulating across the fault (e.g., Yen et al. 2011; Chen et al. 2014).

3. Methods

In this study, we analyzed the distribution of relocated earthquake data to identify the structural patterns of the northernmost Longitudinal Valley. We then combined focal mechanisms of different earthquake sequences occurred in the area to further understand the types of structures identified. Our data source is the earthquake catalogue collected by the Central Weather Bureau Seismic Network (CWBSN; Shin 1992, 1993) of Taiwan from January 1991 to December 2010. Considering the relatively sparse station coverage in eastern Taiwan, we used all events that have arrivals recorded by more than four stations. In total, 56,281 events were selected.

We adapted the 3-D location with station correction (3DCOR; Wu et al. 2003, 2008a) as the method to relocate the earthquakes. This method uses the 3-D velocity model of Taiwan (Wu, Y.-M. et al., 2007, 2009). Other than CWBSN, data from Taiwan Strong-Motion Instrumentation Program (TSMIP) stations, Taiwan Integrated Geodynamics Research (TAIGER) stations, and Japan Meteorological Agency (JMA) stations are also utilized in the earthquake relocation processes in order to improve the station coverage (Fig. 3).