Tectonophysics 679 (2016) 235–245

Contents lists available at ScienceDirect

Tectonophysics

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

The deep structure of south-central Taiwan illuminated by seismic tomography and earthquake hypocenter data

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ARTICLE INFO

Article history:
Received 15 January 2015
Received in revised form 11 June 2015
Accepted 20 September 2015
Available online 30 September 2015

Keywords:
Basement-cover interface
Detachment
Basement involvement
Structural inheritance
Taiwan
Earthquake seismicity

ABSTRACT

The Taiwan mountain belt is generally thought to develop above a through-going basal thrust confined to within the sedimentary cover of the Eurasian continental margin. Surface geology, magnetotelluric, earthquake hypocenter, and seismic tomography data suggest, however, that crustal levels below this basal thrust are also currently being involved in the deformation. Here, we combine seismic tomography and earthquake hypocenter data to investigate the deformation that is taking place at depth beneath south-central Taiwan. In this paper, we define the basement as any pre-Eocene rifting rocks, and use a P-wave velocity of 5.2 km/s as a reference for the interface between these rocks and their sedimentary cover. We found that beneath the Coastal Plain and the Western Foothills clustering of hypocenters near the basement-cover interface suggests that this interface is acting as a detachment. This detachment is located below the basal thrust proposed from surface geology for this part of the mountain belt. Inherited basement faults appear to determine the geometry of this detachment, and their inversion in the Alishan area result in the development of a basement uplift and a lateral structure in the thrust system above them. However, across the Shuilikeng and the Chaochou faults, earthquake hypocenters define steeply dipping clusters that extend to greater than 20 km depth, above which higher velocity basement rocks are uplifted beneath the Hsuehshan and Central ranges. We interpret these clusters to form a deeply penetrating, east-dipping ramp that joins westward with the detachment at the basement-cover interface. It is not possible to define a basal thrust to the east, beneath the Central Range.

1. Introduction

The Taiwan mountain belt has been forming since the Late Miocene as a result of the oblique collision between the southeast continental margin of Eurasia and the Luzon volcanic arc on the Philippine Sea Plate (Byrne et al., 2011; Huang et al., 2006; Lin et al., 2003; Mesalles et al., 2014; Sibuet and Hsu, 2004; Suppe, 1981, 1984; Teng, 1990) (Fig. 1). Studies of the structure of the western flank of the Taiwan mountain belt have led many authors to suggest that it is evolving by thrusting above a shallowly east-dipping basal thrust that extends all the way eastward beneath the orogen (Carena et al., 2002; Ding et al., 2001; Malavieille and Trullenque, 2009; Suppe, 1980, 1981; Suppe and Namson, 1979; Yue et al., 2005). Although both along- and across-strike variations in the depth and stratigraphic location of the basal thrust have been proposed, it is generally thought to be confined to within the sedimentary cover of the margin, either at the base of the syn-orogenic sediments or within the older pre-orogenic platform and slope sediments (Brown et al., 2012; Suppe, 1976, 1980, 1981; Suppe and Namson, 1979; Yue et al., 2005).

There are, however, a number of pieces of evidence in the surface geology (Alvarez-Marron et al., 2014; Brown et al., 2012; Camanni et al., 2014a), as well as in magnetotelluric (Bertrand et al., 2009, 2012), GPS (Chuang et al., 2013), earthquake hypocenter (Gourley et al., 2007; Lacombe and Mouthereau, 2002; Lacombe et al., 2001; Mouthereau and Petit, 2003; Wu et al., 1997, 2004, 2008, 2014; Yue et al., 2005) and seismic tomography data (Alvarez-Marron et al., 2014; Camanni et al., 2014b; Huang et al., 2014; Kim et al., 2005, 2010; Kuo-Chen et al., 2012; Lin, 2007; Rau and Wu, 1995; Wu et al., 2007) which suggest that rocks below the interpreted basal thrust, and even the basement (here, according to Ho(1986, 1988), we define basement as any pre-Eocene rifting rocks, but it is often defined by others as any pre-Miocene rocks) may also be involved in the deformation in much of Taiwan. For example, combining surface geological and borehole data,

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http://dx.doi.org/10.1016/j.tecto.2015.09.016
0040-1951/

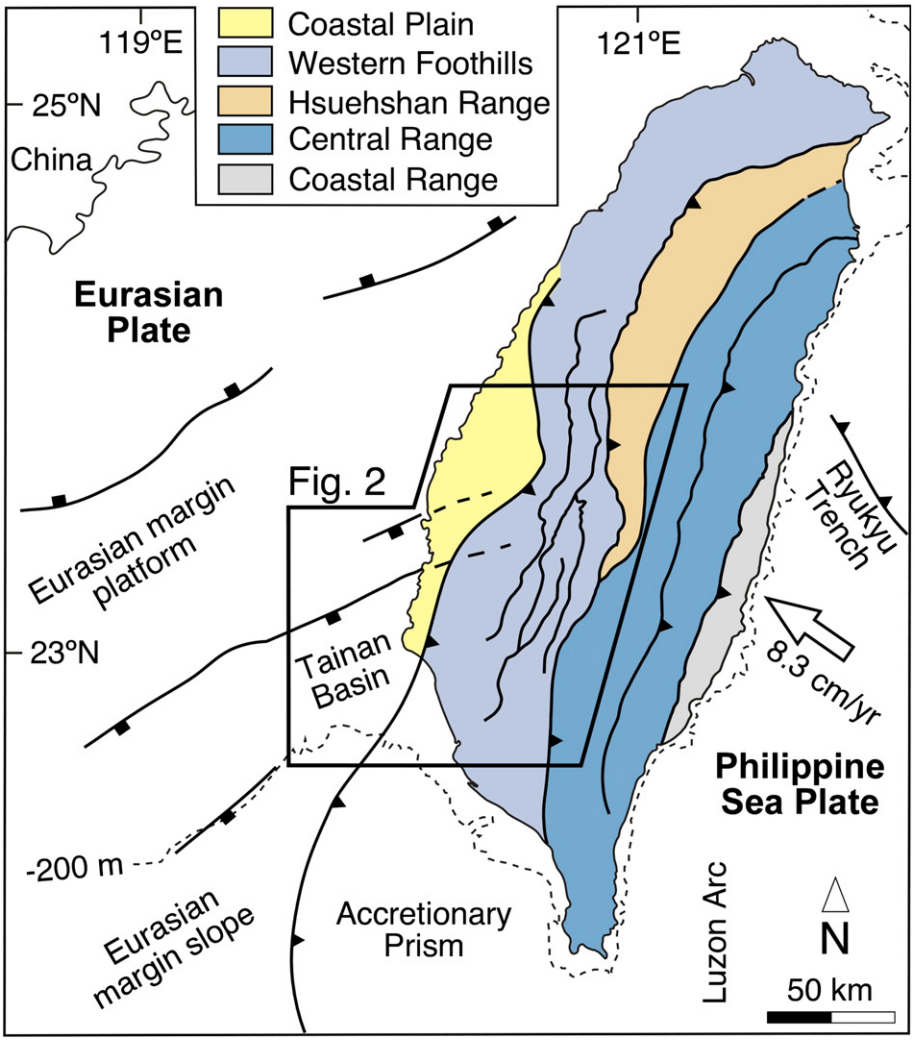

Fig. 1. Tectonic setting and major tectonostratigraphic zones of the Taiwan mountain belt. The −200 m isobath marks the current location of the shelf-slope break in the Eurasian margin. The structures on the Eurasian margin and the location of the deformation front offshore southwestern Taiwan are from Lin et al. (2008), Lin et al. (2003), Shyu et al. (2005), and Yeh et al. (2012). The location of Fig. 2 is shown.

Hickman et al. (2002) and Hung et al. (1999) interpret the basal thrust to cut down section to lie near the basement-cover interface. Similarly, seismic activity beneath the interpreted location of the basal thrust in west-central and southwestern Taiwan also led Mouthereau and Petit (2003) and Yue et al. (2005) to postulate the presence of a second, deeper detachment surface that lies either near the basement-cover interface or within the basement. Furthermore, on the basis of surface geological, borehole and seismicity data, Mouthereau et al. (2001, 2002), Lacombe and Mouthereau (2002), and Mouthereau and Lacombe (2006), interpret the basement (note that they call basement any pre-Miocene rocks) to be involved in the deformation along much of westernmost Taiwan. Eastward, Brown et al. (2012), Camanni et al. (2014a, b), and Chuang et al. (2013) use either surface geology, seismicity, or GPS data to interpret the basal thrust to ramp down into the middle crust and to involve basement in the deformation. These latter observations are further corroborated by the presence of high P-wave velocities (up to 5.5 km/s) close to the surface, suggesting that basement rocks are being uplifted (e.g., Alvarez-Marron et al., 2014; Camanni et al., 2014b; Huang et al., 2014; Kim et al., 2005, 2010; Kuo-Chen et al., 2012; Lin, 2007; Rau and Wu, 1995; Wu et al., 2007). Furthermore, in much of Taiwan Wu et al. (1997, 2004, 2014) and Gourley et al. (2007) have used earthquake hypocenter data to suggest that there are a number of steeply dipping faults that penetrate into the middle and perhaps even the lower crust.

These observations suggest that deformation that is taking place near the basement-cover interface and within the basement may be playing a more significant role in the structural development of the Taiwan orogeny than predicted by the model with a basal thrust confined to within the sedimentary cover. To help place further constraints on the structural architecture of the Taiwan mountain belt, in this paper we use a P-wave tomography model to define a proxy for the basement-cover interface in south-central Taiwan (Figs. 1 and 2). We then use earthquake hypocenter data to evaluate the location and the geometry of deep-seated faults that are contributing to the deformation that is taking place in this part of Taiwan.

2. Geological setting

The outcropping geology of the south-central part of the Taiwan mountain belt (Figs. 1 and 2) is made up of Eocene to Miocene sediments of the continental margin overlain by Pliocene to Holocene syn-orogenic sediments of the foreland basin (Brown et al., 2012; Hickman et al., 2002; Hung et al., 1999; Lacombe et al., 1999; Mouthereau et al., 2001; Rodriguez-Roa and Wiltschko, 2010; Yue et al., 2005). Basement