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Evidence for middle Triassic to Miocene dual subduction zones beneath the Shan–Thai terrane, western Thailand from magnetotelluric data

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ABSTRACT

Kanchanaburi province, western Thailand, is in the middle of Shan–Thai terrane. Paleomagnetic and geological data support the hypothesis of dual subduction zones beneath the Shan–Thai terrane. During the late Triassic there was a westward subduction in the east where the Lampang-Chiang Rai block subducted beneath the Shan–Thai terrane. In addition, in the early Tertiary, the western Burma terrane subducted underneath the Shan–Thai in the west resulting in an eastward subduction. A pioneer survey of this region was therefore conducted using magnetotelluric (MT) techniques with the aim of finding deep structures associated with these ancient subduction zones. 39 MT stations were deployed to cover most of the province. Resistivity structures are obtained from the 3-D inversion. The near surface resistivity structures correspond well with the surface geology. The mid and lower crusts are conductive and this is interpreted as the crusts being composed of mafic granulites of 3% porosity in which the remnant dehydrated fluid was accumulated during the subduction. In addition, the westward and eastward subduction zones generated mafic/ultramafic intrusions which appear as two conductive zones on the east and west, respectively. These two conductors and the conductive lower crust support the hypotheses of the middle Triassic to Miocene dual subduction zones.

1. Introduction

The tectonics of Thailand is complicated and very intriguing. Thailand is located on the southernmost of the Eurasian plate and is enclosed by the Indian plate on the west and the Philippine plate on the east (Fig. 1). It currently consists of two major terranes or micro-plates (Bunopas, 1981; Bunopas and Vella, 1983; Charusiri et al., 2002; Ferrari et al., 2008; Metcalfe, 2011). The east and northeast of Thailand is part of the Indochina terrane. On the west of Thailand and eastern Myanmar is the Shan–Thai terrane which is shown in Fig. 1. Note that the Shan–Thai is sometimes also called the Sinobuma terrane (e.g., Hisada et al., 2004; Hirsch et al., 2006; Ferrari et al., 2008, among many others). Others (e.g. Metcalfe, 2011) regard the Sinobuma terrane as a larger region which includes the Shan–Thai terrane. Both terranes originate from Gondwana. Many publications (e.g., Bunopas, 1981; Barr and Mac Donalds, 1987; Hada et al., 1991) have proposed that the Nan suture zone divides the two terranes (Fig. 1). However, Ueno and Hisada (2001) proposed instead that the Nan suture zone is the remnant of a closed back-arc basin. Metcalfe (2011) suggested that the smaller Sukhothai terrane and Chantaburi terrane divided these two main terranes.

The tectonic evolution of Thailand is still not completely understood after the original scheme proposed by Bunopas (1981). Since then, many further studies resulting in other proposed schemes have been carried out (see e.g., Lee and Lawver, 1995; Charusiri et al., 2002; Metcalfe, 2002; Morley, 2002; Hirsch et al., 2006; Ferrari et al., 2008; Metcalfe, 2011; among many others). It is also difficult to judge which theory is the most suitable and beyond the scope of this paper. In this paper, we closely follow Thailand tectonic evolution scheme developed by Charusiri et al. (2002). They divided the tectonic evolution of Thailand into four main stages: (1) Precambrian to early Cambrian, (2) Cambrian to early Triassic, (3) middle Triassic to Miocene, and (4) early Tertiary to present. Selected schematic diagrams for each stage are re-plotted from Charusiri et al. (2002) in Fig. 2.

From Precambrian to Cambrian (Fig. 2a), Shan–Thai terrane was in Gondwana and was close to what is now northwestern Australia. Indochina was part of the Pan-Cathaysia continent which is adjacent to what is now northern and northeastern Australia. Since then both Shan–Thai and Indochina had gone through many tectonic developments (Bunopas, 1981; Charusiri et al., 2002). During the Cambrian to Permian, many events occurred in the Paleotethys between the Shan–Thai and Indochina terranes. These include the rifts that separated the Shan–Thai from Gondwana and the development of two small tectonic blocks: the subducted Nakorn Thai oceanic crust beneath the

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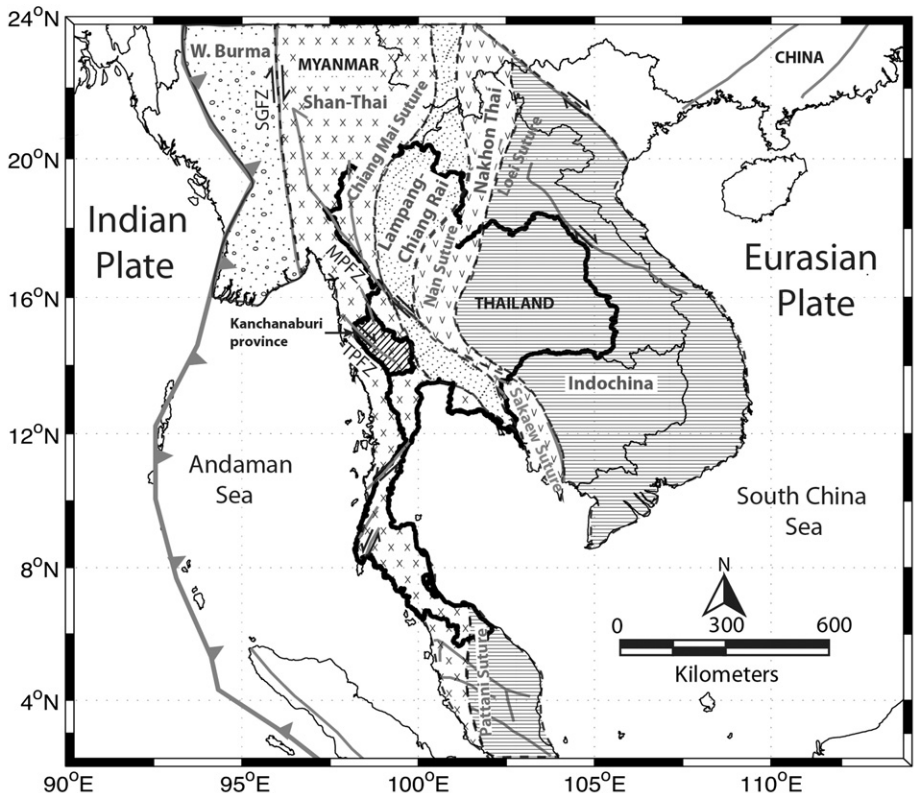

Fig. 1. Map showing tectonics of Thailand. Hatched zone: Shan–Thai terrane; parallel lines: Indochina terrane. The major fault zones in the areas are the Sagaing Fault Zone (SGFZ), the Mae Ping Fault Zone (MPFZ), and the Three Pagoda Fault Zone (TPFZ). The study area in Kanchanaburi province is marked at the center. (Redrawn from Charusiri et al., 2002).

Indochina terrane on the east and the volcanic arc Lampang-Chiang Rai to the west (Fig. 2b).

The two most important events related to this paper occurred during the Triassic to Cretaceous (Fig. 2c). First, the Lampang-Chiang Rai block subducted beneath the Shan–Thai terrane resulting in the westward subduction in the Triassic (Chaodumrong and Burrett, 1997). This also marked the end of the Paleotethys. The other event is the eastward subduction of Mesotethys under the Shan–Thai during the Jurassic-Cretaceous. In the early Tertiary, West Burma subducted beneath Shan–Thai ending the Mesotethys (Metcalfe, 1996). This is similar to the dual larger scale subduction of the Pacific and Indo-Australian plates.

In the early Tertiary to present (Fig. 2d), the Indian plate collided with the Eurasian plate terminating the Neotethys in Middle Tertiary. The interaction of the two major plates alternated and rotated the tectonic motion (Achache et al., 1983) causing the faults to move in opposite directions (Rhodes et al., 2005). The extension from the rift caused the pulling apart of basins and the opening of the Gulf of Thailand and Andaman Sea (Tapponnier et al., 1982). During this stage, the tectonics is still evolving as indicated by the occurrence of hot springs and earthquakes in the region.

The idea of tectonic evolution was proposed by Bunopas (1981) and later modified to fit with more evidence by Charusiri et al. (2002) as shown in Fig. 2. Most of the evidence was from paleomagnetic studies (Morley, 2002; Aihara et al., 2007), palaeontological studies (Metcalfe, 2002; Ishida et al., 2006), and surface geology (Chaodumrong and Burrett, 1997; Rhodes et al., 2005; Srithai, 2005; Ridd, 2009). However, there is no evidence of deep structures to support this tectonics evolution. This is due to the lack of "deep" geophysical studies in Thailand.

To understand the tectonic evolution of the region, it is necessary to locate and identify deep geophysical structures. Magnetotelluric (MT) method has been used in many parts of the world to study the deep structures (e.g., Jones, 1992; Ogawa et al., 1994, 1996; Unsworth et al., 2000; Ogawa, 2002; Patro et al., 2005; Uyeshima, 2007; Patro and Egbert, 2010; Unsworth, 2010; among many examples). We therefore conducted the first deep crustal study project in Thailand by using a MT study in Kanchanaburi province, western Thailand, about 180 km from the capital Bangkok. The province is about 100 km wide and 200 km long oriented in northwest-southeast direction (Figs. 1 and 3). It is almost in the middle of the Shan–Thai terrane (Fig. 1) where the tectonic evolution of the northern part and the southern part from the late Triassic appears to differ (Fig. 2). It is therefore a favorable location to study the ancient collisions where the subduction zones occurred on both sides.

MT methods have been used to identify the subduction zones (e.g., Wannamaker, 1989; Ogawa et al., 1994; Wannamaker et al., 2009; Patro and Egbert, 2010; Unsworth, 2010), fluid content and thermal structure of the crustal and upper mantle structure (e.g., Stanley et al., 1990; Naganjaneyulu and Santosh, 2010; Unsworth, 2010; Bertrand et al., 2012), and many geothermal studies (e.g., Newman et al., 2008; Arnason et al., 2010). Fluid and/or partial melt play significant roles in subduction processes. A study of two active continent-continent collisions by Unsworth (2010) showed a low resistivity structure at the mid-crustal depth of around 10–20 km. Similarly, numerous publications have shown that there are low resistivity regions in mid to lower crust where there is subduction (Wannamaker, 1989; Ogawa et al., 2001; Ogawa and Honkura, 2004; Wannamaker et al., 2009; Campanya et al., 2011; Worzewski et al., 2011). These low resistivities result from a combination of a partial melt and the associated aqueous fluid (Unsworth, 2010; Campanya et al., 2011). If the westward and eastward subduction zones beneath Shan–Thai terrane really existed during the middle Triassic to Miocene, there should be some lower resistivities at the mid crustal depth. One of our aims is therefore to use the MT studies to search for the deep low resistivity evidence for the proposed tectonic evolution of the region.