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Original Article

Geothermal and seismic evidence for a southeastern continuation of the three pagodas fault zone into the Gulf of Thailand

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Abstract

Aerial photographic maps and landsat image interpretations suggest the major fault segments of the Three Pagoda Fault (TPF) Zone and Sri Swat Fault (SSF) Zone are oriented parallel or sub-parallel in the same NW-SE directions. The Kwae Noi River is running along the TPF in the south whereas the Kwae Yai River is running along the SSF in the north. The southeastern continuation of both faults is obscured by thick Cenozoic sediments. Hence, surface lineaments cannot be traced with confidence. However, based on some interpretations of the airborne magnetic survey data, the trace of such faults are designated to run through the western part of Bangkok and the northern end of the Gulf of Thailand. Paleo-earthquakes and the presence of hot springs along the fault zones indicate that they are tectonically active. The changes of both physical and chemical properties of the water from Hin Dart Hot Spring and those of the surface water from a shallow well at Ban Khao Lao during the Great Sumatra–Andaman Earthquake on 26th of December 2004 clearly indicated that the southeastern continuation of the TPF is at least as far south as Pak Tho District, Ratburi. Our new evidence of the alignment of the high heat flow in the upper part of the Gulf of Thailand verified that the TPF also extend into the Gulf via Samut Songkhram Province. Studies of the seismic data from two survey lines along the Western part of the upper Gulf of Thailand acquired by Britoil Plc. in 1986, namely Line A which is approximately 60 km long, starting from Bang Khen passing through Bang Khae and ending in Samut Songkhram and Line B is approximately 30 km long starting from Samut Sakon ending in Samut Song Khram suggest that all the faults or fractures along these seismic profiles are covered by sediments of approximately 230 m thick which explain that the fault underneath these seismic lines is quite old and may not be active. The absent of sign or trace of the TPF Path to the west suggested that there is no segment of such fault along these seismic lines.

Keywords: three pagodas fault, Sri Sawat Fault, Gulf of Thailand, hot springs, seismic studies

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1. Introduction

During the Great Sumatra Andaman Earthquake on 26th of December 2004, there were a number of unrecorded reports on the observations of the changes of both physical and chemical properties of the water from many hot springs and one shallow well, with a depth of approximately five meters and a water level in the well of 2 meters, located along the TPF alignment. In the northwestern part of the TPF, water at the Hin Dart Hot Spring, Thong Phaphoom District, Kanchanaburi Province, had turned milky and its temperature was observed to be elevated significantly at around 8 a.m. on that morning. In the case of the southwestern part of the TPF at Ban Khao Lao, Tambon Wung Manao, Pak Tho District, Ratchaburi Province, water from the above mentioned shallow well was observed to be elevated to 48°C on 28th of December. The water temperature was then measured by the well owner who found that the water temperature dropped 2°C per day and it took 10 days to bring the water temperature back to room temperature which at that time was 28°C. It was a pity that the owner did not use water from that well prior to 28th of December, therefore we do not know when the water temperature started to rise.

Since that great earthquake in 2004 followed by the terrible tsunamis that destroyed a huge number of lives and properties, geoscientists have paid more attention to the study and understanding of the nature of the regional active faults and their potential threats. The TPF of the west and central Thailand (Figure 1) and its tectonic evolution have received great interests from both academic and public sectors. The main reason for trying to understand the mechanism of the faults is that there are some large dams constructed on segments of the fault zone. It is uncertain whether the southeastern continuation of the TPF runs through the highly populated area of Bangkok and the adjacent areas, which are covered by thick sequences of young unconsolidated sediments. Geology and the Cenozoic tectonic evolution of Southeast Asia have been studied and described by many researchers, such as Workman (1975), Bunopas (1981), Nutalaya *et al.* (1985), Fenton *et al.* (1997) and Chaodumrong and Chaimanee (2002). Additional studies of the area have focused on its petroleum potential (Pigott and Sattayarak, 1993; Polachan and Racey, 1993; Jadine, 1997; Morley *et al.*, 2007; Shoup, 2008).

A number of the studies extend the southeastern continuation of the TPF or its parallel segment through Bangkok or close to the center part of it (Hada *et al.*, 1997; Tulyatid and Fairhead, 1999). Based on geophysical data interpretation of magnetic and regional gravity, a sub-surface lineament was suggested as the fault path for the Three Pagodas

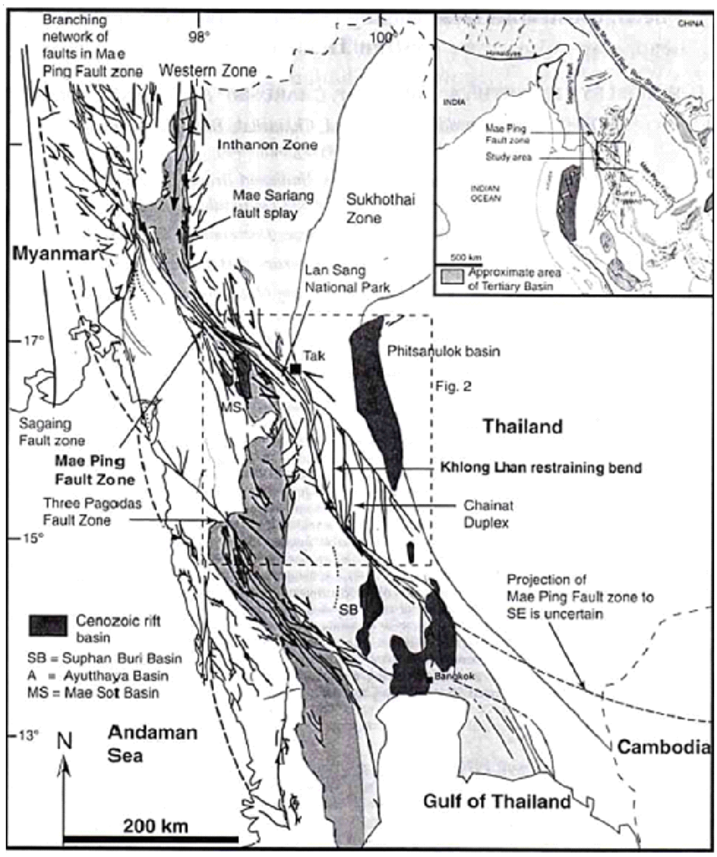

Figure 1. Three Pagodas strike-slip fault zone (TPFZ) of the west and central Thailand in relation to the regional tectonic setting, after Morley *et al.* (2007).

(Tulyatid and Charusiri, 1999; Tulyatid and Fairhead, 1999). In this paper, we present evidences for an alternative, more probable, southeastern continuation of this Three Pagodas Fault Zone.

2. Methodology

The available geological data including, NOAA satellite images, aerial photographs, topographic maps, locations distribution of hot springs, and heat flow information, as well as older seismic data were re-examined. Geological field surveys were carried out in order to investigate in greater details the geomorphology of the lineament and the associated or nearby located hot springs.

2.1 Geological setting

Morphologically, Western Thailand includes high mountains, the Tenasserim range, along the Thai-Myanmar border in the west. Mountain slopes with colluvium and alluvial fan deposits, low hills and rolling land appear in the central region. The land with gentle slope and flat land overlaid by alluvium, flood plain and deltaic deposits along the eastern part of the study area in the lower central plain. In terms of geology, the area is composed of wide-ranging rock types; sedimentary, igneous, and metamorphic rocks, which range in age from inferred Pre-Cambrian to Quaternary. However, Paleozoic rocks are predominant, in particular, Ordovician, Silurian-Devonian and Permian clastic and carbonate rocks and Permo-Carboniferous glacio-marine facies of the Kang Krachan Formation or former Phuket Series. Structurally, the rock units show a preferred strike orientation in a northwest-southeast direction, parallel or sub-parallel to the SSF, along parts of the Kwae Yai River in the northern and the TPF along the Kwae Noi River in the southern part of the area (Figure 2). An updated active fault map of Thailand was prepared by the Active Fault Research Section of the Environmental Geology Division and published by the Department of Mineral Resources in 2007. There on the map no TPF extends to the Cenozoic Basin of Central Thailand (Department of Mineral Resources, 2007)

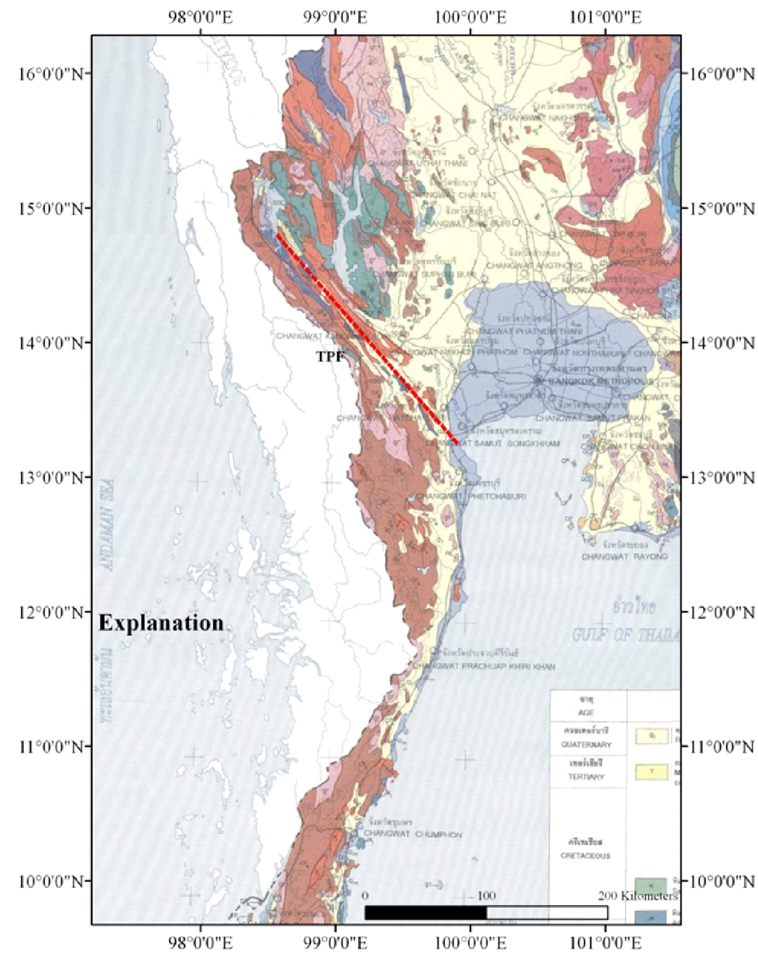

Figure 2. Geologic map of West and Central Thailand shows a preferred orientation in a northwest–southeast direction, parallel or sub-parallel to the regional strike-slip zone of the Three Pagodas Fault Zone (TPF) (modified from Geological Map of Thailand, Scale 1: 2,500,000, Department of Mineral Resources, 1999).

2.2 Heat flow data

Hot springs in the non-volcanic terrain like Thailand have long been known to be closely related to active fault zones (Takashima and Jarach, 1981; Thienprasert and Rank-saskulwong, 1984; Takashima *et al.*, 1989; Raksaskulwong, 2000; Raksaskulwong and Thienprasert, 1995). We have investigated the existing hot springs as well as a former hot spring along the Three Pagodas Fault Zone and the nearby Sri Sawat Fault Zone. Locations of these hot springs and former hot spring and five submarine high heat flow spots (100-200 mw/m^2) in the Gulf of Thailand were plotted on the map (Figure 3 and 4). The submarine high heat flow locations were obtained from the heat flow map of Southeast Asia, scale 1:5,000,000 (Geological Survey of Japan and Coordinating Committee for Coastal and Offshore Geoscience Programmes in East and Southeast Asia, 1997 or GSJ&CCOP, 1997).

2.3 Seismic data

Two seismic lines acquired along the western part of the upper Gulf of Thailand, by Britoil Plc. in 1986 were kindly provided by the Department of Mineral Fuels for profile re–interpretation: Line A, approximately 60 km long, from Bang Khen through Bang Khae to Samut Song Khram, and Line B, approximately 30 km long from Samut Sakon to Samut Song Khram (Figure 5). The seismic profiles of these two seismic lines are presented in Figure 6 and 7, respectively.

3. Results

Both heat flow and seismic data are carefully examined and interpreted. Highlights of the results are presented below.

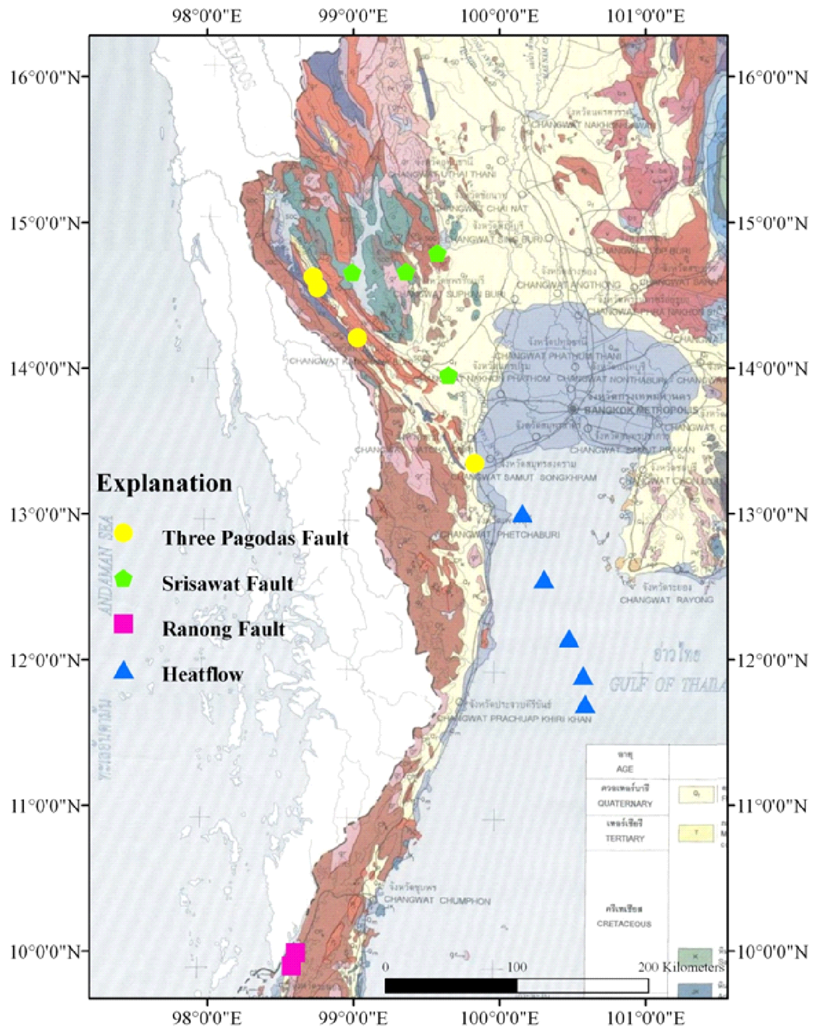

Figure 3. Map shows locations of the hot springs along the Three Pagodas Fault Zone (circles): Hin Dart (northwestern end), Lin Thin, Wang Krajae and one former-hot spring (southeastern end), Pak Tho and five submarine high heat flow spots (triangles); GT1, GT2, GT3, GT 4, and GT5 in the Gulf of Thailand (GSJ & CCOP, 1997). Pentagons are location of hot springs along segments of the Sri Sawat Fault Zone and Squares are Ranong Fault Zone.

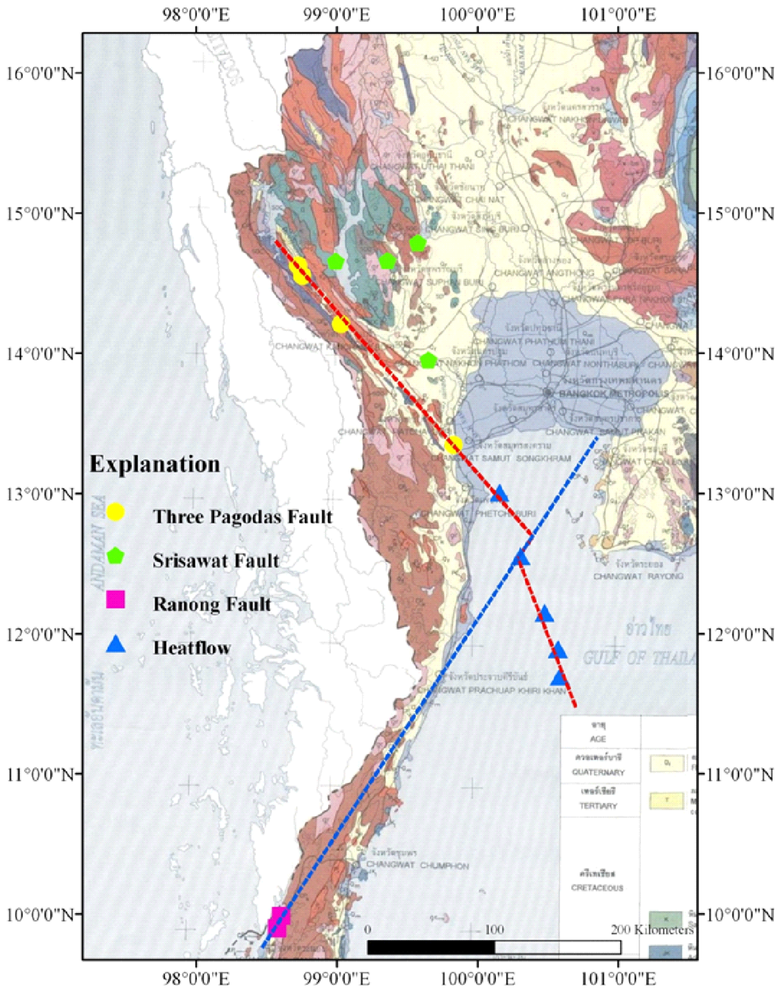

Figure 4. Map shows three hot springs and one former hot spring on land and one high heat flow spot offshore, GT1, forming a straight line which runs at N044W suggesting the main path of the Three Pagodas Fault Zone in the region. The other four submarine high heat flow spots, which form another perfect straight line sub-parallel to the first one have a trace of N020W. The apparent offset is possibly the northeastward continuation of the Ranong Fault Zone which runs at N025E.

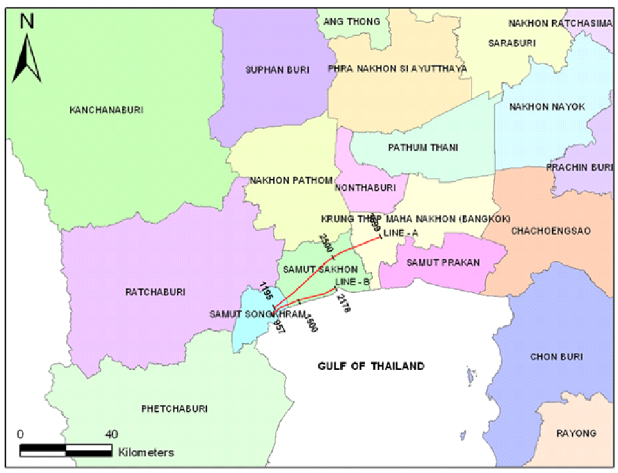

Figure 5. Two seismic lines acquired by Britoil Plc. in 1986 along the western part of the upper gulf of Thailand: Line A extends approximately 85 km long from Bang Khen through Bang Khae to Samut Song Khram, and Line B is approximately 40 km long from Samut Sakon to Samut Song Khram Province.

3.1 Nature of heat flow in the area

There are three existing hot springs and one former hot spring lying in the proximity to the trace of the Three Pagodas Fault Zone. They are namely, from northwest to southeast, Hin Dart Hot Spring, Lin Thin Hot Spring, Wang Krajae Hot Spring, and Pak Tho former hot spring. The last one is believed to be reactivated temporarily during this 2004 earthquake when the temperature of the water from one surface well rose to 48°C on 28th of December 2004. Five submarine high heat flow spots (100-200 mw/m^2) are in the Gulf of Thailand (triangles in Figure 3). They are aligned sub-parallel to the fault trend, so we consider that these geothermal spots most likely mark the southeastern continuation of the TPF path in the Gulf. However, if we take a closer look, only one star that closest to the shore, fit very well with the onshore hot springs line which runs at N044W, but the other four submarine high heat flow spots are not quite in-line but they form another distinct straight line, which has a trace of N020W. These two lines or fault traces appear to offset each other (Figure 4).

3.2 Seismic data interpretation

The lower Chao Phraya Basin or the Upper Gulf of Thailand was formed by half graben blocks faulting along the N-S and NNE-SSE trends during early Tertiary. The continental collision between the India-Australian Plate and Eurasian Plate in the Oligocene are believed to be the major mechanism that caused this rifting (Polachan and Sattayarak, 1989; Morley *et al.*, 2007). The only available detailed stratigraphy of this area was derived from borehole data of an over 1,775 m deep well, which was drilled by the Thailand Gulf Oil Company. The pre-Tertiary rock is quartzite, which underwent deformation twice in early Permian and late Cretaceous. The Tertiary rocks are divided into five units; the lower most is Oligocene flood plain and lacustrine deposits of shale intercalated with thin bedded sandstone and brownish red limestone of 169.5 m thickness (Unit A). Miocene fluviatile sediments (Unit B) consist of white sandstone, shale, mudstone, brown limestone, and some coal beds with a total thickness of 515 m. The units are overlain unconformable by Unit A. The Unit C, 745 m thick comprises also of fluviatile sediments similar to those of the previous unit. The youngest unit of the Tertiary (Unit D) consists also of fluviatile sediments, sandstone, shale and gravel with a total thickness of 345 m. They unconformable overly the Unit C and in turn underlain by unconsolidated Quaternary sediments (Chardumrong and Chaimanee, 2002).

Interpretation of the seismic profiles Line A and Line B indicates that there exists a relatively higher deformed pre-Tertiary strata as clearly seen in the profile, compared to the relatively flat lying strata of the younger Tertiary and Quaternary sequences (Figures 6 and 7). Moderate to low angle block faults, dipping eastwards can be identified from Line A whereas two small half grabens can be clearly observed from Line B. This might imply that the minor fault trends observed from both seismic lines could be a part of a horse spray of the major TPF, which is possibly located southwestern side of these faults. These minor faults are also relatively gentle normal faults and play a major role in the basin formation during Tertiary time, while the major fault could behave as a strike-slip feature, where steeply dipping strata could be observed if data were available. However, all these faults were concealed and the youngest one on the furthest west side of both profiles is covered by undisturbed sediments of approximately 230 m thickness (0.3-0.5 second TWT). With the thickness of these sediments the deposition under a floodplain environment could be roughly taken 1-2 Ma (Strogen, 1994). We reckon that the faults underneath these

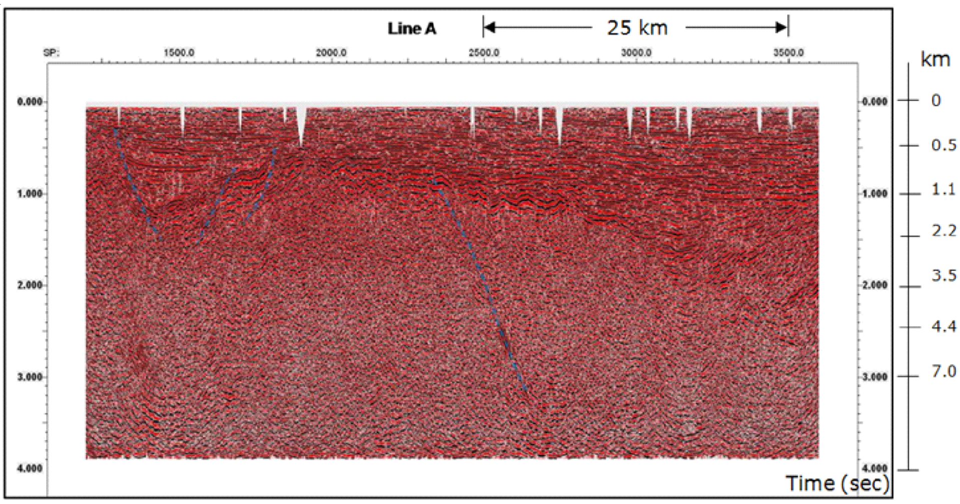

Figure 6. Seismic profile Line A indicates the relatively higher deformed Pre-Tertiary strata compared to the relatively flat lying strata of the younger Tertiary and Quaternary sequences. Moderate to low angle block faults, dipping eastwards can be identified.

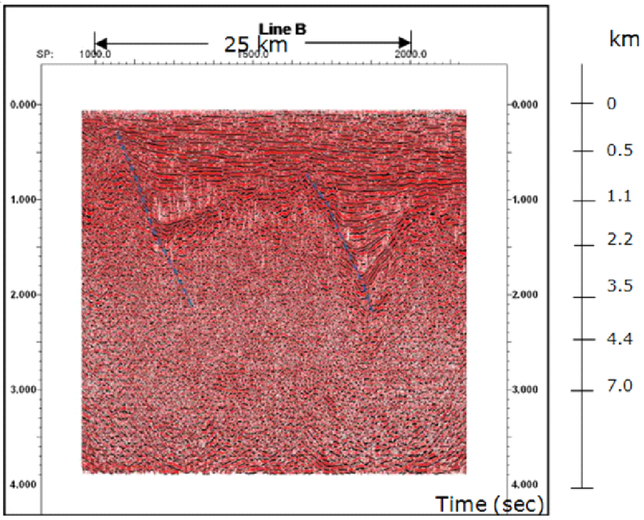

Figure 7. Seismic profile Line B indicates the relatively higher deformed Pre-Tertiary strata compared to the relatively flat lying strata of the younger Tertiary and Quaternary sequences. Moderate to low angle block faults, dipping eastwards can be identified. Two small half grabens can be clearly observed.

two seismic lines are rather old and no longer active. Furthermore, the absent of sign or trace of the TPF Path to the west suggested that there is no segment of the TPF along these seismic lines.

4. Discussion and Conclusions

Lineaments obtained from aerial photography and remote sensing image interpretation are in very good agreement with the alignment of the four hot springs on land and the nearest offshore high heat flow spot forming a straight line, which runs at N044W. The line most likely indicates the main TPF path in the region. The other four submarine high heat flow spots, which formed another perfect straight line sub-parallel to the first one, has a trace of N020W. This trace is considered to be the most southeastern continuation of the TPF Zone. We interpret that the above two lines were offset by the northeastward extension of the Ranong Strike Slip Fault Zone (RFZ) which runs at N025E. The sense of the present movement clearly indicates right lateral features for the RFZ (Figure 4). The evidence from seismic profiles suggested that the main path of the TPF did not run through Bangkok Metropolis.

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