CHAPTER V

DISCUSSION

In this chapter, all previously-mentioned information and results obtained from the previous chapters are used for discussion. The major topics which are described in detail include nature and characteristics of the Three-Pagoda Fault Zone (TPFZ),tectonic regime of the investigated area, fault assemblages and strain ellipsoid, neotectonic scenario, and rank of active faults, fault assemblages and strain ellipsoid, neotectonic scenario, and rank of active faults.

5.1 Nature and Characteristics of the TPFZ

Results on remote-sensing and field information indicate clearly that the TPFZ mostly follow the predated regional geological structures which, to some extent, develop in the NW trend. Although the most prominent fault traces, as observed from both Landsat Thematic Mapper (TM5) and JERS radar images, are in the NW-trend following the original major structure. Others interesting directions of lineament features which, in several cases, are regarded as structural faults, are also encountered. They are mostly observed in the N-, E- and NE- directions.

Remote-sensing information clearly indicates that the most probable oldest faults are those occurred in the NE direction where faults cross-cut Permian limestone (area S5-1) in a right lateral sense and cross-cut the NW-trending faults as well. The fault also extends northeastward and can be recognized as the deviated channel of the Khwae Noi River. However it is quite difficult to compare the age with that of the NW-trending faults by which the left lateral sense of movement is indicated. As stated in the earlier chapters, the NW-trending faults, particularly those following the Khwae Noi and Khwae Yai Rivers, recorded both sinistral and dextral senses of movement, though the left-lateral movement which mostly took place within the bedrocks are quite clearly observed in some areas. Such the left-lateral strike slip displacement may postdate the right strike-slip one that principally developed in the Cenozoic alluvial deposits. Therefore, for the overall figure, it should be noted herein that for the NW-trending faults, those representing right-lateral movement are likely to occur later than those with the left-slip component.

It is also noteworthy that most of the faults orientating in the N-S direction are recognized as normal faults which are principally associated with Cenozoic basins (e.g. that in Area S3-3). Although in some areas (e.g. that in Area 3-2), faults with both dip-slip and right-lateral movements are clearly observed, they are regarded older than those with the almost entirely vertical slip movement. At Huai Khli Ti, west of Khao Bo Ngam (25 km west of Amphoe Sri Sawat) the N-trending fault without any obvious lateral movement is recognized in the Silurian-Devonian clastic rocks and is considered as an old thrust fault, although relation with the faults of the other direction is ascertained. Additionally the E-trending faults are also developed in some areas, especially in areas where faults are observed in bedrocks, and right lateral displacements are encountered in Ban Kung Ka area, Amphoe Sai Yok. Most of the faults recognized, however, are low-angle reverse (or thrust fault), such as that in the alluvial basin about 3-4 km northwest of the Three-Pagoda pass. It is interesting to note here that the faults of the E-W trend show much less vertical slip movement. The other E-trending faults encountered along Huai Sai Yok is of interest, since it truncates into basin-enclosing limestone terrain without any slip component. Such fault is regarded to be thrust or reverse and perhaps is not old. Although this faults is mostly associated with the normal fault, the relation with the faults of the other directions are poorly-defined. However the basin-bounded thrust faults of the E-W direction are likely to be younger than those of the N-S direction which mostly developed only in the hard-rock geology.

Folds or vergences are also recognized along and in the vicinity of the TPFZ. Their axes are mostly oblique to the main TPFZ and their orientations, in most cases, advocate the right-lateral movement (see also Figure 5.1). It is likely, therefore, that faults with such the right lateral sense are more evolved than those of the left-lateral one.

To comply with the tectonic scenario, it is likely that the NW-trending faults with the right-lateral component and their associated N-trending normal faults and E-trending thrust faults, are quite prominent and seem to have occurred later than the faults of other directions with the contrasting senses of movement.

5.2 Relative Age Relations of TPFZ Based on Geochronological Results

In this context, the main discussion is focused upon geochronological results. It is visualized, as indicated geochronologically in Table 4.2, that the main NW-trending TPFZ shows both sinistral and dextral natures of movements and perhaps the right-lateral sense of movement is regarded younger than that of the left-lateral one (see areas S1-1 and S5-1). Present-day seismology as indicated by epicentral distribution (Figure 5.2) reveals two major alignments where earthquakes are mostly taken place one - is in the NW-trending direction and the other in the N-trending direction. Though very few focal mechanism have been computed for earthquakes in Thailand, the careful investigation (see Bott et al., 1997) along the TPFZ shows the well-constrained dextral strike-slip tectonic movement (Figure 5.1) which are consistent with that obtained from

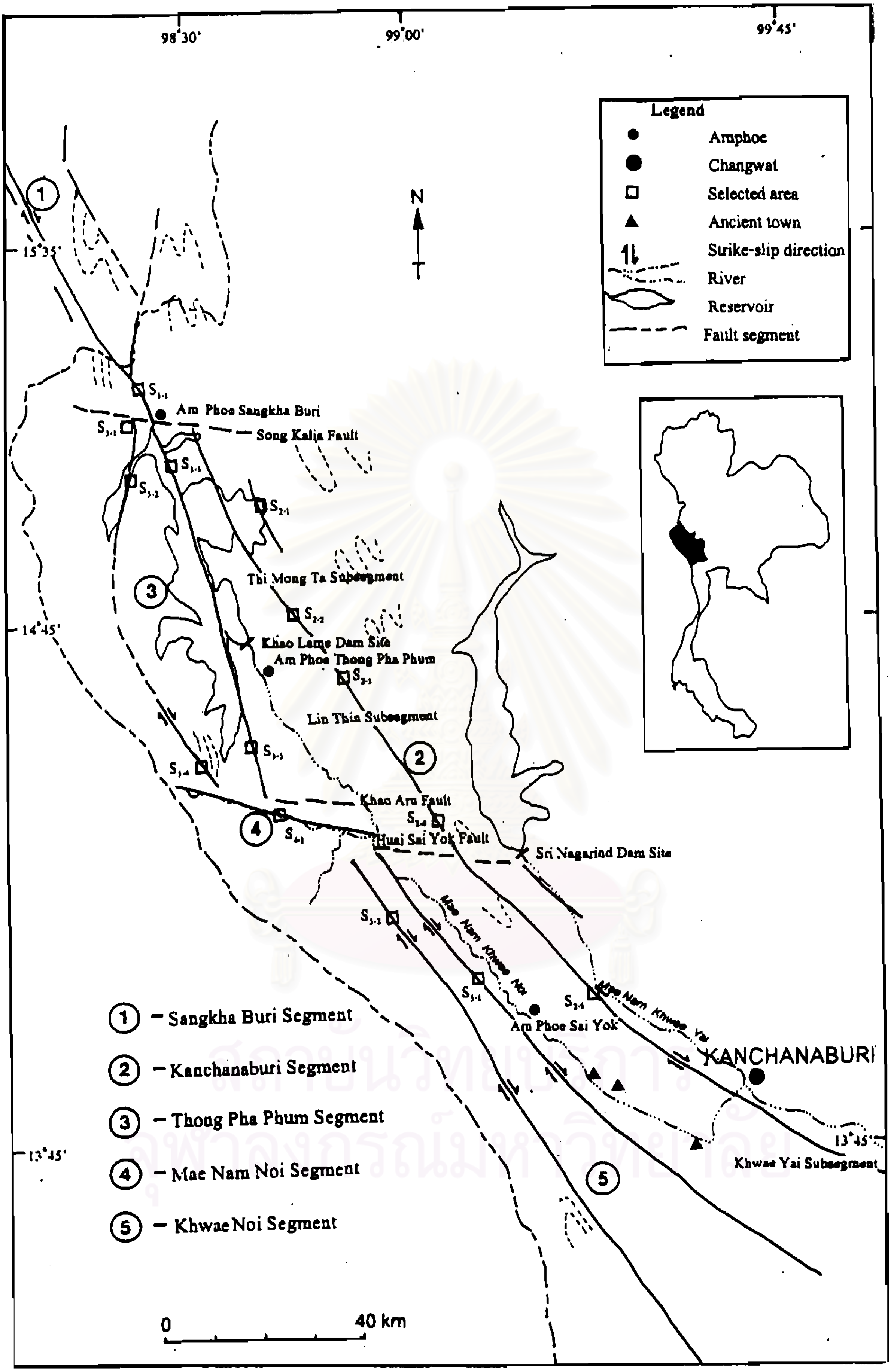

Figure 5.1 Map of the Three Pagoda area showing the fault segments and folds ( ).

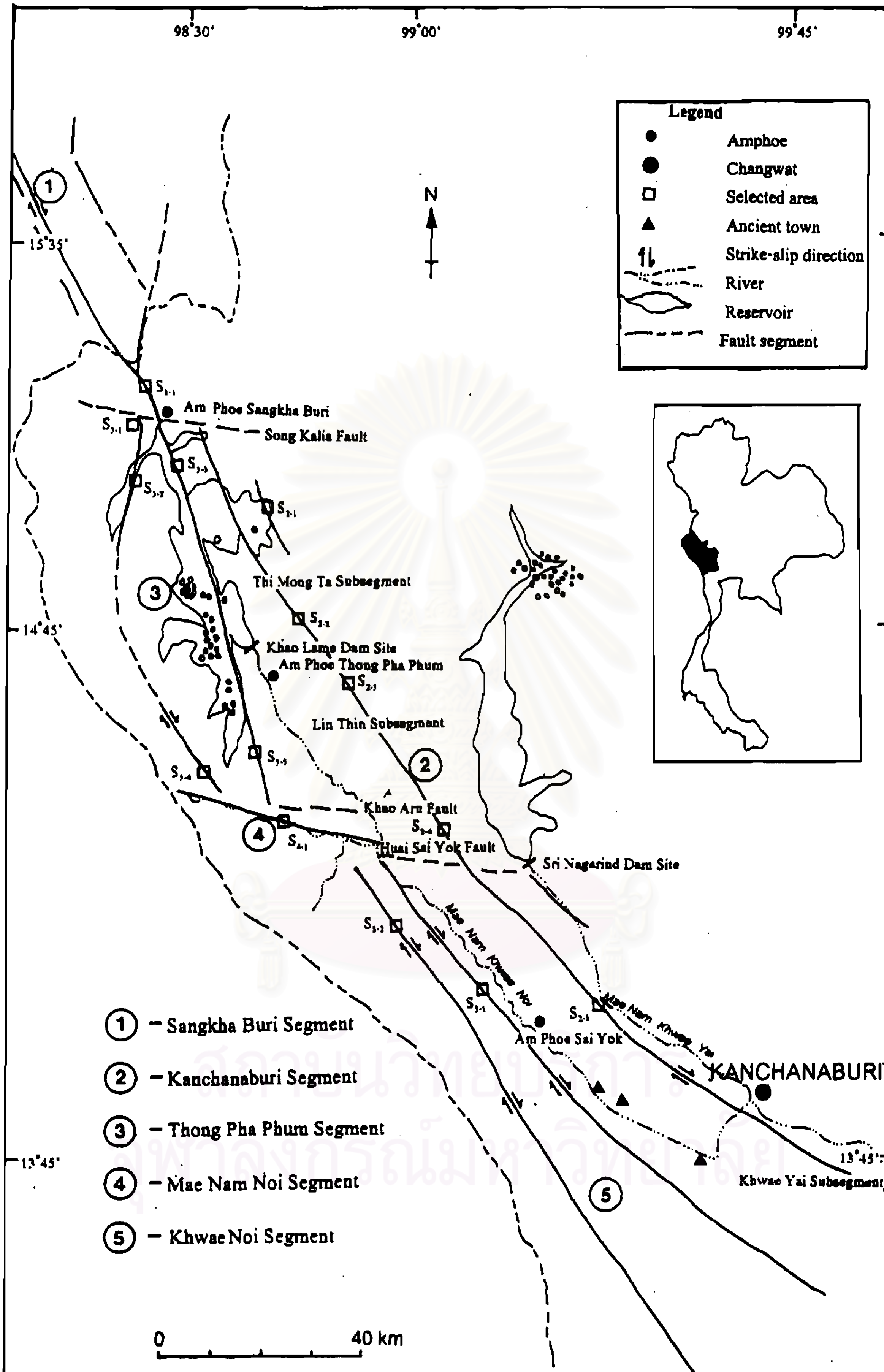

Figure 5.2 Map of the Three Pagoda segments showing the epicenters (o).

the current remote-sensing result in this study. This strongly advocates that the NW-trending TPFZ is presently active with the right-lateral slip component. Another word, the movement with the sinistral sense along the TPFZ occurred prior to that of the dextral sense. In addition, it is noteworthy that other kinds of evidences including location of hot springs (Figure 5.3), and heat-flow data (Figure 1.4), all support the cryptic idea that neotectonics is still persisted through the present-day period of time. As shown in Table 4.4 which TL and ESR geochronological results are presented, it is assured, as supported by geochronological results along the main NW-trending TPFZ, that the TPFZ has occurred since over 1 million years. However, Charusiri (1989) reported the $^{40}Ar/^{39}Ar$ ages of about 70-77 Ma on separated muscovite extracted from the NW-trending tin-bearing pegmatite in the area dominated by stressed granite very close to the Sangkhla Buri - Myanmar border. The fault in that previously-investigated area indicates the left-lateral movement. From this synthesis, it is quite likely that sinistral fault movement along the TPFZ may have occurred during approximately Cretaceous-Tertiary period. Subsequently, there may become dextral movement afterward (see supporting evidences in the next section). However the time when the change in movement occurred is the main topic of interest. According to Tapponier et al. (1986), tremendous change in tectonic style of the mainland SE Asia and, of course, Thailand may have occurred since the time Indian continent collided drastically with Asia mega-continent during 40-45 Ma. Perhaps, such Indian-Asian collision may have exerted a stop of reactivation to the NW-trending sinistral fault movements which may have developed as Western Burma block obliquely collided with Shan-Thai plate (or amalgated continental blocks of mainland SE Asia) in the roughly N-S direction. The tremendous change in tectonism may have caused the extrusion of SE Asian continental block along the NW-trending faults (between the Red River fault in Vietnam and the TPFZ) and the anti-clockwise rotation of South-China block. Transpression associated with pull-apart basins may have been subsequently developed along the TPFZ in response to such tectonic adjustment. The N-trending fault-bounded basins with the rhombic grabens are developed associated with the E-W extension tectonics, similar to those proposed by Mann et al. (1983) for basin development (Figures 5.4a, 5.4b, 5.4c).

5.3 Fault Assemblages and Strain Ellipsoid

Both remote-sensing data and field-survey result indicate that the NW to NNW-trending Sangkhla Buri Segment disconnects to the NW-trending Kanchanaburi Segment, by the WNW-trending Song Kalia fault and the NNW-trending Thong Pha Phum Segment and Mae Nam Khwae Noi Segment by the WNW-trending Huai Sai Yok Fault (of the Khwae Noi Segment). The occurrence of these two WNW-trending faults are of prime interest, since based upon the

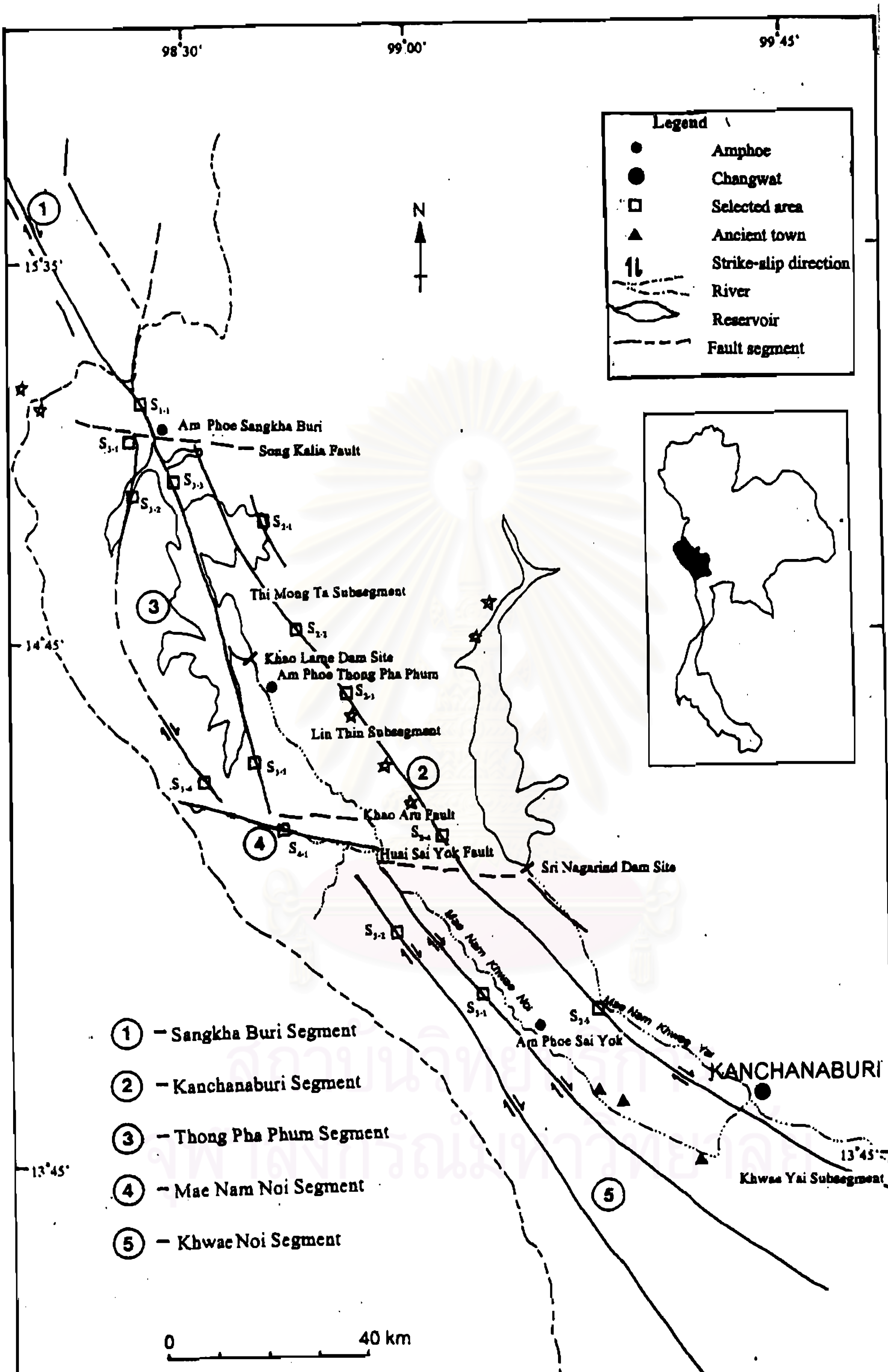

Figure 5.3 Map of the Three Pagoda segments showing the hotspring (☆).

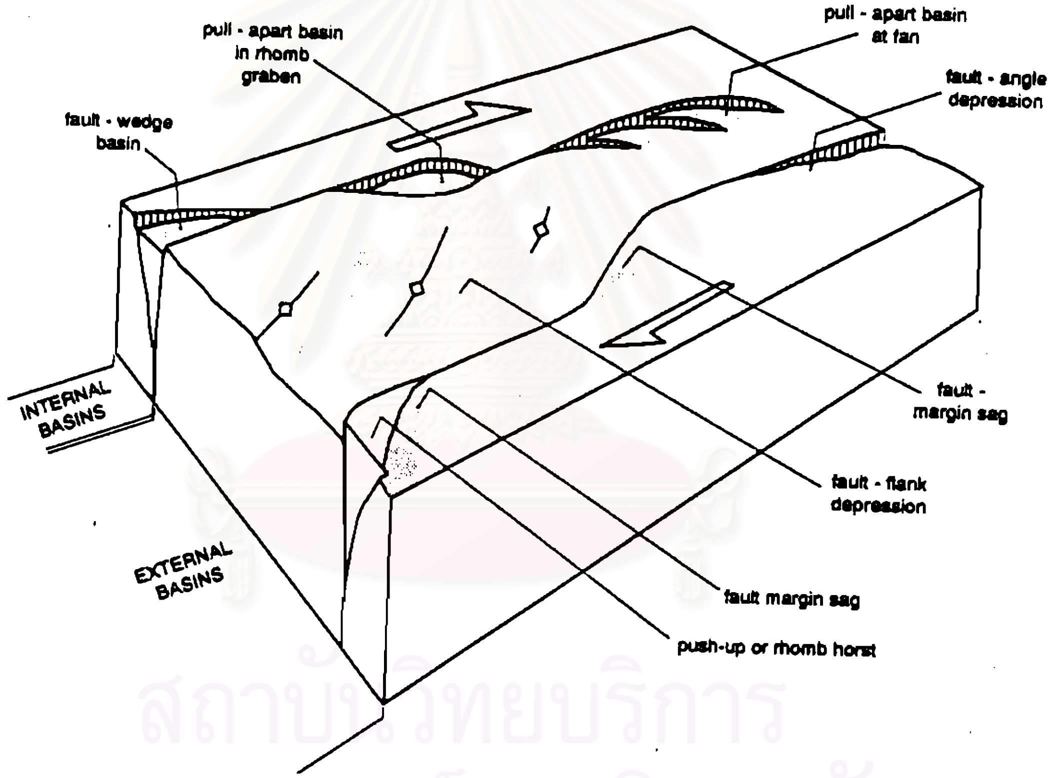

Figure 5.4a Models of basin formation in and adjacent to a strike-slip fault zone (Woodcock and Schubert, 1994).

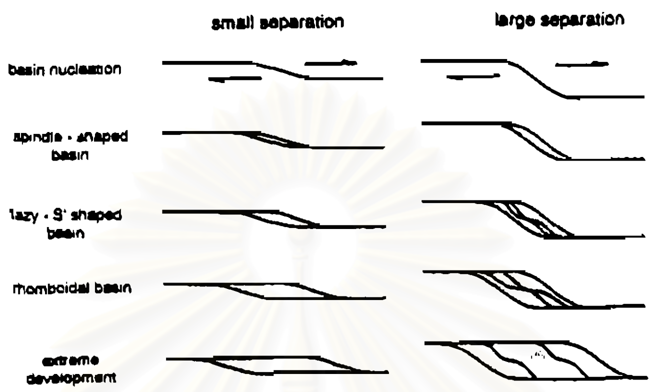

Figure 5.4b Proposed development (Mann et al.,1983) of pull apart basin in stepovers with small and large separation.

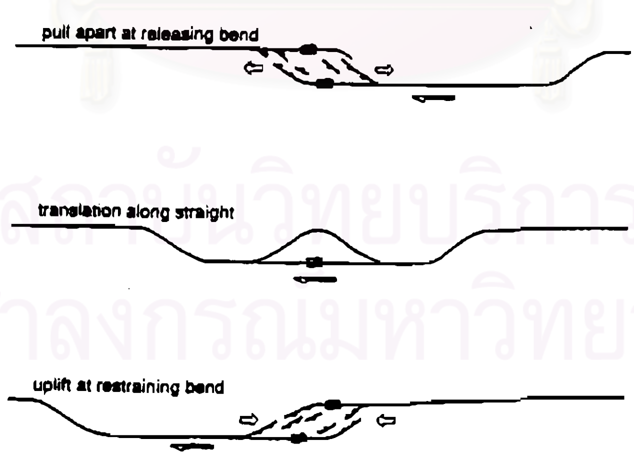

Figure 5.4c Scheme for the inversion of a pull-apart basin by its translation from a releasing bend to a restraining bed (Woodcock and Schubert, 1994).

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cross-cutting relationship, such faults show the relatively young age as compared with the other roughly NW-trending faults. It is also visualized from morphotectonic landforms that most of the N-trending normal faults are invariably associated with the Huai Sai Yok and Song Kalia Faults and that the E-trending faults which are frequently associated with those two faults.

On the contrary, the older NW-trending faults such as those of the Sangkhla Buri, Thong Pha Phum, and Mae Nam Khwae Noi Segments, are invariably associated with the probably N-trending thrust faults and the discontinuous E-trending faults. The orientation and sense of movements of NW- to WNW-trending faults, their mutually related faults of the other direction, and the age relation of individual faults lead to the delineation and analysis of strain ellipsoid. Figure 5.5 shows the orientation of strain ellipsoid (A) for the NW-trending strike-slip fault whose major sense of movement is left-lateral. It is noted that the conjugate NE-trending faults and E- and N- trending minor ones are also shown. The orientation of ellipsoid (B) for the WNW-trending right-lateral fault together with the less prominent conjugate ENE-trending faults and E-and N-trending minor faults is also illustrated in Figure 5.5.

Based upon the result of strain-ellipsoid analysis, it is indicated, as shown in Figures 5.6 and 5.7, that the maximum stress for the occurrence of the NW-trending faults and their associated faults is in the E-W direction and that the maximum stress for the commence of WNW-trending faults and their related features is in the N-S direction. It is also inferred from the strain analysis that the stress axis which is from the E-directed trajectory may predate the stress axis of the N-S direction.

5.4 Neotectonic Scenario

If this assumption is correct, then the tectonic scenario of this study region can be resolved. The ellipsoid with the E-W stress axis corresponds with the interaction of Shan-Thai continental block with Indochina and their intervene oceanic plates during Late Triassic (see Charusiri et al., 1997). Such the continental collision may have caused the left-lateral fault movement probably along the major NW-trending faults of the Sangkhla Buri, Kanchanaburi, Thong Pha Phum, and Khwae Noi Segments.

Their conjugate sets with the NE trend along with the N-trending thrust and E-trending normal faults may have formed contemporaneously. Subsequently, as a result of Western Burma collision to SE Asia landmass, sporadic magmatism with Sn-W mineralization along the previously-occurred NW-trending fault may have developed as evidence by the appearance of

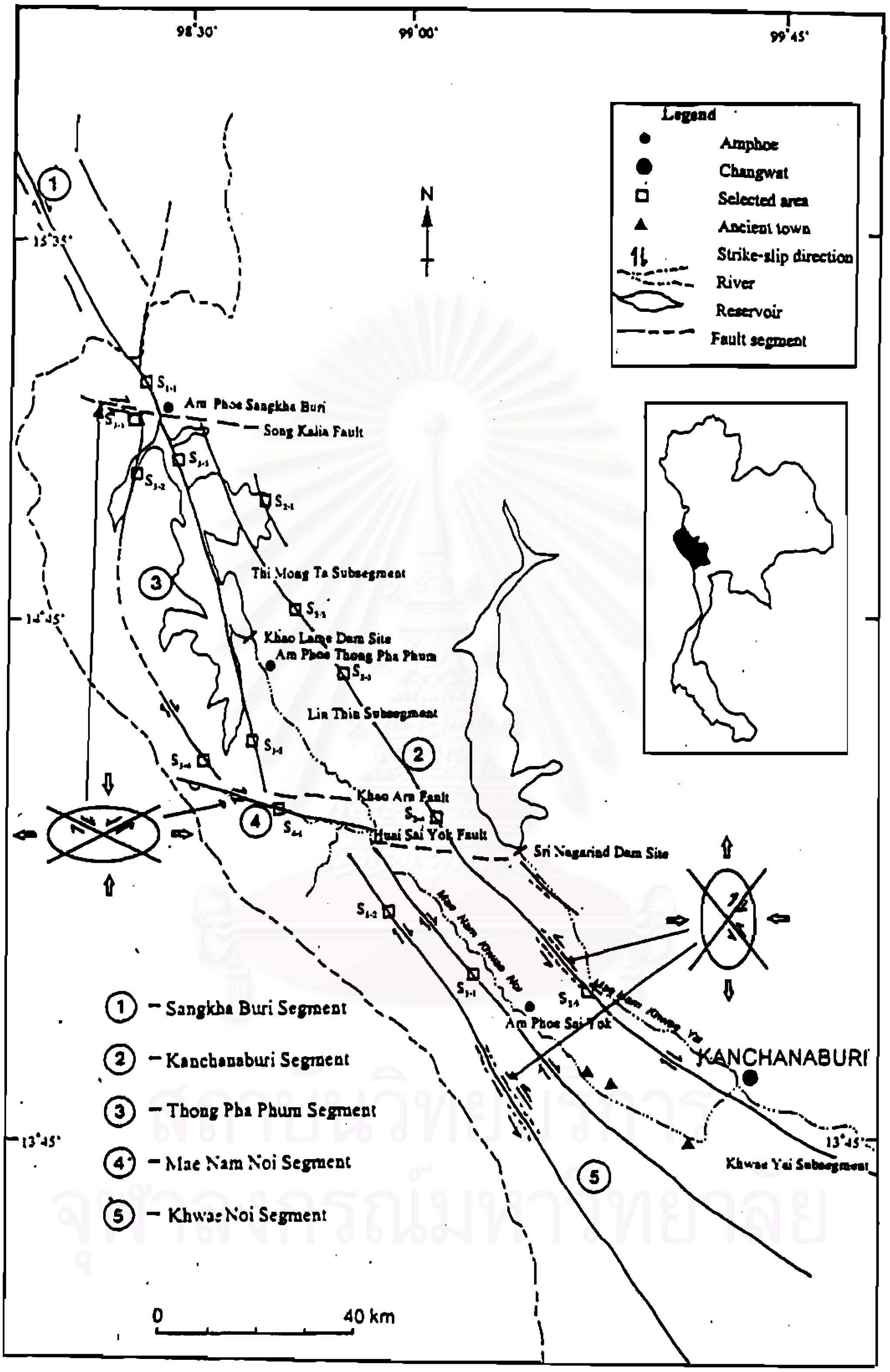

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Figure 5.5 Major fault segments of the TPFZ showing two contrasting strain ellipsoids.

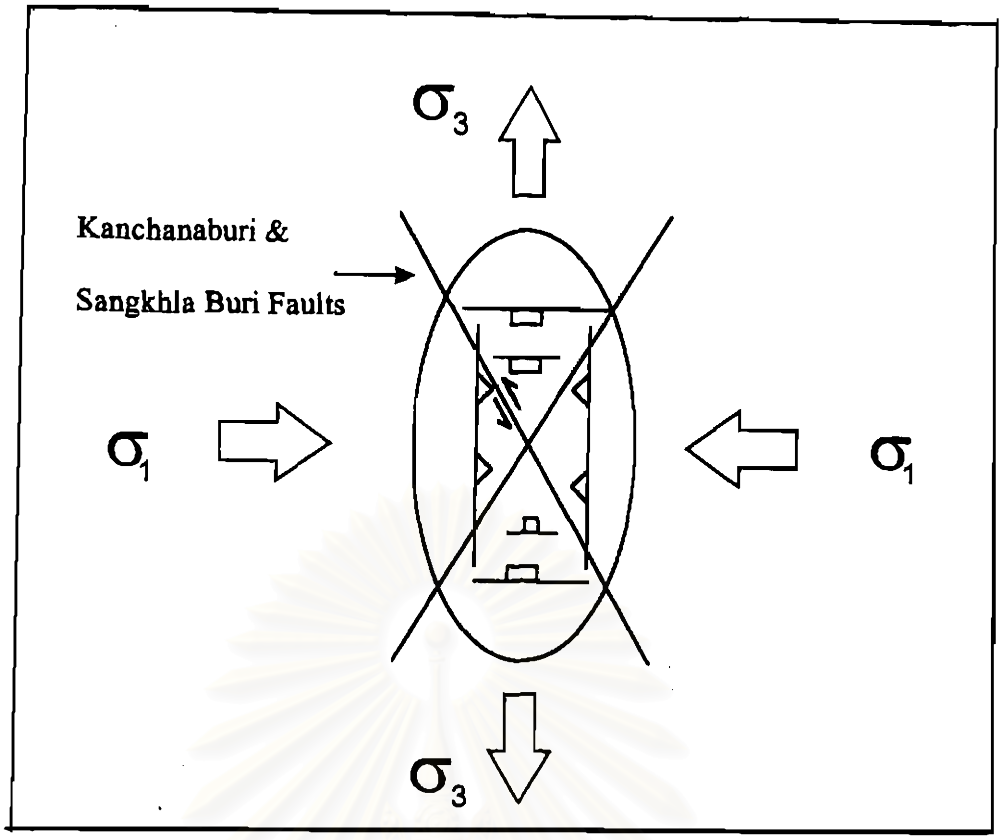

Figure 5.6 Strain ellipsoid with the E-W maximum stress axis, occurring in the earlier stage.

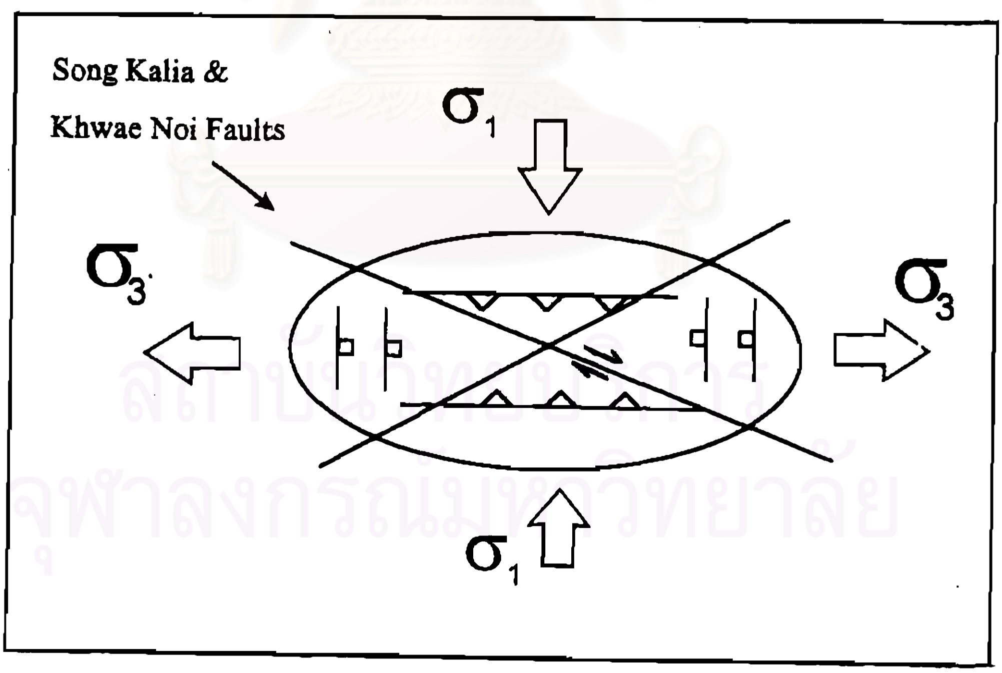

Figure 5.7 Strain ellipsoid with the N-S maximum stress axis, occurring in the later stage till present.

70-77 Ma tin-bearing pegmatitic and quartz veins (see Charusiri, 1989). This perhaps marks the stop of left-lateral movement during Cretaceous-Tertiary period. It is inferred from this current investigation that the onset of neotectonic activity in Thailand may be marked when Western Burmar block (see Mitchell, 1981) completely united as part of mainland SE Asia. Then by the time India collided with Asia (40-45 Ma), the drastic northward-pushing tectonism may have caused the extrusion of the SE Asia amalgamated plates with immense clockwise rotation (Charusiri et al., 1999a). The SE Asian plates were repeatedly disrupted particularly along the NW-to WNW-trending faults. The change in major displacement may have developed the WNW-trending right-lateral faults like those of the Song Kalia and Mae Nam Noi Segments. The associated N-trending normal faults may have formed due to such tectonic stress. The transpression tectonics may have triggered and the tectonic pull-apart basins may have developed along the NW-trending fault (see also Figure 5.4, in response to this transpression activity, perhaps during early Miocence times (see Charusiri et al., 1999b). The basins may have progressively wider, and deposition onto the basins may have occurred continuously. The subsequent neotectonic activity may have triggered along the N-trending faults including the major Sri Sawat Fault, as supported by the extrusion of gem-bearing basalts during 3.17-4.17 Ma (see Barr and Macdonald, 1978, Sutthirat et al., 1994). Therefore, it is likely that neotectonism by the end of Tertiary is characterized by development of pull-apart basins in conjunction with the mantle-plume basaltic magmatism.

However, based upon TL and ESR dating results, neotectonic activity has been denoted particularly along the main NW-trending TPFZ since 1.5 Ma (see Table 4.2) and five episodes are encountered (Table 5.1).

Table 5.1 Age grouping based on TL & ESR data for the samples collected along the TPFZ.

Stage	Event	Sample dated
1	920-1575 Ka	TP 8-1, TP 8-2
2	465-580 Ka	TP 9, TP 6
3	180-225 Ka	TP 3, TP 4-1, TP 4-2
4	140-145 Ka	TP 1, TP 10
5	20-22 Ka	TP 2

The first episode occurred during 920-1,575 Ka at the southern end of the Sangkhla Buri Segment. The second episode took place during 465-580 Ka immediately at the southern part of the Thi Mong Tha subsegment (Kanchanaburi

Segment). The third episode is the one which accounts for 180-225 Ka neotectonic activity and happened at the northern part of the Khwae Noi Segment. The forth episode belongs to the 140-145 Ka event which took place at the southern part of the Sangkhla Buri Segment, immediately north of the first episode. The last episode is the 20-22 Ka activity that occurred at the middle part of the Thi Mong Tha subsegment (Kanchanaburi Segment). As shown in Fig 1.2B, three TL dates along the TPFZ were previously reported including 0.012 Ma, 0.3 Ma and 1.0 Ma - which recorded the other episodes of neotectonic activities. The first date seems to be of the most interest, since it may indicate the most probable youngest date for the TPFZ activity. Perhaps the occurrence of the 0.012 Ma (or 12 Ka) earth-tremor activity more or less effected the ancient-city settlement (Prasart Muang Sing) very close to the southern portion of the TPFZ. However the geochronological results obtained form this and previous studies do not cover all the fault segments, therefore the results indicate some constraints on probable neotectonic activities during Quaternary period.

Moreover, the neotectonic activity of the study area persists to the present-day time as visualized from the hot-spring locations along the main TPFZ (Figure 5.3) and the occurrence of high-heat flow to the north of the Sangkhla Buri Segment (see Figure 1.4). Additionally, focal mechanism deduced from contemporary seismicity as reported by Bott et al. (1997) and Klaipongpan et al. (1997) indicate strike-slip neotectonism developed within the study area and with the roughly N-S compressional stress axis. The axis is quite similar to that obtained from the remote-sensing data interpretation.

5.5 Rank of Active Faults

In the light of activeness of fault and based upon the works of Hinthong (1995), the TPFZ is regarded as the active fault. His conclusion is similar to that of Shrestha (1987). However, Charusiri et al. (1999b) in their study on active fault zones in Thailand demonstrate that the active faults in Thailand can be grouped into 5 seismically active belts (SAB) (see Figure 1.2 B). Within each SAB, three ranks of active faults are recognized as active, potentially active, and tentatively active. The TPFZ is assigned to belong to the West and Northwest SAB. These SAB is denoted as one of the most seismic risk zones of the country. However the TPFZ as ranked by Charusiri et al. (1999b) is regarded as potentially active fault whereas its conjugate sets and associated branches represent the “active” fault, sensu stricto.

It is possible, as visualized from the new results clearly presented in the above section, that the TPFZ, its conjugate sets, and associated branches are likely to be more ‘active’ than recently mentioned by Charusiri et al. (1999b).