CHAPTER IV
IDENTIFICATION OF ACTIVE FAULTS

Fault rupture is a hazard that should be considered when conducting a seismic investigation of a particular site. Recognition of active fault requires geological, historical and seismological accounts of the region of interest. As an essential element of seismic hazard assessment, this chapter provides a review of available information regarding Thailand's seismicity and active faults.

4.1   Definition of Active Faults

Fault rupture is a fracture in the Earth's crust along one side of which, a relative movement occurs with respect to the other side. As weaknesses in the rocks, these faults generate seismic waves that are felt as ground shakes (Shrestha, 1987).

As the crust is composed of enormous plates that are in constant slow motion with one another, friction between these plates develops until such time when a threshold of accumulated strain is reached as dictated by the material properties of the rock and the fault's surface. This strain energy may be consumed during rock heating and fracturing or may be released in the form of elastic waves that travel through the ground. Sudden movement along a fault radiates these seismic waves which are typically strongest near the source and attenuates away from the fault (Lay and Wallace, 1995).

Through trenching, borehole, remote sensing, age dating and other exploratory methods, active faults are identified and delineated. The degree of activity differs in various faults. Hence, geologists and seismologists designate a certain fault as either potentially active or inactive in accordance with the displacement that transpired along the rupture zone.

In the foregoing discussion, the term active fault has had numerous established usages among engineers, geologists and seismologists. The following definitions

include those which are compiled by Shrestha (1987), Hinthong (1995) and Charusiri *et al.* (1999).

Hart (1972) defines an active fault as one having a surface displacement within Holocene time (last 11,000 years) and regarded as potentially active if there's indication of surface displacement within Quaternary time (last 1,600,000 years).

On the other hand, the International Atomic Energy Agency formulated two additional criteria in 1974 in order to classify an active fault. First, there should be an evidence of creep movement along the fault. Second, a topographic evidence of surface rupture, surface warping or offsetting of geomorphic features should be visible.

Wesson *et al.* (1975) proposes that the activeness of a fault depends on the length of time comprised of a million years that it has been historically active, the movement in the current time and the potential movement in the future.

Costa and Baker (1981) as well as Shrestha (1987) define a fault of active nature if one movement happened during the last 35,000 years or more than one movement transpired within 500,000 years. In the same manner, U.S. Nuclear Regulatory Commission considers a fault active if it shows evidence of multiple displacements within past 500,000 years or evidence of a single displacement within past 35,000 years. Similarly, Charusiri *et al.* (1998) consider a tectonic fault active if it has a history of strong earthquake or surface faulting in the past 35,000 years or a series of earthquakes during 500,000 years.

Ziony and Yerkes (1985) ascertain a fault situated at dam sites to be active if it has undergone slip within the past 100,000 years while for nuclear power sites, if slip has occurred within the last 500,000 years.

Slemmon and Depolo (1988) associate an active fault with the frequency of occurrence of earthquakes, physiographic evidences of current activities, offset in the contemporary seismotectonic regime as well as the possible reappearance of offset in the future.

Matsuda and Kinugasa (1991) interpret the fault to be active based on the repetition of movement in latest geologic time.

Hinthong (1995) classifies some of these definitions of active fault and related concepts under three categories such as general, engineering and regulatory in his study of active faults in Thailand.

Fenton *et al.* (2003) infers that for a fault to be active, its geomorphic features should exhibit proof of recent fault activity or displacement in young deposits or surfaces. Also, the fault should be associated with moderate to large historical earthquakes or a trend of micro-earthquakes indicative of its active nature.

From these definitions, the age of last fault movement finds its significance in classifying the nature of a fault whether active or inactive. The definition proposed by Costa and Baker in 1981, Shrestha in 1987 and Charusiri *et al.* in 1999 that a fault exhibiting a slip movement in the ground at least once in the past 35,000 years or more than once in the past 500,000 years is adopted in this research. Table 4.1 summarizes the activity of faults in Thailand based on ages after Charusiri *et al.* (1999)

Table 4.1 Activity of faults in Thailand based on ages

Era	Period	Epoch	Years Before Present	Fault Activity
Cenozoic	Quaternary	Holocene		
			11,000	Fault active during this range 35,000 years for nuclear site one quake within 100,000 years for large dams 500,000 years for nuclear sites (many quakes)
		Pleistocene		
			1,600,000	
	Tertiary	Pliocene		
			5,300,000	
		Pre-Pliocene		Neotectonics commenced
Pre-Cenozoic				

4.2   Significant Fault Parameters

A tectonic fault is characterized in terms of key parameters such as rate of strain release or fault slip, amount of fault displacement in each event, length or area of fault rupture, earthquake size, and earthquake recurrence interval. These variables depend on tectonic environment, fault type and geometry, as well as the physical properties of the fault zone (Idriss and Archuleta, 2005).

Slip rate is approximated by getting the ratio of cumulative displacement along the displaced geologic attribute, with the estimated age of such feature. Slip per event is often represented by the maximum and average value of the amount of slip taken during the field investigation for the entire fault segment. The rupture area incorporates the maximum rupture length and maximum rupture width. Fault rupture length gauges the geographic extent of fault slip as it provides an estimate of the distribution of seismic energy. Earthquake size ascertains the energy released by an earthquake. Recurrence interval describes the relative activity of faults specifically the time between earthquake events of similar size (Idriss and Archuleta, 2005).

In order to estimate the largest earthquakes that a particular fault can generate, these various fault parameters are used to calculate the maximum earthquake magnitude. To correlate these source parameters to estimates of earthquake size, a number of published empirical relationships are available in literature—some of which are quoted by Idriss and Archuleta (2005) from the following authors:

Wyss (1979) derived Equation 4.1 to determine magnitude based on rupture area:

$$M = 4.15 + \log_{10} A_f \tag{4.1}$$

in which A_f is the rupture area in sq. km. Using least square method, another expression is formulated which is represented by Equation 4.2.

$$\ln A_f = 2.146M - 8.384 \tag{4.2}$$

wherein M can either be surface wave or moment magnitude as well as local

magnitude for magnitude less than 6.

Slemmons (1977) proposed Equations 4.3a to 4.3c to determine magnitude for strike-slip, reverse and normal faults using rupture length:

$$M_s = 1.404 + 1.169 \log_{10} L \qquad (4.3a)$$

$$M_s = 2.021 + 1.142 \log_{10} L \qquad (4.3b)$$

$$M_s = 0.809 + 1.341 \log_{10} L \qquad (4.3c)$$

where M_s is surface wave magnitude while L is the rupture length in m.

In 1982, Slemmons relate the total fault displacement to magnitude for strike-slip, reverse and normal faults which are represented by Equations 4.4a to 4.4c:

$$M_s = 6.974 + 0.804 \log_{10} D \qquad (4.4a)$$

$$M_s = 6.793 + 1.306 \log_{10} D \qquad (4.4b)$$

$$M_s = 7.668 + 0.750 \log_{10} D \qquad (4.4c)$$

where M_s is surface wave magnitude while D is the fault surface displacement in m.

Wells and Coppersmith (1994) used a worldwide database comprising of shallow focus continental interplate or intraplate earthquakes of magnitudes greater than approximately 4.5 and arrived at Equations 4.5a to 4.5e. These well-known and widely accepted equations relate moment magnitude to surface rupture length (SRL in km), rupture area (RA in sq. km), subsurface rupture length (RLD in km), maximum surface displacement (MD in m) and average surface displacement (AD in m).

$$M_w = 5.08 + 1.16 \log_{10}(SRL) \qquad (4.5a)$$

$$M_w = 4.07 + 0.98 \log_{10}(RA) \qquad (4.5b)$$

$$M_w = 4.38 + 1.49 \log_{10}(RLD) \qquad (4.5c)$$

$$M_w = 6.69 + 0.74 \log_{10}(MD) \qquad (4.5d)$$

$$M_w = 6.93 + 0.82 \log_{10}(AD) \qquad (4.5e)$$

4.3   Potential Active Faults in Thailand

The study conducted by Warnitchai in 2004 regarding the development of seismic design requirements for buildings in Bangkok takes into consideration the seismotectonic features of Burma-Thailand-Indochina region as depicted in Figure 4.1. Instrumental earthquake records from 1910 to 2000 in this region have shown a number of active seismic sources that could possibly generate large magnitude earthquakes. The approximated distance of these seismic zones is about 400 to 1000 km from Bangkok.
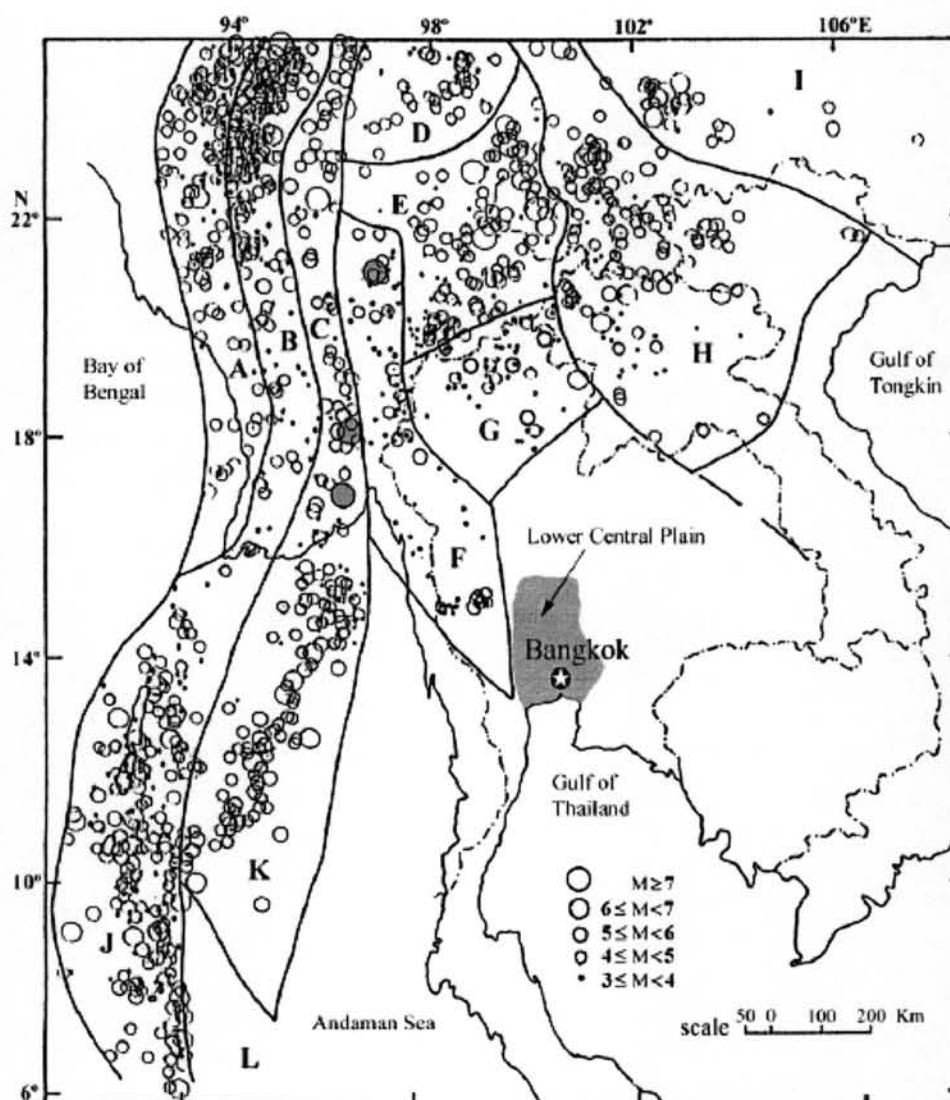

Figure 4.1 Regional seismic sources (A-L) of Thailand-Burma-Indochina region and recorded earthquakes from 1910 to 2000 (Warnitchai, 2004)

The seismotectonic setting of Southeast Asia is a result of the interaction between the Indo-Australian, Eurasian, Philippine and West Pacific plates. Thailand is situated within the Eurasian plate and is bounded by the Andaman thrust in the west, Sunda arc in the south and Philippine trench in the east (Fenton *et al.*, 2003). The tectonic framework of Thailand and mainland Southeast Asia can be visualized in Figure 4.2.
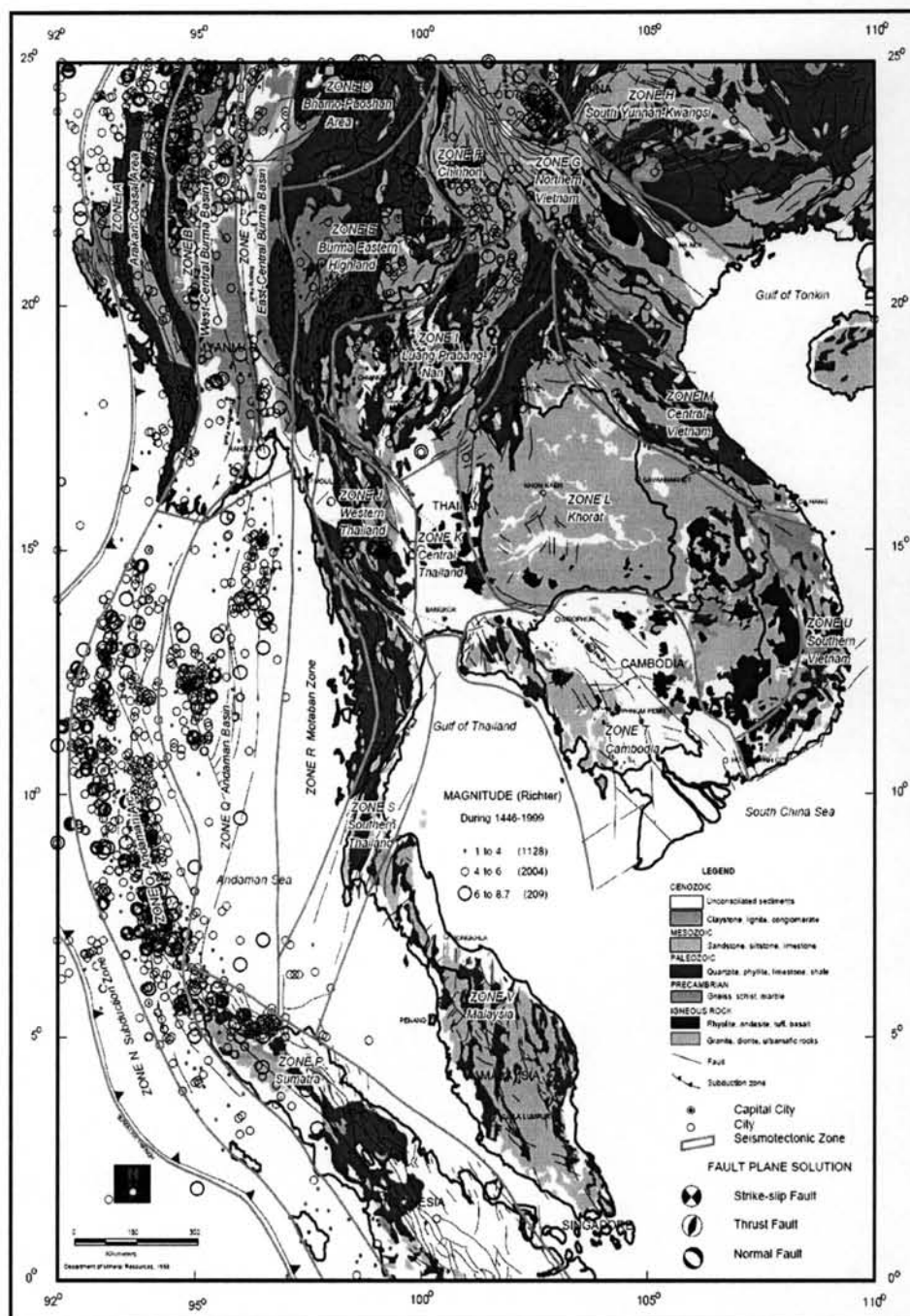

Figure 4.2 Seismotectonic map of Thailand and mainland Southeast Asia

(Charusiri *et al.*, 2000)

Recent paleoseismic investigations in northern and western Thailand revealed that the low slip rates, long recurrence intervals and large magnitude paleo-earthquakes are tectonically similar with the Basin and Range province of Western United States. Hence, Fenton *et al.* (1997) have called these zones as Northern Basin and Range Province. These zones are bounded in the west by the Western Highlands, by Loei or Eastern Fold Belt in the east and Central Plain in the south. This is illustrated in Figure 4.3. Historical records suggest that the Northern Basin and Range seismotectonic province may not be associated with active faults. Related investigations imply that no clear surface expressions or geologic structures can be linked to its seismicity. Furthermore, it was inferred that focal mechanisms for western Thailand indicate strike-slip faulting while the northern region is undergoing east-west to northwest-southeast extension on north to northeast-striking normal or normal-oblique faults (Fenton *et al.*, 2003).
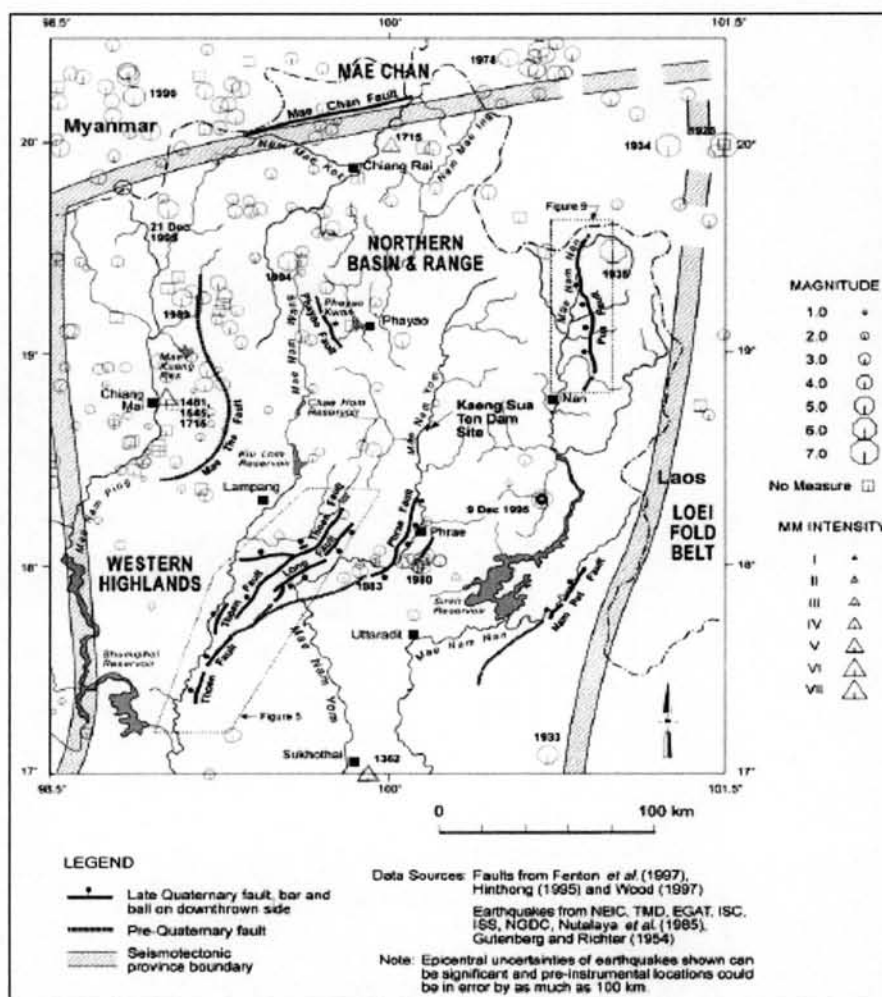

Figure 4.3 Seismicity in the Northern Basin and Range (Fenton *et al.*, 1997)

A number of researchers have identified a number of fault zones in Thailand (Fenton *et al.*, 2003).

In 1984, Le Dain *et al.* investigated the recent seismicity of Myanmar-Thailand regions and proposed that northwest striking Papun (Moei or Mae Ping) fault might be an active fault. Thiramongkol (1986) investigated the Holocene movement on Bang Pakong Fault on the eastern border of the Central Plain. Nutalaya (1994) and Hinthong (1995, 1997) provided an inventory consisting of 23 active, potentially active and suspected active faults based primarily on geomorphic expressions and thermoluminescence ages—11 of which are found in Northern Thailand. These zones are depicted in Figure 4.4. In 1996, Rhodes *et al.* observed faulting along Chiangmai basin and discovered young faulting within Cenozoic sediments. Woodward-Clyde Federal Services (1996, 1998) provided evidences on Three Pagodas Fault in Western Thailand as well as in Tavoy, Tennasserim and Kungyaungale faults located along the borders of Myanmar. Using trenching methods, Rymer *et al.* (1997) confirmed the Late Quaternary faulting on Mae Chan fault. In 2004, Rhodes *et al.* observed movements in Mae Kuang Fault which is situated northeast of Chiangmai.

The Three Pagodas and Mai Ping faults are prominent features in western part of the country which form zones within the range of 25 km wide of northwest-southeast directions. (Morley, 2002) Chiang Rai fault is located in the outermost northern part of Thailand. Thoen and Phrae fault zones are also in the northern part. Only a few earthquakes of low magnitude were recorded along these fault zones. Another fault zone in the north is the Moei Uthai Thani fault. Unlike the previous zones, the magnitudes of the few earthquake events that were recorded in this zone were quite high. Mae Tha is an arc shaped fault zone approximately 100 km in length and concaves towards Chiang Mai. On the other hand, Si Sawat is a rupture zone near the Three Pagodas fault that follows a northwest-southeast path. (Shrestha, 1987) Mae Kuang is a predominantly left-lateral strike slip fault with a total slip of roughly 3.5 km. (Rhodes *et al.*, 2004) Ranong and Khlong Marui are northeast-striking and a suspected left-lateral strike-slip fault. These faults have no associated seismicity (Fenton and Sutiwanich, 2005).

1	Mae Chan Fault
2	Fang Fault
3	Mae Saraing Fault Zone
4	Mae Rim Fault
5	Mae Tha Fault Zone
6	Wang Nua Fault
7	Mae Chang Fault
8	Thoen Fault Zone
9	Phrae Fault Zone
10	Hot Fault
11	Moei Fault Zone
12	Si Sawat Fault Zone
13	Three Pagodas Fault Zone
14	Ranong Fault Zone
15	Klong Mauri Fault Zone
16	Ao Luk Fault Zone
17	Khlong Thom Fault Zone
18	Kantang Fault
19	Saba Yoi Fault
20	Khok Pho Fault
21	Yala Fault
22	Betong Fault
23	Bang Pakong Fault

Figure 4.4 Active and suspected active faults in Thailand (Fenton *et al.*, 2003)

In the light of activeness of a tectonic fault, Hinthong (1995) and Charusiri *et al.* (1999), in their inventory of active faults and fault zones in Thailand, have adopted a systematic classification. Hinthong categorized the active faults as potentially active, historically and seismologically active, neotectonically active and tentatively active based principally on the available data on activities of the faults. On the other hand, Charusiri *et al.* (1999) recognized three ranks of active faults namely active, potentially active and tentatively active. In both investigations, Three Pagodas Fault Zone, whose southeastward extension passes very close to Bangkok, is regarded as active fault based on evidences from epicentral and hot spring distribution, heat flow data and focal mechanisms (Won-in, 1999).

Other major fault zones which may be considered as potentially active in Thailand are listed in Tables 4.2 and 4.3 with the corresponding fault parameters taken from different sources as indicated in the footnote.

Table 4.2 Seismic source parameters of major faults in Thailand (Fenton *et al.*, 2003)

Fault Zone	Length (km)	Slip Rate (mm/yr)	Maximum Credible Magnitude
1. Three Pagodas	350	0.5-2.0	7.5
2. Mae Chan	140	0.3-3.0	7.5
3. Thoen	120	0.6	7.5
4. Pua	68	0.6	7.25
5. Phrae Basin	59	0.1	7
6. Phrae Fault Zone	51	0.1	7
7. Phayao	28	0.1	7
8. Nam Pat	35	0.1	7
9. Long	56	0.1	7

Table 4.3 Seismic source parameters of major faults in Thailand (Shrestha, 1987)

Fault Zone	Length (km)	Slip Rate (mm/yr)	Maximum Credible Magnitude
1. Moei Uthai Thani	250	0.76	5.6
2. Mae Tha	100	0.59	5.5
3. Chiang Rai	-	3.69	4.9
4. Si Sawat	-	0.73	5.9

The empirical relationships for surface rupture length and rupture area as proposed by Wells and Coppersmith (1994) are applied to calculate the maximum moment magnitude for each fault in Table 4.2. The length specified for Three Pagodas is the total fault length while for other fault zones, the given length refers to the fault length exhibiting recent faulting. It was mentioned that Three Pagodas has a

complex geometry which suggests that it is highly improbable that the entire fault ruptures in a single event. The segmentation model of Woodward-Clyde Federal Services (1998) is utilized in order to come up with an estimate of the maximum magnitude for this fault (Fenton *et al.*, 2003). From Equation 4.5a, a moment magnitude of 7.5 corresponds to a surface rupture length of about 122 km for Three Pagodas Fault Zone. On the other hand, source parameters listed in Table 4.3 are approximated using the available earthquake data from Nutalaya *et al.* (1985) and TMD (1986). However, empirical relations employed in the process were not mentioned.

Of interest in this part of the research is the seismic fault of active nature that is situated near Bangkok. The essence of this chapter is to provide a comprehensive review and summary of available information regarding the activity of seismic faults in Thailand. In this manner, the faults of active nature situated near Bangkok are determined with the corresponding source parameters approximated by a number of researchers.

A number of figures are depicted showing the proximity of tectonic faults to the city. Figure 4.5 depicts the geological map of Three Pagodas fault zone. It illustrates the strands of the fault zone that appear to splay to E-W and NNW-SSE striking strands. Also the zone trending into the NW corner of the Gulf of Thailand is emphasized. Figure 4.6 illustrates the outcrop maps illustrating some of the identified traces of Mae Ping and Three Pagodas fault zones. The latter lies to the south and parallel to the former with the trace further SE of Mae Ping fault zone not well defined (Morley, 2002).
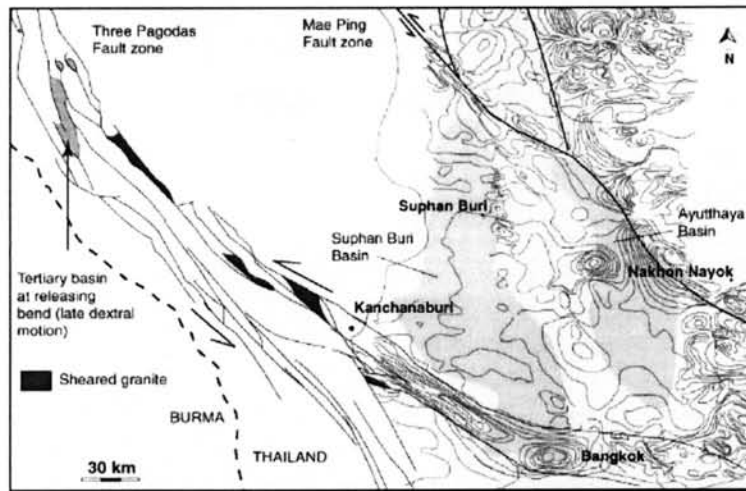
Figure 4.5 Geological map of Three Pagodas Fault Zone (Morley, 2002)
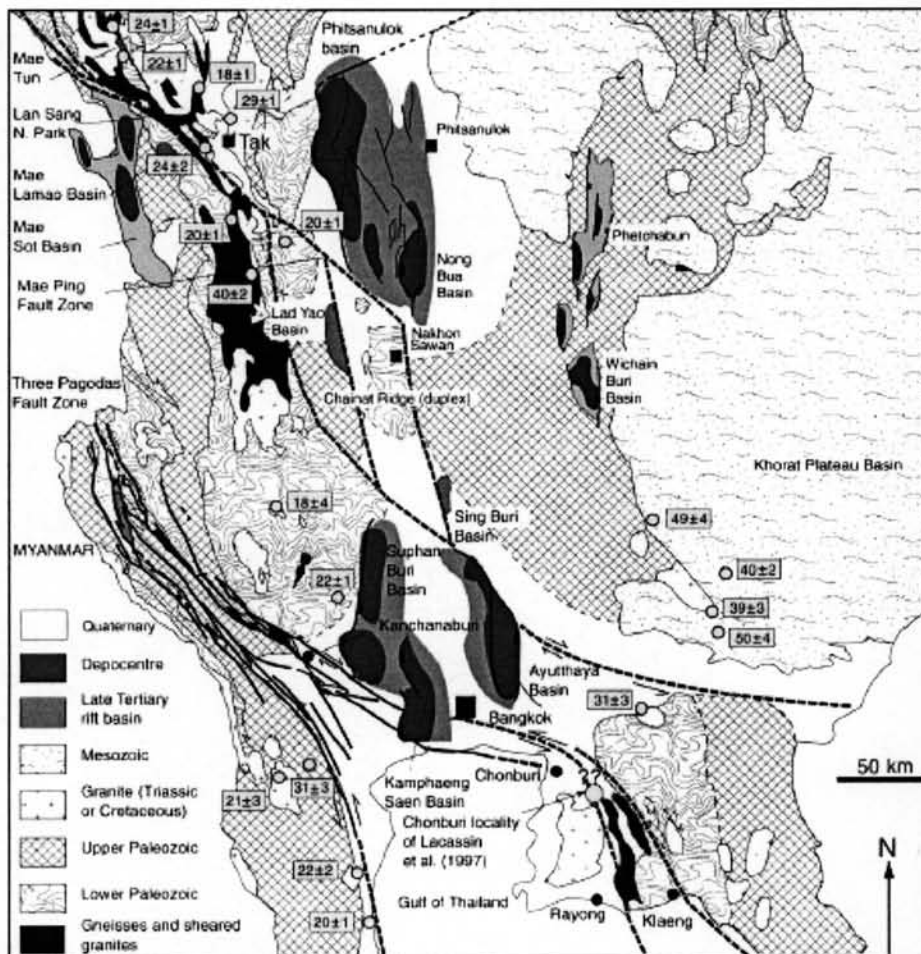

Figure 4.6 Geological map of known and interpreted traces of the Mae Ping and Three Pagodas Fault Zone (Morley, 2002)