CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Five Tertiary basins in northern Thailand were chosen for the study area, namely Mae Moh coal field, Chiang Muan coal field, Mae Teep coal field, Ngao coal field, and Wang Nua coal field. Nine hundred and forty one samples of coal, sediment, gypsum, pyrite, gastropod, and bivalve were collected. These samples were studied by using proximate and ultimate analyses, X-ray diffractometry, X-ray fluorescence spectrometry, induced couple plasma, coal petrography, sulfur isotope analyses, carbon isotope analyses, and oxygen isotope analyses to determine the depositional process, sediment sources, changes in depositional environments, and source of sulfur.

5.1 Mae Moh coal field

According to sedimentary sequences of Mae Moh coal field could be reconstructed the environment of deposition from the beginning of sedimentation in Tertiary time. First of all, the Huai King Formation are clearly fluviatile of high energy deposits and the channel characters are produced. The evidence of repeating fining upward sequences throughout the formation indicated the rapid basin filling, which could reflect the extensional tectonic during the beginning of basin rifting. The continuous movement of fault system must have been keeping up lifting long enough to produce such thick repeating sedimentation sequences.

The successive formation of Na Khaem, which reflected the long period of comparatively stable time of Mae Moh tectonism with water log due to the thick sequence of fine-grained sediments together with coal deposits. The alternated series of mud rock facies and coaly facies, and gradually changed from fluviatile environment to swamp environment of S coal zone at the lower part of Na Khaem Formation (Member III) indicated the cease of strong tectonic activities. Thick organic layer those produce thick coal bed especially of Q zone and K zone indicated the long time continuous slowly subsidence of the basin. The depositional environment of Na Khaem Formation was general dominated by lacustrine and forest swamp. The coal is a massive seam and thick in the central part of the basin, but is splitted in the north and south parts of the basin indicated that these was deep water lacustrine or swamp. At the upper part of the sequence, the basin is closed to the seashore. There were marine incursions at upper part of Na Khaem Formation, which indicated by sulfur isotope analyses.

The depositional environment of the lower sequence of Na Khaem Formation, underburden zone was calcium-silica rich lacustrine environment or lake deposit with some calcareous claystone (quartz 54.1 %, calcite 36.6 %) (Table 5.1). This zone is high concentration of SiO_2, Al_2O_3, and CaO (36 6, 11.6 and 14.7 % respectively) (Table 5.2). The trace element of Ba and Zn (166 and 218 ppm respectively) (Table 5.3) are high concentration in the underburden.

In Q zone, the depositional environment was silica rich lacustrine environment and lake deposit of claystone and coal (quartz 82.3 %). Kaolinite (10.8 %), illite (5.28 %), chlorite (0.15 %), and montmorillonite (1.20 %) were found in this zone could derived from the weathered rhyolite flanked the Mae Moh basin. High quartz content indicated strongly influx of silica transported during this period. The major oxides of Q zone are high concentration of SiO_2 (46.4 %) and Al_2O_3 (13.5 %). The trace

Table 5.1 Average semi-quantitative XRD analysis result of sediment samples from Mae Moh, Chiang Muan, Mae Teep, and Wang Nua coal fields (%).

Area	Zone	Mont	Chlo	Ill	Kaol	Qtz	Cal	Gyp	Py	other
Mae Moh	RB	-	-	1.92	6.07	84.9	3.34	3.02	-	0.75
	I	0.49	-	0.78	3.95	89.1	2.25	0.97	1.22	1.24
	TZ	-	-	0.96	4.66	91.8	1.15	0.07	-	1.36
	J	0.15	-	3.10	4.99	46.0	41.3	1.94	0.90	1.62
	OB	4.01	-	4.77	6.77	62.6	16.0	0.00	1.14	4.71
	K	-	-	2.38	2.20	8.56	82.1	2.15	2.10	0.51
	IB	-	0.86	4.47	3.75	25.9	57.6	0.88	4.28	2.26
	Q	1.20	0.15	5.28	10.8	82.3	-	-	-	0.27
	UB	-	-	2.06	3.32	54.1	36.6	-	3.92	-
Chiang Muan	OB	-	-	1.02	7.22	78.1	12.9	0.04	0.17	0.55
	U1	-	-	2.08	2.69	92.4	0.26	2.38	-	0.19
	IB1	0.74	-	1.66	3.68	92.1	-	0.74	-	1.08
	U2	0.41	-	1.02	2.11	91.2	2.79	0.19	-	2.28
	IB2	-	-	-	0.41	98.0	0.61	-	-	0.98
	LM	2.86	-	1.71	2.29	92.0	1.14	-	-	-
	IB3	1.60	-	0.60	2.19	88.1	-	-	-	7.51
	LS	2.46	-	-	2.46	95.1	-	-	-	-
	UB	1.04	-	-	0.85	96.4	-	-	-	1.71
Mae Teep	OB	4.18	3.95	2.36	6.98	69.6	2.67	0.16	-	10.1
	MS	-	-	9.70	15.4	62.1	-	-	-	12.8
	UB	-	-	0.55	4.32	79.9	15.2	0.05	-	-
Wang Nua		-	-	4.53	20.4	74.3	-	0.77	-	-

Remark: Mont: montmorillonite Chlo: chlorite Ill: illite Kaol: kaolinite Py: pyrite
Qtz: quartz Cal: calcite Gyp: gypsum other: the others minerals

Table 5.2 Average geochemical analysis results of major oxide of Mae Moh, Chiang Muan, Mae Teep, Wang Nua, and Ngao coal fields (%).

Area	Zone	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	SO_3	LOI
Mae Moh	RB	16.1	2.16	7.41	2.97	1.45	0.07	0.17	0.15	57.5	0.79	1.41	9.82
	I	14.1	1.74	4.36	1.88	1.24	0.06	0.24	0.07	47.7	0.54	1.24	26.8
	TZ	16.4	3.39	4.63	2.36	2.15	0.06	0.27	0.11	57.8	0.73	1.12	11.0
	J	9.87	11.5	5.01	2.04	1.29	0.06	0.27	0.15	22.4	0.33	2.71	44.4
	OB	10.4	10.9	6.00	2.37	2.00	0.11	0.20	0.14	42.6	0.49	0.88	23.9
	K	2.83	11.4	3.59	0.80	0.54	0.13	0.14	0.15	8.32	0.14	1.10	70.9
	IB	9.71	27.9	7.32	1.71	1.64	0.16	0.21	0.20	24.9	0.39	1.19	24.7
	Q	13.5	0.48	2.18	1.87	0.73	0.02	0.17	0.05	46.4	0.53	0.63	33.4
	UB	11.6	14.7	5.54	2.43	1.59	0.14	0.19	0.14	36.6	0.55	0.76	25.8
Chiang Muan	Q	11.8	0.51	5.23	1.36	1.22	0.06	0.87	0.07	72.2	0.60	0.14	5.94
	OB	15.0	7.69	5.09	2.03	0.81	0.13	0.19	0.10	54.0	0.61	0.98	13.4
	U1	13.1	1.75	6.40	1.70	0.86	0.06	0.20	0.06	38.4	0.39	5.26	31.8
	IB1	18.1	0.77	5.65	2.34	1.08	0.04	0.21	0.08	59.5	0.76	1.23	10.2
	U2	14.6	2.02	4.97	1.69	1.08	0.04	0.24	0.06	37.1	0.39	3.13	34.7
	IB2	9.62	1.70	4.35	0.82	0.83	0.07	0.10	0.05	73.9	0.64	0.17	7.75
	LM	13.7	3.37	2.05	1.29	1.19	0.02	0.27	0.04	24.6	0.33	1.21	51.9
	IB3	22.3	0.80	6.96	1.94	1.53	0.04	0.17	0.08	50.7	0.70	0.17	14.6
	LS	13.7	1.37	2.60	0.97	1.07	0.02	0.36	0.02	27.6	0.34	1.46	50.5
	UB	16.1	0.60	5.43	1.24	1.10	0.05	0.10	0.05	64.0	0.71	0.14	10.5
Mae Teep	OB	11.3	4.18	9.00	2.45	1.83	0.15	0.20	0.16	47.5	0.65	0.69	21.9
	MS	7.81	0.97	6.68	1.66	0.74	0.08	0.14	0.12	20.9	0.32	1.25	59.3
	UB	12.3	7.10	4.09	1.84	1.08	0.08	0.19	0.13	60.1	0.72	0.59	11.8
Wang Nua	OB	17.1	0.24	5.72	2.10	0.76	0.02	0.18	0.10	56.1	1.29	0.58	15.8
	Coal	0.54	0.62	1.69	0.47	0.49	0.02	0.05	0.08	12.3	0.13	1.31	82.3
Ngao		1.12	0.68	0.93	0.59	0.13	0.01	0.05	0.03	11.1	0.18	1.38	84.9

Table 5.3 Average geochemical analysis results of trace elements of Mae Moh, Chiang Muan, Mae Teep, Wang Nua, and Ngao coal fields (ppm).

Area	Zone	V	Cr	Co	Ni	Cu	Zn	As	Zr	Ba	Pb	B	Mo	Sb
Mae Moh	RB	64.9	39.9	14.0	43.8	26.9	181	30.3	43.3	371	51.4	-	-	-
	I	37.2	19.2	14.0	45.9	27.1	184	68.0	8.31	44.4	51.3	-	-	-
	TZ	29.9	14.5	7.9	25.3	16.5	94.9	19.5	4.05	138	21.4	-	-	-
	J	82.4	42.3	17.9	51.9	28.2	164	126	28.2	376	36.3	-	-	-
	OB	68.0	2.5	16.9	78.5	37.1	222	35.1	50.4	163	44.9	-	-	-
	K	52.9	18.6	17.8	52.4	37.6	210	169	48.6	194	30.7	-	-	-
	IB	56.6	18.5	16.4	94.6	32.7	283	12.2	25.9	138	48.1	-	-	-
	Q	77.5	30.7	17.1	43.9	39.3	152	101	105	175	38.0	-	-	-
	UB	71.5	28.5	16.5	74.2	38.2	218	36.4	63.5	166	44.9	-	-	-
Chiang Muan	Q	25.2	50.7	18.7	56.2	11.6	123		3.31	66.3	46.3	32.9	5.46	
	OB	26.0	20.3	10.4	38.3	31.4	198	9.02	6.57	761	64.4	28.6	17.3	41.5
	U1	86.3	39.0	16.7	66.4	34.0	247	138	20.2	203	52.7	30.9	16.7	14.7
	IB1	21.4	23.1	8.52	37.7	27.2	192	-	5.82	49.3	55.9	31.2	-	-
	U2	49.9	21.7	15.6	62.9	35.5	205	154	9.50	199	44.8	27.4	6.40	36.7
	IB2	18.9	16.7	18.5	28.4	8.43	165	-	3.33	38.6	46.1	25.7	12.9	-
	LM	28.0	20.3	20.7	43.5	31.8	174	64.7	8.83	1056	50.3	28.2	8.94	-
	IB3	34.4	43.1	12.2	62.8	28.5	194	-	3.53	77.4	60.9	18.6	-	86.4
	LS	233	56.7	15.0	100	57.7	301	115	11.3	899	62.8	16.8	4.34	17.7
	UB	31.6	12.4	8.79	26.9	15.1	133	-	2.88	86.8	47.0	21.3	9.42	-
Mae Teep	OB	84.5	38.8	18.3	55.4	43.1	179	54.1	57.9	171	43.4	-	-	-
	MS	87.7	61.3	19.3	42.1	47.9	113	173	104	240	31.1	-	-	-
	UB	74.9	46.5	16.5	69.3	74.9	150	32.7	106	159	45.7	-	-	-
Wang Nua	OB	148	186	17.6	20.7	75.4	199	149	83.9	184	32.9	-	-	-
	Coal	181	138	21.7	34.2	59.4	78.1	330	60.7	328	13.5	-	-	-
Ngao		73.1	15.7	19.7	29.4	36.5	217	132	22.2	163	34.8	-	-	-

element of As, Ba, Zn, and Zr are high content in Q zone (14.0-251 ppm of As, 139-221 ppm of Ba, 40.7-228 ppm of Zn, and 42.7-157 ppm of Zr). The source of trace elements could come from weathered rhyolite flanked the Mae Moh basin. The environment of Q zone is shallow water and dried up and occasionally basin fire occurred as indicated by the present of semifusinite and fusinite, the result of burning. Alginite rare in Q zone indicated the water log was not common during the peat accumulation. The high positive sulfur isotope values of total sulfur in coal (+14.4 ‰) and the positive sulfur isotope values of pyrite in Q zone (+4.23 ‰) indicated normal accumulation of sediments in fresh water environment at that time.

In the interburden zone was calcium-silica rich lacustrine environment or lake deposit with some calcareous claystone (quartz 25.9 %, calcite 57.6 %). Pyrite (1.78-11.5 %) referred to strongly reducing environment. The trace element of Ba and Zn high concentration in this zone. The trace elements were supplied by from weathered rhyolite continuously from the Q zone.

Consequently, in the K zone, the environmental deposition was slowly changes from silica rich lacustrine to calcium lacustrine or alkaline environment as indicated by SiO_2/CaO ratio (18.2 to 0.24). The concentration of As, Ba, and Zn are rich in this zone. The concentration of trace elements of V, Cr, Ba, and Pb are high in K zone (range 40.0-71.4 ppm of V, 0.01-46.0 ppm of Cr, 126-268 ppm of Ba, and 10.3-49.0 ppm of Pb). The trace element pattern of V-Cr-Co-Ba-Pb show that the source of trace elements could come from weathered rhyolite flanked the Mae Moh basin. The siliceous diatom rich in the K zone could be resulted from the input of volcanic ash into the basin (Ratanasthien and others, 1997). In the K zone was inferred by the sporinite rich coal whereas the tree trunk remains or texto-ulminite indicated the area of forest swamp. The water in the lacustrine was fresh water as indicated by freshwater diatom and dominated thin walled alginite and the present of sporinite. The high positive sulfur isotope values of total sulfur in coal (+14.8 to +17.4 ‰), high positive sulfur isotope value of pyrite (+10.9 ‰), and high positive sulfur isotope values of gypsum (+11.2 to +12.2 ‰) confirmed the fresh water environment. The present of the macrofossil (Ratanasthien and others, 1997) could indicate the catastrophism during this period. However, the carbon isotope values of Planorbidae in K1 (-1.8±1.4 ‰), *Bellamya* sp. from K2 (+3.5±0.7 ‰), and *Bellamya* sp. from gastropod bed in between K3 and K4 (+5.4±0.9 ‰) indicated that the depositional area closed to the seashore.

In the overburden zone was silica rich lacustrine environment or lake deposit with some calcareous claystone (quartz 62.6%, clay minerals 15.6%, and calcite 16.0%). The concentration of trace element of Ba and Zn are high in this zone. The trace elements were supplied by weathered rhyolite continuously from the K zone.

In J zone, the lower portion is depositional environment is freshwater under the oxic condition and changed to brackish environment under periodic anoxic condition. The lenses of intrabasinal clasts of pumice were found in J1, J2, J4, and J5. It indicated that there were volcanic eruptions during J zone deposited. The trace element of As, Ba, Cr, V, and Zn high concentration in J zone (0.42-472 ppm of As, 104-1150 ppm of Ba, 2.39-121 ppm of Cr, 1.89-273 ppm of V, and 30.0-365 ppm of Zn). The concentration of Ba is very high in this zone especially J3 to J6. The intrabasinal clast of pumice is mainly source of trace elements supplied in to the basin during coal deposited. The high concentration of Ba has associated with the Ba in rhyolite. It supported that there was rhyolitic eruption at that time. The others sources of trace elements were supplied by from weathered rhyolite flanked the Mae Moh basin.

At J zone the environmental deposition was abruptly change to strongly high calcium rich lacustrine (CaO 11.5%, calcite 41.3%). High *Melanoidis* sp. association with this J-zone indicated the poor quality of water. Alginite and cutinite association in the coals throughout J-zone indicate the intermediate depth to shallow water. The changing water level to shallow water led to refill the trace element from the surrounding weathered rocks. The variation of alginite especially the present of lamaginite (alginite B) with various kind of telalginite (alginite A) such as *Reinschia, Pila* algae, *Botryococcus sp.* and other *Botryococcus* relate could also indicated the change of water qualities. The present of fusinite rich layer especially in the J6 indicated the bush fire around the basin and produced char into the basin.

The low to very low negative sulfur isotope values of total sulfur in high sulfur content coal from J1 to J4 zone (-0.5 to –18.8‰) and pyrite rich could be resulted from marine incursion. Moreover that ratio of carbon and sulfur values are supported that there were marine incursion in J zone. The carbon isotope values of *Bellamya* sp. from J5 (+4.6±0.7 ‰), *Bellamya* sp. from J4 (–3.4±0.4 ‰), and *Melanoides* sp. from J4 (-1.7±1.4 ‰) indicated that the depositional area closed to the seashore. It can be concluded that the basin might be opened to the sea. So marine incursions could periodically occur during the deposition of J zone that supported by sulfur isotope study.

In I zone, this zone was calcareous rich lacustrine environment or lake deposit with some calcareous claystone with well preserved *Margarya* sp. and *Hyriopsis* sp. The low negative sulfur isotope values in pyrite (-6.17 and –11.0 ‰) and the abundance of framboidal pyrite indicated the marine incursion supported by the decreasing of Sr/Ca ratio from lower to upper sequence (208.4×10^{-4} to 28.34×10^{-4}) (Tankaya, 2001).

The Mae Moh coal bearing formation was terminated by the flooding resulted in deep water lacustrine which enrich in sulfate solution. Huai Luang Formation (Red bed) was in silica rich lacustrine environment (quartz 84.9%). Barium concentration (184-924 ppm) is very high in Red Bed zone. The sulfate solution is rich in this zone (gypsum 18.1 %, Anhydrite 0.88%). The high positive value of sulfur isotope from gypsum (+16.1‰ to +18.6‰) indicated there were marine incursion in Huai Luang Formation. It can be concluded that there were marine incursions in Mae Moh coal field since J zone until in Huai Luang Formation.

5.2 Chiang Muan coal field

According to sedimentary sequences of Chiang Muan coal field could be reconstructed the environment of deposition from the beginning of sedimentation in Tertiary time. First of all, the lower portion of the underburden is clearly fluviatile of high-energy deposit. At upper portion of underburden, the fine grained sedimentary rock indicated that there was deposited in silica rich lacustrine environment or lake deposit (quartz 96.4 %).

In the lower coal seam, at the lower split coal seam (LS zone), there was silica rich lacustrine environment or lake deposit (quartz 95.1 %). The gelinite formation indicates the oxidation at surface of peat deposit. The texto-ulminite and tree trunk remains indicate the area of herbaceous to forest swamp. The presence of semifusinite indicates that there was at times shallow water and dry periods that likely led to natural fires before the deposition. The claystone in the interburden 3 zone was silica rich lacustrine environment or lake deposit (quartz 88.1 %). In the lower massive coal seam (LM zone), there was silica rich lacustrine environment or lake deposit (quartz 92.0 %). The lower coal seam is high concentration of As (64.7-115 ppm), Ba (187-1926 ppm), V (19.6-446 ppm), and Zn (91.5-339 ppm). The concentration of Ba is very high in coal of lower split coal seam (LS zone) the lower massive coal seam (LM zone). The trace elements in lower coal seam were supplied by the volcanic rock surrounding Chiang Muan basin. The alginite-rich and sporinite-rich coal and tree trunk remains in this zone indicated that the depositional area was forest swamp. The water in the depositional area was essentially freshwater. The association of the macrofossil; mastodonts (Gomphotheriidae of *Tetralophodon* cf. *xiaolongtanensis*), Suidae (*Propotamochoerus/Hippopotamodon* spp.), Tragulidae (*Dorcatherium* small species), Bovidae, Rhinocerotidae, primates of Hominoidea genera and large species (*?Lufengpithecus keiyuanensis*) and tree trunks in both of the lower split coal seam and the lower massive coal seam could indicate the catastrophism during this period.

The lower coal seam of Chiang Muan coal field is good quality. The proximate and ultimate analysis shows higher coalification. This zone deposited in forest swamp with good quality water. The tree trunk remains supported that it was rich of tree in the forest. High concentration of Ba in lower coal seam indicated strongly volcanic activity refill into the basin during coal deposited.

In the interberden 2 (IB2), this zone is separated lower coal zone and upper coal zone. This zone is very thick in the southern part of the basin and thin into the northern part of the basin. This zone was silica rich lacustrine environment (98 %). There was fluviatile of high-energy deposits in the middle portion of this zone. This zone is dominant of quartz and apatite. Palsson and others (1980) concluded that the amount of apatite in a rock is associated with the erupted volume of volcanic rocks. Since the southern part of Chiang Muan mine is flanked by Jurassic volcanic rocks, this volcanic rocks may have been the source, and controlled the amount, of apatite that occurs mainly in this zone.

In the upper coal seam, at upper coal seam 2 (U2), this zone was silica-calcium rich lacustrine environment or lake deposit with some calcareous claystone (quartz 91.2 %, calcite 2.79 %). The concentration of As (35.6-402 ppm), Ba (41.4-448 ppm), and Zn (159-250 ppm) are high in this zone. The trace elements upper coal seam 2 was supplied by the weathered volcanic rock surrounding Chiang Muan basin. The densinite and collinite indicated that the depositional area was forest swamp. The environment of the upper coal seam 2 zone is shallow water and dried up as indicated by the present of semifusinite, the result of burning. The present of the macrofossil; Suidae (*Propotamochoerus/Hippopotamodon* spp.), Tragulidae (*Dorcatherium* small species), Bovidae, Rhinocerotidae, primates of Hominoidea genera and large species (?*Lufengpithecus keiyuanensis*) could indicate the catastrophism during this period and the very low negative value of sulfur isotope from pyrite (-11.3 ‰ to –15.5 ‰) indicated the incursion of marine water into the basin. The source high concentration of sulfur and pyrite in upper coal seam2 could come from marine incursion during coal deposit.

At the interburden 1 zone (IB1), which separated upper coal seam1 (U1) and upper coal seam 2 (U2), was in silica rich lacustrine environment or lake deposit (quartz 92.1%). Kaolinite (3.68 %) and illite (1.66 %) were found in this zone could derived from the weathered Jurassic volcanic rocks flanked the Chiang Muan basin.

In the upper coal seam 1 (U1), this zone was in silica rich lacustrine environment or lake deposit (quartz 92.4%). The concentration of As (108-159 ppm), Ba (64.4-379 ppm), V (16.3-186 ppm), and Zn (155-498 ppm) are high in this zone. The trace elements upper coal seam 1 was supplied by the weathered volcanic rock surrounding Chiang Muan basin. The alginite-rich and sporinite-rich coal and tree trunk remains in this zone indicated that the depositional area was forest swamp. The water in the depositional area was essentially freshwater. The environment of the upper coal seam 1 (U1) zone is shallow water and dried up as indicated by the present of semifusinite, the result of burning. The very low negative sulfur isotope values of total sulfur in high sulfur content coal from the upper coal seam 1 (-9.74 ‰ to –18.2 ‰) indicated the incursion of marine water into the basin during coal deposited. This supported that marine incursion is the others cause of high sulfur in coal in this zone. Moreover, the ratio between carbon and sulfur values support that there were marine incursions in both of the upper coal seam 1 and the upper coal seam 2 zone. The Chiang Muan coal bearing formation was terminated by the flooding resulted in deep water lacustrine of silica-calcium rich lacustrine at overburden zone (quartz 78.1 %, calcite 12.9 %). The concentration of Ba (26.5-1455 ppm) is high in the overburden zone show that was supplied by volcanic rock surrounding the basin.

5.3 Mae Teep coal field

According to sedimentary sequences of Mae Teep coal field could be reconstructed the environment of deposition from the beginning of sedimentation in Tertiary time. First of all, the lower portion of the underburden is alluvium deposit.

The upper portion of underburden was deposited in silica rich lacustrine environment or lake deposit with some calcareous claystone (quartz 79.9%, calcite 15.2%).

In coal seam, this zone was in silica rich lacustrine environment or lake deposit (quartz 62.1%) and enrich of iron and carbonate solution. Siderite (22.6-67.8 %) referred to strongly reducing environment. It means that there was oxidation environment in close system of basin. After peat accumulation, the basin changed to strongly reducing environment. The carbonate solution would react with iron to form siderite. The concentration of As (10.8-359 ppm), Ba (176-299 ppm), V (65.4-129 ppm), Zn (9.22-296 ppm), and Zr (12.1-199 ppm) are high in the coal seam. The trace elements were supplied by weathered rhyolite flanked the Mae Teep basin. The tree trunk remains, densinite, and texto-ulminites indicated the area of forest swamp. The alginite-rich and sporinite-rich coal and tree trunk remains in this zone indicated that the depositional area was forest swamp. The water in the depositional area was essentially freshwater. The environment of Mae Teep coal is shallow water and dried up as indicated by the present of semifusinite, the result of burning.

The Mae Teep coal bearing formation was terminated by the flooding resulted in deep water lacustrine of the overburden zone, which enrich in silica (quartz 69.6 %). Kaolinite (6.98 %) and illite (2.36 %) were found in this zone could derived from the weathered rhyolite flanked the Mae Teep basin.

5.4 Wang Nua coal field

According to sedimentary sequences of Wang Nua coal field could be reconstructed the environment of deposition from the beginning of sedimentation in

Tertiary time. First of all, the lower unit (Unit A) was deposited in lacustrine environment.

The successive formation of middle unit (Unit B), coal unit, which reflected the long period of quiet time of Wang Nua tectonism due to the thick sequence of fine-grained sediments. This unit was silica rich lacustrine environment or lake deposit (quartz 74.3 %). Kaolinite (20.4%) and illite (4.53%) were found in this zone could derived from the weathered granite flanked the Wang Nua basin. The concentration of As, Ba, V, and Zn are high in the coal seam (348 ppm, 436 ppm, 191 ppm, and 146 ppm respectively). The trace elements were supplied by weathered granite flanked the Wang Nua basin. The tree trunk remains, densinite, and texto-ulminites indicated the area of forest swamp. The environment of coal in Wang Nua coal field is shallow water and dried up as indicated by the present of semifusinite. The carbon and oxygen isotopic study shows that this was warm condition during deposition. The low negative sulfur isotope values of total sulfur in high sulfur content coal from Wang Nua coal field (-5.86 ‰) indicate marine incursion during coal deposited. Moreover the carbon isotope values of *Brotia* sp. (-2.91±0.9 ‰) indicate that the depositional area closed to the seashore. It can be concluded that it might be marine incursion in Wang Nua coal field.

The Wang Nua coal bearing formation was terminated by the flooding resulted in deep water lacustrine of the lower portion of the upper unit (Unit C) and changed to fluvial deposit at the upper portion of Unit C.

5.5 Ngao coal field

According to sedimentary sequences of Ngao coal field could be reconstructed the environment of deposition from the beginning of sedimentation in Tertiary time. First of all, the lower unit (Unit A) was deposited in lacustrine environment.

The successive formation of middle unit (Unit B), coal unit, which reflected the long period of quiet time of Ngao tectonism due to the thick sequence of fine-grained sediments and coal. This unit was deposited in lacustrine environment or lake deposit. The concentration of As, Ba, and Zn are high in coal seam (132 ppm, 168 ppm, and 217 ppm respectively). The trace elements should be supplied by weathered volcanic rock from the southern part of the basin. The texto-ulminite and tree trunk remains indicate the area forest swamp. The semifusinite indicated the dried up of the basin, which indicates an arid to semi-arid condition of the basin. The low negative sulfur isotope values of total sulfur in high sulfur content coal from Ngao coal field (-2.94 ‰) indicate marine incursion during coal deposited.

The Ngao coal bearing formation was terminated by the flooding resulted in deep water lacustrine of the lower portion of the upper unit (Unit C) and changed to fluvial deposit at the upper portion of Unit C.

There are some reports claiming that there was a marine incursion in northern Thailand. Ratanasthien (1989) reported an assemblage of tropical pollen with mangrove elements from the Mae Lamao basin. The pollen assemblage includes rare to common mangrove pollen including *Florschuetzia* spp. (sonneratioid type), *Zonocosites ramonae* (rhizophoroid type), and *Spinizonocolpites* spp. (nypoid type). This pollen assemblage is evidence of coastal vegetation, suggesting there was a marine incursion in the Mae Lamao basin during deposition. Waton (1996) also reported mangrove pollen from some horizons of core samples from Phrae basin including *Acrostichum aureum*-type, *Acrostichum speciosum*-type, *Florschutzia trilobata*, *Florschuetzia semilobata*, and *Zonocosites ramonae*. Waton concluded that the depositional environment was a preponderance of continental lacustrine (deep and shallow water/ ephemeral) depositional settings and tentative evidence from several samples suggested the possibility of slight marine influences on deposition for those samples.

The relationship between these study basins can be correlated only the Mae Moh, Chiang Muan, Ngao and Wang Nua basins. Mae Moh and Chiang Muan basins are closely related with time and events as they were recorded by paleomagnetic data (Benammi and others, 2002; Chaimanee and others, 2003; Suganuma and others, 2002) and marine incursion events by sulfur isotopic study (Figure 5.1). The Ngao and Wang Nua basins are also falling in the same event of marine incursion events by sulfur isotopic study but Mae Teep basin does not show any evidence of marine incursion during depositing period.

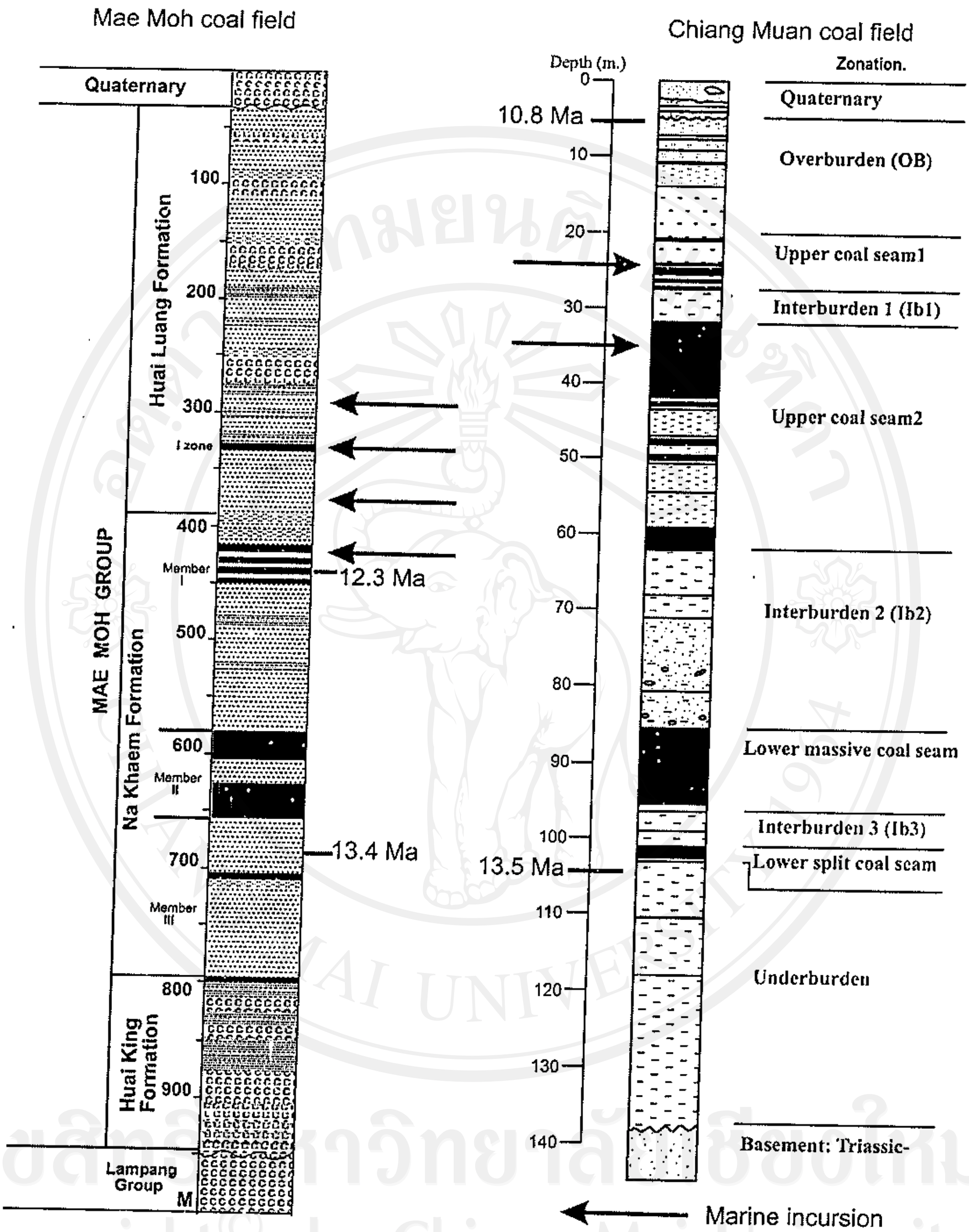

Figure 5.1 Correlation of paleomagnetic data and marine incursion events between Mae Moh and Chiang Muan coal fields. Please notice they are not the same depth scale (modified from Sompong and others, 1996; Corsiri and Crouch, 1985; Chaodumrong, 1985; Uttamo, 2000; Benammi and others, 2002; Chaimanee and others, 2003; Suganuma and others, 2002).

5.6 Recommendations

The study of the depositional environment of coal fields in northern Thailand need more the further study as follow:

1. There are pyrite spot in claystone layer in J zone, especially J1 and J2. This study collected pyrite spot from both of J1 and J2. But it was quickly oxidized, so this study could not prepare the sample from the pyrite spot from J zone. The sulfur isotopic study of pyrite in J zone needs more study and correlate with the sulfur isotope study in coals.
2. The carbon and oxygen isotopic study need more study for every layer contained the gastropod and bivalves. Before study carbon and oxygen isotope, the sample should be studied the mineral in the sample. The carbon and oxygen isotopic study from coal sample is very interesting to correlate with The carbon and oxygen isotopic study from shell samples.
3. Paleomagnetic study is very important for Mae Teep, Wang Nua, and Ngao coal fields to correlate with Mae Moh and Chiang Muan coal fields. Moreover, Wang Nua and Ngao coal fields need to collected more samples in every layer to study the mineralogy, geochemistry, isotopic study of carbon, oxygen, and sulfur.
4. Diatom and ostracod need to deeply identify type for defining the depositional environment of diatom and ostracod.
5. For the source of trace elements, the igneous rocks surrounding the study areas need to study the geochemistry.
6. The X-ray diffractometry study need more treated sample in the sample contained montmorillonite.
7. The study of algae, pollen, and spore in Mae Teep, Wang Nua, and Ngao coal fields is very important to correlate with Mae Moh and Chiang Muan coal fields.
8. The trace element of strontium (Sr) is an important element to support marine environment. The further study of geochemistry needs to analyze strontium and correlate with calcium for supporting marine incursion events.