CHAPTER 4

RESULTS AND INTERPRETATION

4.1 Proximate and ultimate analyses

4.1.1 Proximate analysis

Proximate analysis is the analysis of coal as expressed in terms of moisture, ash, volatile matter, and fixed carbon (Table 4.1, 4.2, 4.3, and Appendix B). It provides a general appraisal of coal characteristics.

Moisture content

In low rank coals moisture occurs as bulk or free water (in the exterior or particles and in large pores) within capillaries and weakly bonded to coal surface. Moisture is a critical coal quality parameter and has indirect influence over a variety of other properties. Specific energy is also very sensitive to moisture content.

Ash content

Ash represents the inorganic, non-combustible residue that remains when the coal is burned. It is derived from the various components of the total mineral matter including discrete crystalline minerals, water soluble and inorganic elements.

Volatile matter

Volatile matter is a measure of the thermal decomposition products formed during heating. It is mostly derived from the breakdown of organic components of the coal. Volatile matter is strongly related to coal rank.

Table 4.1 The proximate and ultimate analyses of Mae Moh coals.

Zone		Proximate analysis				Ultimate analysis			
		Moisture	Ash	Volatile matter	Fixed carbon	Carbon	Hydrogen	Nitrogen	Sulfur
		(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
I zone		12.0	31.5	35.0	21.5	46.9	3.92	1.17	2.59
J zone	Min	5.86	11.1	24.3	1.21	10.4	1.6	0.37	1.09
	Max	18.3	64.4	44.8	34.3	55.2	3.97	1.48	20.8
	Averg	11.6	35.0	36.5	17.0	32.2	2.84	0.97	8.52
K zone	Min	14.2	6.61	39.5	27.8	51.1	7.01	1.86	0.25
	Max	18.9	14.2	41.7	36.5	55.8	8.85	2.02	1.68
	Averg	16.7	11.0	40.7	31.7	52.5	8.06	1.93	0.85
Q zone	Min	13.1	9.21	38.6	24.1	46.9	7.22	1.44	1.01
	Max	17.1	17.3	42.4	34.8	51.4	10.3	1.70	1.66
	Averg	15.3	13.6	40.4	30.7	48.9	8.61	1.53	1.24

Table 4.2 The proximate and ultimate analyses of Chiang Muan coals.

Zone		Proximate analysis				Ultimate analysis			
		Moisture	Ash	Volatile matter	Fixed carbon	Carbon	Hydrogen	Nitrogen	Sulfur
		(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
U1	Min	13.6	31.7	25.8	13.1	16.3	2.01	0.49	4.17
	Max	19.3	47.5	32.8	17.3	37.5	3.13	1.01	8.31
	Averg	17.4	37.7	29.3	15.6	24.4	2.48	0.67	6.13
U2	Min	12.8	31.7	17.3	4.50	16.3	2.01	0.49	0.88
	Max	17.4	61.7	30.8	18.3	42.5	3.44	1.05	6.41
	Averg	15.8	52.0	22.6	9.62	33.1	3.10	0.86	2.76
LM		33.1	11.2	32.2	23.5	25.8	16.9	1.09	0.01
LS		20.5	51.9	20.9	6.67	55.8	16.9	1.29	1.48

Table 4.3 The proximate and ultimate analyses of Mae Teep, Wang Nua, and Ngao coals.

Area		Proximate analysis				Ultimate analysis			
		Moisture	Ash	Volatile matter	Fixed carbon	Carbon	Hydrogen	Nitrogen	Sulfur
		(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Mae Teep	Min	6.32	8.16	23.8	8.25	17.7	5.39	0.61	0.00
	Max	14.0	61.6	43.4	39.6	58.9	8.52	2.24	0.22
	Averg	11.3	23.3	36.0	29.4	46.8	6.83	1.59	0.02
Wang Nua	Min	11.3	18.8	38.4	29.3	39.9	3.41	1.04	0.00
	Max	11.6	19.8	39.6	31.2	42.1	4.23	1.06	0.00
	Averg	11.5	19.3	39.0	30.3	41.0	3.82	1.05	0.00
Ngao		12.5	19.6	40.3	27.6	41.2	3.24	1.24	4.19

Fixed carbon

Fixed carbon represents the combustible portion of the residue after removal of moisture and volatile matter. It is obtained by difference (after evaluation of ash and volatile matter) and is not necessarily the true combustible carbon percentage of coal.

4.1.1.1 Mae Moh coal field

Moisture content is high in K3 (18.9%) and low in J1/5 (5.86%). Ash content is high in J3A (64.4%) and low in K3 (6.61%). Volatile matter is high in J6A (44.8%) and low in J3A (24.3%). Fixed carbon is high in K3 (36.5%) and low in J1/5 (1.21%).

4.1.1.2 Chiang Muan coal field

Moisture content is high in LM (33.1%) and low in U2-1 (12.8%). Ash content is high in U2-4 (61.7%) and low in LM (11.2%). Volatile matter is high in LM (32.2%) and low in U2-4 (17.3%). Fixed carbon is high in LM (23.5%) and low in U2-4 (4.50%).

4.1.1.3 Mae Teep coal field

Moisture content is high in MTC5 (14.0%) and low in MTC3 (6.32%). Ash content is high in C3 (61.6%) and low in MTC11 (8.16%). Volatile matter is high in MTC11 (43.4%) and low in MTC3 (23.8%). Fixed carbon is high in MTC5 (39.6%) and low in MTC3 (8.25%).

4.1.1.4 Wang Nua coal field

Moisture content is 11.5%. Ash content is 19.3%. Volatile matter 39.0%. Fixed carbon is 30.3%.

4.1.1.5 Ngao coal field

Moisture content is 12.5%. Ash content is 19.6%. Volatile matter is 40.3%. Fixed carbon is 27.6%.

4.1.2 Ultimate analysis

Ultimate analysis of coal involves determination of the concentration of C, H, N, and S (Table 4.1, 4.2, 4.3, and Appendix B) which carbon and hydrogen occur in the coal substance in combination with each other as complex organic compounds. Carbon occurs in the organic compounds (aromatic and aliphatic) and carbonate mineral. Hydrogen content derived from the organic compound and the moisture in coal, including the hydroxyl group (-OH) in the clay minerals. The carbon and hydrogen contents can indicate the rank of coalification. Chemically, the passage from wood to anthracite is mainly an increase in carbon coupled with a decrease in oxygen. Hydrogen also decreases, but much less rapidly (Francis, 1960). Hydrogen, contents are reflected by a high-hydrogen organic source.

Most of the nitrogen compounds derive from the organic matter and from animal and plant fossils. Nitrogen is present in coal as amino groups or as a substitution for carbon in the ring structure. The nitrogen is derived from this part of protein and mostly from animal matter. The lacustrine environments are the areas where protein from dead animals or algae could deposits with coals. The nitrogen causes air pollution (oxides of nitrogen and photochemical organic compounds) if the coal is burnt at high temperature.

Sulfur content in coal occurs from both the organic and inorganic matter. In the form of inorganic compounds, sulfur is in the form of pyrite, marcasite, and sulfate, whereas organic sulfur can be in forms of mercaptanes and other compounds containing sulfur. In nature, the sulfur can be divided into three forms as followed: pyretic sulfur (FeS_2, FeS), sulfate sulfur, and organic sulfur. Sulfur in coals, apart from the organic protein contribution, is also liberated by the reducing bacteria in the reducing environment. In this environment sulfur from sulfate solution or minerals is liberated. In which case, high sulfur coal, especially those containing the form of framboidal pyrite could indicate the association of high-sulfate water. High sulfate water could be brackish. Both usually rich nutrient supply for both bacteria and other organisms.

General compositions of the plants that are major contributors to the coals are the sugar-complex molecules, mainly cellulose and lignin $(C_6H_{12}O_6)_n$. In the swamp area, the condition is generally an oxidizing environment, the dead plant material usually decomposes into ulmin or humic acid, which is high oxygen. Conditionally, the film of humic acid or ulmin will cover the surface of the organic mass and prevent the penetration of oxygen for further oxidation. Sealing the matter with this film causes reducing conditions. The reducing bacteria, *Desulfovibrio* extracts the oxygen from the surrounding sulfate and nitrate compounds, liberating sulfide and ammonia which escapes. Later, sulfide is deposited with coals in form of iron sulfide or pyrite and/or marcasite.

The overloading from deep burial will cause further dehydration and degasification. The water will be lost from the organic substance and ascend upward accompanied by the diagenetic gasses. Early diagenetic gases include carbon dioxide, ammonia, and sulfur dioxide which will be easily squeezed out. During later diagenesis gas, mainly methane will be driven off. The deeper the burial, the higher is the remaining carbon residue. This condition and less oxygen content gives rise to the higher coal ranks (Ratanasthien and others, 1992).

The weight ratio of Total Carbon (TC) and Total Sulfur (TS) (C/S ratio) is indicator for distinguishing the original deposition under freshwater and marine conditions, and thus give a qualitative indication of the redox status environment of deposition (Berner and Raiswell, 1984; Berner, 1984; Sampei and others, 1997; Sampei and Matsumoto, 2001). High C/S ratio (higher than 5), indicates the mainly oxic (oxygen-rich) sediments in terrestrial depositional environment which results from formation in a coal swamp or a lake. In contrast, low C/S ratio (less than 1.5) can be an indicator that a greater abundance of euxinic (oxygen-poor) basin environments. This combined with evidence of deposition of a more reactive type of organic matter in the remaining oxygenated portions of a basin. In addition, the C/S ratio in the range from 1.5-5 corresponds to poorly laminated sediments deposited under periodic anoxia condition (meaning a range from oxic to anoxic environments).

The weight ratio of total carbon to total nitrogen (C/N ratio) is used for the determination of organic type in depositional environments. The positive intercepts of 0.025 to 0.11 % on the TN axis of the TN-TC regression line suggest that inorganic nitrogen is presented. Generally, freshly deposited organic matter, which is derived mainly from plankton, has C/N ratios of 6 to 9. The C/N ratios of planktonic organisms increase with sedimentation, e.g. the C/N ratio of deep sea (greater 1000 meters) sediments reaches values greater than 10 to 15, due to preferential loss of nitrogen relative to carbon. On the other hand, terrestrial vascular plants and their derivates in sediments have C/N ratios is greater than 15 (Sampei and others, 1997; Sampei and Matsumoto, 2001). Because the higher plants are the main organic producers in the terrestrial environment and they consist mainly of cellulose and lignin they contain fewer nitrogen compounds. The difference of the average C/N ratio in the part of plants is; 209 for wood; 28 for leaf; 46 for macrophyte material in the watershed area. (Hedges and others, 1986).

The C/N and C/s ratios in coal samples from Mae Moh coal field, Chiang Muan coal field, Mae Teep coal field, Wang Nua coal field, and Ngao coal field are listed in Table 4.4 to 4.7.

4.1.2.1 Mae Moh coal field

In the Q zone, carbon content ranges from 46.9 to 51.4% with average 48.9%. Hydrogen content ranges from 7.22 to 10.3% with average 8.61%. Nitrogen content ranges from 1.44 to 1.70% with average 1.53%. Sulfur content ranges from 1.01 to 1.66% with average 1.24%. The C/N ratio ranges from 29.2 to 34.0 (C/N>15), which indicates the higher plants that grew in the terrestrial environment. The C/S ratio ranges from 29.8 to 47.3 (C/S>5), which indicates that the depositional environment is freshwater under the oxic condition.

In the K zone, carbon content ranges from 51.1 to 55.8%, an average 52.5%. Hydrogen content ranges from 7.01 to 8.85%, an average 8.06%. Nitrogen content ranges from 1.86 to 2.02%, an average 1.93%. Sulfur content ranges from 0.25 to 1.68%, an average 0.85%. The C/N ratio ranges from 26.4 to 28.2 (C/N>15), which indicates the higher plants that grew in the terrestrial environment. The C/S ratio ranges from 30.6 to 224 (C/S>5), which indicates that the depositional environment is freshwater under the oxic condition.

In the J zone, carbon content ranges from 10.40 to 55.2% with average 32.2%. Hydrogen content ranges from 1.60 to 3.97% with average 2.84%. Nitrogen content ranges from 0.54 to 1.48% with average 0.97%. Sulfur content ranges from 1.09 to 20.8% with average 8.52%. The C/N ratio ranges from 17.8 to 44.5 (C/N>15), which indicates the higher plants that grew in the terrestrial environment. The C/S ratio of

Table 4.4 C/N and C/S ratios of coal samples from Mae Moh coal field.

Sample No	Elements (%)				C/S	C/N
	Carbon	Hydrogen	Nitrogen	Sulfur		
I2	46.9	3.92	1.17	2.59	18.1	40.1
J1/1	11.5	0.00	0.54	5.71	2.01	21.3
J1/2	17.4	0.01	0.98	5.41	3.22	17.8
J1/3	24.6	0.00	0.92	11.60	2.13	26.7
J1/4	21.7	0.00	0.81	16.90	1.28	26.8
J1/5	10.4	1.94	0.37	20.80	0.50	28.1
J1/6	25.3	0.00	0.81	8.45	3.00	31.2
J1/7	37.6	0.00	1.16	4.23	8.88	32.4
J2/1	35.6	0.00	1.17	4.87	7.30	30.4
J2/2	23.0	0.00	0.83	6.57	3.50	27.7
J3A	26.9	2.72	0.71	9.24	2.91	37.9
J3B1	19.1	2.03	0.65	7.23	2.64	29.4
J3B2	43.6	3.39	1.08	9.27	4.71	40.4
J4	47.4	3.21	1.18	7.09	6.68	40.2
J5A	47.5	3.33	1.32	14.40	3.29	36.0
J5B1	47.9	3.45	1.26	9.47	5.06	38.0
J5B2	49.0	3.35	1.16	6.47	7.57	42.2
J5C	55.2	3.97	1.24	6.10	9.05	44.5
J6A	45.9	3.73	1.48	6.42	7.16	31.0
J6B	38.3	2.43	0.98	1.09	35.1	39.1
K1A	51.4	8.32	1.89	1.68	30.6	27.2
K1B	51.8	8.65	1.86	0.77	67.4	27.8
K2A	51.1	8.85	1.87	1.05	48.5	27.3
K2B	51.3	7.76	1.93	0.74	68.9	26.6
K3	55.8	7.79	1.98	0.25	224	28.2
K4	53.4	7.01	2.02	0.63	84.7	26.4
Q1	47.6	8.25	1.47	1.01	47.3	32.4
Q2	46.9	10.3	1.44	1.15	40.8	32.6
Q3	51.4	8.67	1.51	1.13	45.4	34.0
Q4	49.6	7.22	1.70	1.66	29.8	29.2

Table 4.5 C/N and C/S ratios of coal samples from Chiang Muan coal field.

Sample No	Elements (%)				C/S	C/N
	Carbon	Hydrogen	Nitrogen	Sulfur		
U1-1	37.5	3.13	1.01	8.31	4.51	37.1
U1-2	16.3	2.01	0.51	5.91	2.76	32.0
U1-3	19.3	2.29	0.49	4.17	4.63	39.4
U2-1	32.9	3.11	0.79	1.86	17.7	41.6
U2-2	26.8	2.57	0.64	0.88	30.4	41.9
U2-3	30.1	3.14	0.95	6.41	4.69	31.7
U2-4	42.5	3.44	1.05	1.87	22.8	40.5
LM	25.8	16.9	1.09	0.00	Undet.	23.7
LS	55.8	16.9	1.29	1.48	37.7	43.3

Remark: Undet. = undetermine because the values is subdiveded by zero

Table 4.6 C/N and C/S ratios of coal samples from Mae Teep coal field.

Sample No	Elements (%)				C/S	C/N
	Carbon	Hydrogen	Nitrogen	Sulfur		
MT-C12	58.9	6.81	2.24	0.00	Undet.	26.3
MT-C11	58.4	6.34	2.05	0.00	Undet.	28.5
MT-C10	56.1	5.83	2.00	0.00	Undet.	28.1
MT-C9	50.6	6.93	1.77	0.00	Undet.	28.6
MT-C8	53.8	6.65	1.76	0.00	Undet.	30.6
MT-C7	44.6	8.44	1.42	0.00	Undet.	31.4
MT-C6	35.7	6.59	1.14	0.00	Undet.	31.3
MT-C5	56.3	8.52	1.78	0.00	Undet.	31.6
MT-C4	45.5	8.21	1.53	0.00	Undet.	29.7
MT-C3	17.7	6.27	0.61	0.00	Undet.	29.0
MT-C2	35.4	6.01	1.13	0.00	Undet.	31.3
MT-C1	49.1	5.39	1.62	0.22	225	30.3

Remark: Undet. = undetermine because the values is subdiveded by zero

Table 4.7 C/N and C/S ratios of coal samples from Wang Nua coal field and Ngao coal field.

Sample No	Elements (%)				C/S	C/N
	Carbon	Hydrogen	Nitrogen	Sulfur		
NGAO	41.2	3.68	1.24	4.19	9.82	33.2
WN C1	42.1	4.23	1.06	0.00	Undet.	39.7
WN C2	39.9	3.41	1.04	0.00	Undet.	38.4

Remark: Undet. = undetermine because the values is subdiveded by zero

J1/1, J1/2, J1/3, J1/4, J1/5, J1/6, J2/2, J3 zone, and J5A range from 0.50 to 4.71 (C/S <5). This ratio indicates planktonic organic matter from a brackish environment under periodic anoxic condition. The C/S ratio of J1/7, J2/1, J4, J5 zone, and J6 zone range from 5.06 to 35.1 (C/S>5), which indicates that the depositional environment is freshwater under the oxic condition.

In the I zone, carbon content is 46.9%. Hydrogen content is 3.92%. Nitrogen content is 1.17%. Sulfur content is 2.59%. The C/N ratio is 40.1 (C/N>15), which indicates the higher plants that grew in the terrestrial environment. The C/S ratio is 18.1 (C/S>5), which indicates that the depositional environment is freshwater under the oxic condition.

4.1.2.2 Chiang Muan coal field

In the LS zone, carbon content is 55.8% (Table 4.5). Hydrogen content is 16.9%. Nitrogen content is 1.29%. Sulfur content is 1.48%. The C/N ratio is 23.7 (C/N>15), which indicates the higher plants that grew in the terrestrial environment. The C/S ratio is 37.7 (C/S>5), which indicates that the depositional environment is freshwater under the oxic condition.

In the LM zone, carbon content is 25.8%. Hydrogen content is 16.9%. Nitrogen content is 1.09%. Sulfur content is 0.01%. The C/N ratio is 43.3 (C/N>15), which indicates the higher plants that grew in the terrestrial environment.

In the U2 zone, carbon content ranges from 16.3 to 42.5%, an average 33.1%. Hydrogen content ranges from 2.01 to 3.44%, an average 3.10%. Nitrogen content ranges from 0.49 to 1.05%, an average 0.86%. Sulfur content ranges from 0.88 to 6.41%, an average 2.76%. The C/N ratio ranges from 31.7 to 41.9 (C/N>15), which indicates the higher plants that grew in the terrestrial environment. The C/S ratio of U2-3 is 4.67 (C/S <5), which indicates planktonic organic matter from a brackish environment under periodic anoxic condition. The C/S ratio of U2-1, U2-2, and U2-4 range from 17.7 to 30.4 (C/S>5), which indicates that the depositional environment is freshwater under the oxic condition.

In the U1 zone, carbon content ranges from 16.3 to 37.5% with average 24.4%. Hydrogen content ranges from 2.01 to 3.13% with average 2.48%. Nitrogen content ranges from 0.49 to 1.01% with average 0.67%. Sulfur content ranges from 4.17 to 8.31% with average 6.13%. The C/N ratio ranges from 32.0 to 39.4 (C/N>15), which indicates the higher plants that grew in the terrestrial environment. The C/S ratio ranges from 2.76 to 4.63 (C/S <5), which indicates planktonic organic matter from a brackish environment under periodic anoxic condition.

4.1.2.3 Mae Teep coal field

Carbon content ranges from 17.7 to 58.9% with average 46.8% (Table 4.6), hydrogen content ranges from 5.39 to 8.52% with average 6.83%, nitrogen content ranges from 0.61 to 2.24% with average 1.59% while sulfur content is very low. The C/N ratio ranges from 26.3 to 31.6 (C/N>15), which indicates the higher plants that grew in the terrestrial environment. The C/S ratio in MT-C1 is very high (224) (C/S> 5), which indicates that the depositional environment is freshwater under the oxic condition.

4.1.2.4 Wang Nua coal field

Carbon content is between 39.9 and 42.1% with average 41.0%, hydrogen content is between 3.41 and 4.23% with average 3.82 %, nitrogen content is between 1.04 and 1.06% with average 1.05% while sulfur content is very low (Table 4.7). The C/N ratio ranges from 38.4 to 39.7 (C/N>15), which indicates the higher plants that grew in the terrestrial environment.

4.1.2.5 Ngao coal field

Carbon content is 41.2%, nitrogen content is 1.24 %, sulfur content is 4.19%, and hydrogen content is 3.24 % (Table 4.7). The C/N ratio is 33.2 (C/N>15), which indicates the higher plants that grew in the terrestrial environment. The C/S ratio is 9.82 (C/S>5), which indicates that the depositional environment is freshwater under the oxic condition.

4.1.3 Result of proximate and ultimate analyses

4.1.3.1 Mae Moh coal field

Fixed carbon in Q zone (30.7%) and K zone (31.7%) indicate the higher coalification correlated with J zone (17.0%) and I zone (21.5%). Ash content is low in Q zone (13.6%) and K zone (11.0%), but is high in J zone (35.0%) and I zone (31.5%). It indicated that there was inorganic input in J zone and I zone during coal deposited. The carbon contents in Q zone (48.9%) and K zone (52.5 %) are supported the coalification in this zone. The sulfur content is low in Q zone (1.24%) and K zone (0.85%). K zone and Q zone coal are good quality correlated with J zone and I zone.

4.1.3.2 Chiang Muan coal field

Fixed carbon is high LM zone (25.8%) but is low in LS (6.67%), U2 (18.3%), and U1 (15.6%). Ash content is high in LS (51.9%) and U2 (52.0%). The high ash content indicated that there was clay mineral or inorganic input in LS and U2 during coal deposited. Sulfur content is very low in LM (0.01%). LM coal is good quality coal.

4.1.3.3 Mae Teep Coal field

Mae teep coal is good quality coal. It is very low sulfur content (0.02%). Carbon content is high (46.8%). Fixed carbon is 29.4 % and ash content 23.3%.

4.1.3.4 Wang Nua coal field

Wang Nua coal is good quality coal. It is very low sulfur content. Carbon content is high (41.0%). Fixed carbon is 30.3 % and ash content 19.3%.

4.1.3.5 Ngao coal field.

Ngao coal is poor quality coal because it is high sulfur content (4.19%). But Ngao coal is high carbon content (41.2%). Fixed carbon is 27.6 % and ash content 19.6%.

In this study, there is only one sample from Ngao coal field and two samples from Wang Nua coal field. These results are not represented for all of Ngao and Wang Nua coal field. It needs more samples to study for the further study.

The proximate and ultimate analysis can be concluded that the moisture content shows negative correlation with ash while positive correlation with volatile matter and fixed carbon (Figure 4.1). The moisture content, volatile matter, and fixed carbon show negative correlation with ash content (Figure 4.2). The correlation between hydrogen and carbon are negative correlation with ash but sulfur with ash shows positive correlation (Figure 4.3).

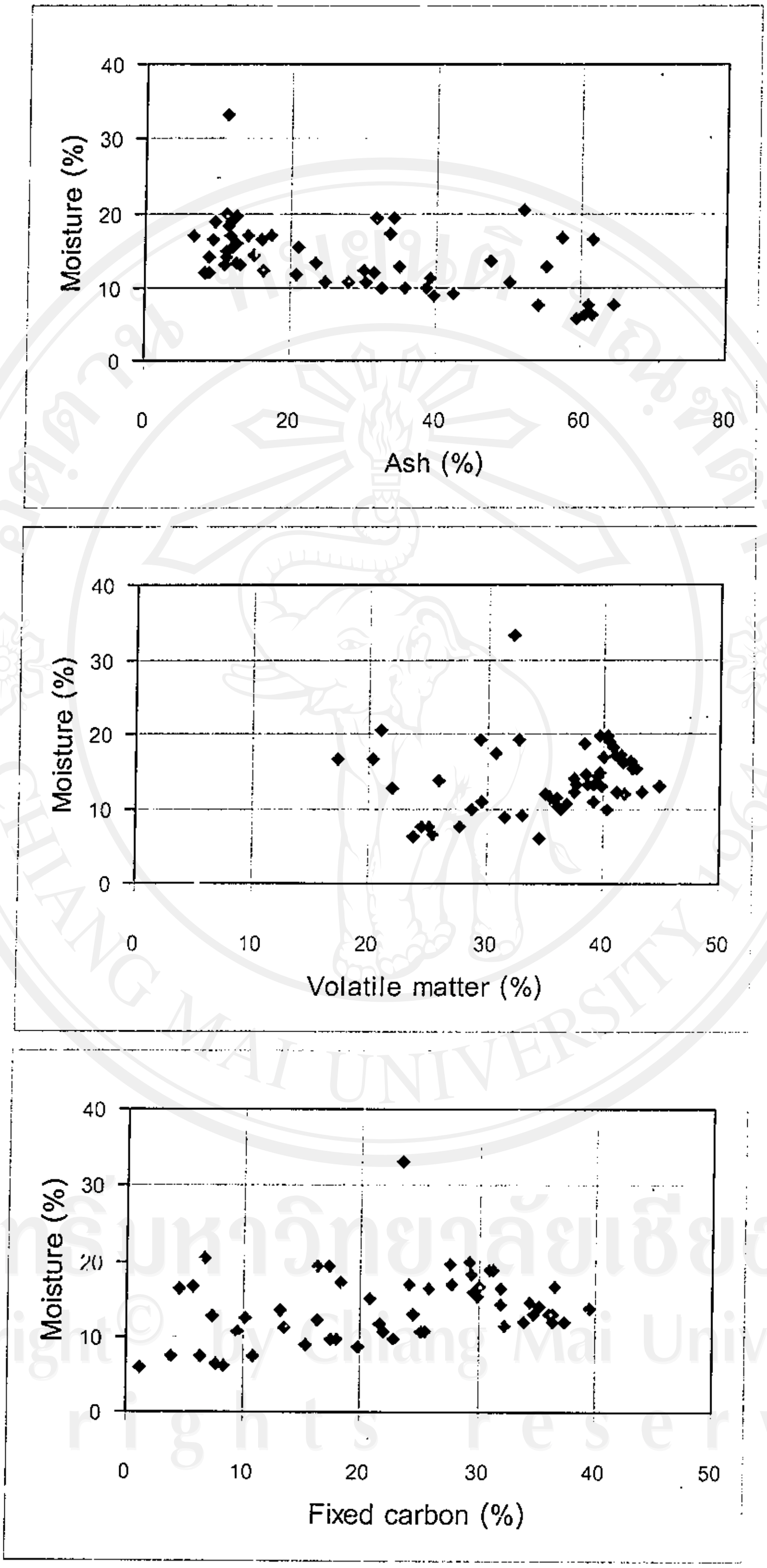


Figure 4.1 Diagram of coal samples plotted between moisture/ash, moisture/volatile matter, and moisture/fixed carbon.

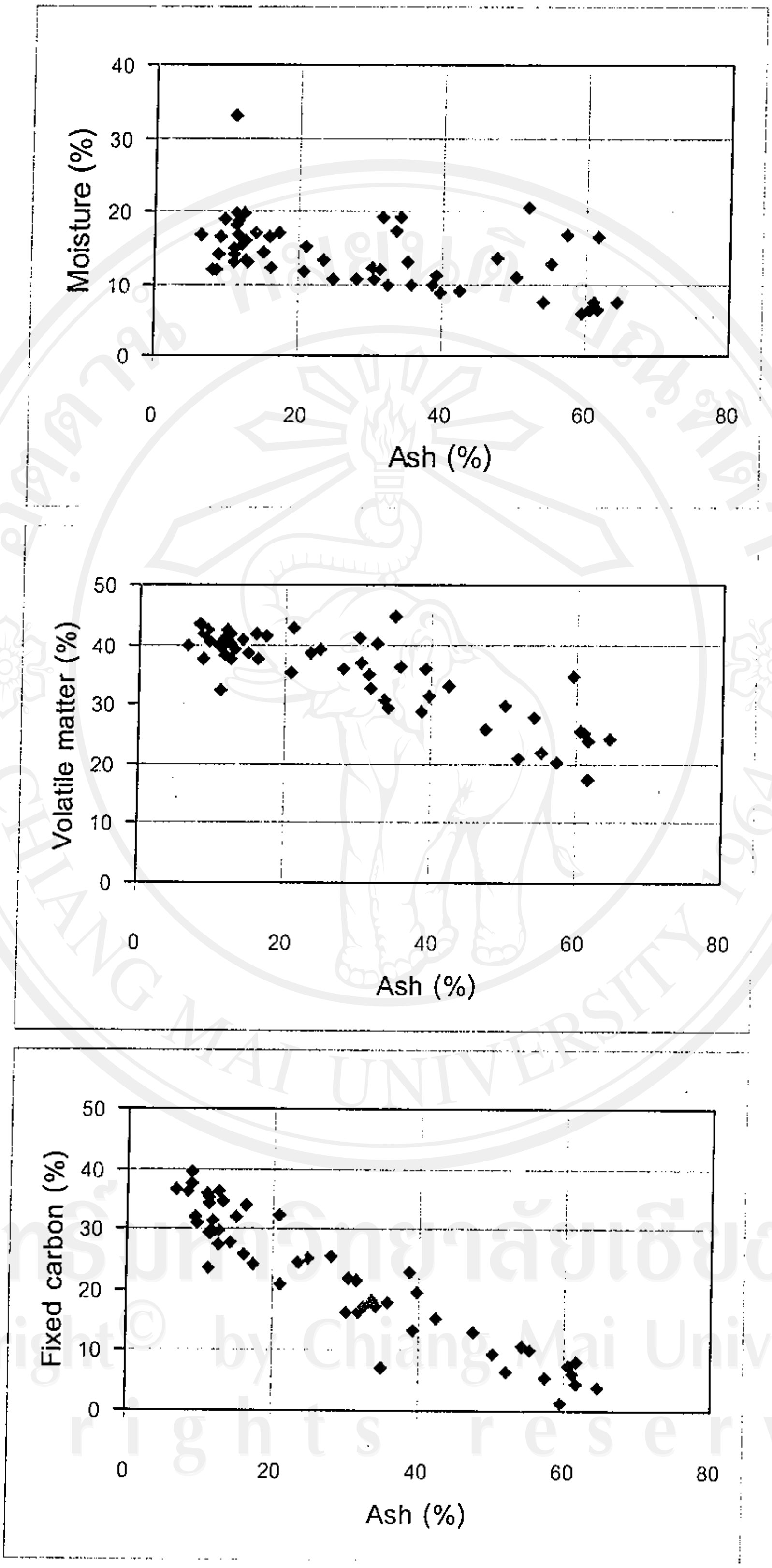


Figure 4.2 Diagram of coal samples plotted between moisture/ash, volatile matter/ash, and fixed carbon/ash.

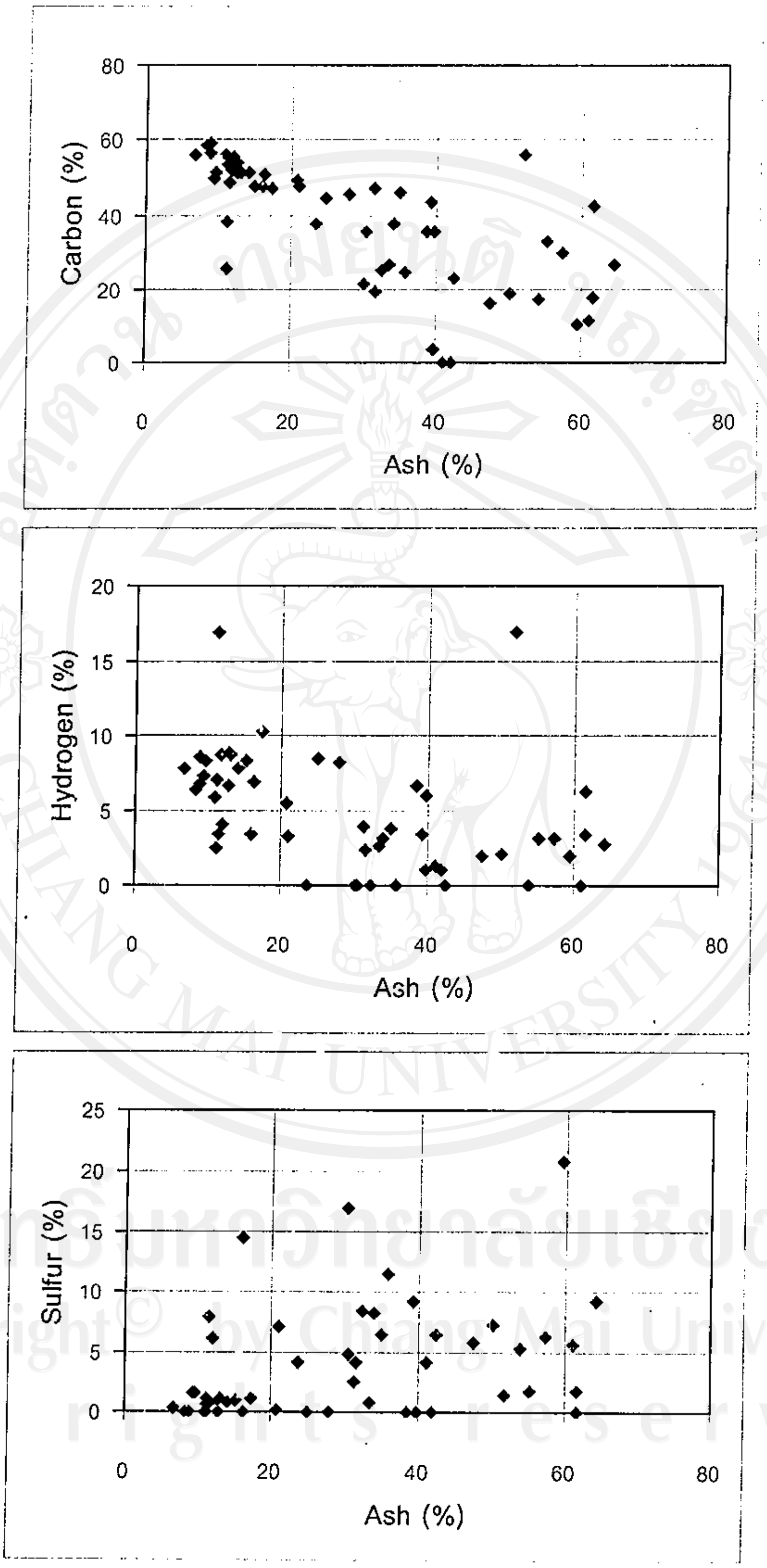


Figure 4.3 Diagram of coal samples plotted between carbon/ash, hydrogen/ash, and sulfur/ash.

4.2 X-ray diffraction

In the study of X-ray diffracttograms show qualitative diffraction peaks of samples that illustrate the known ranges of mineral composition in the samples, and Table 4.8 to 4.12, and Appendix C show their qualitative and semiquantitative values. The X-ray diffracttograms were interpreted by using Griffin (1971) method.

4.2.1 XRD analysis result

4.2.1.1 Mae Moh coal field.

The percent of mineral content of rocks in the Mae Moh coal field is shown in Table 4.8 and Appendix C.

The predominant minerals are quartz, kaolinite, illite, and calcite. The trace minerals are montmorillonite, chlorite, gypsum, pyrite, goethite, albite, anhydrite, apatite, and hematite.

Quartz, kaolinite, and illite are dominant in all samples. Montmorillonite is dominant in I zone, J zone, overburden, and Q zone. Chlorite is dominant in interburden and Q zone. Calcite is dominant in most samples except the sample from Q zone. Gypsum is dominant in red bed, I zone, transitional zone, J zone, K zone, and interburden. Pyrite is dominant in I zone, J zone, overburden, K zone, interburden, and underburden. Goethite is dominant in J zone, K zone, and interburden. Albite is dominant in J zone, overburden, and Q zone. Anhydrite is dominant in red bed, I zone, transitional zone, and J zone. Apatite is dominant in I zone and transitional zone. Hematite is dominant in red bed and transitional zone.

Table 4.8 Semi-quantitative XRD data of sediment samples from Mae Moh coal field (%).

Zone		Mont	Chlo	Ill	Kaol	Qtz	Cal	Gyp	Py	Goet	Ab	An	Apat	He
RB zone	Min	-	-	0.29	3.73	70.5	-	-	-	-	-	-	-	-
	Max	-	-	6.94	12.1	94.9	10.4	18.1	-	-	-	0.88	-	2.95
	Averg	-	-	1.92	6.07	84.9	3.34	3.02	-	-	-	0.27	-	0.49
I zone	Min	-	-	0.38	0.76	78.5	-	-	-	-	-	-	-	-
	Max	1.56	-	1.56	7.46	97.4	9.00	3.90	2.92	-	-	0.38	2.43	-
	Averg	0.49	-	0.78	3.95	89.1	2.25	0.97	1.22	-	-	0.10	1.18	-
TZ zone	Min	-	-	0.26	1.55	86.3	-	-	-	-	-	-	-	-
	Max	-	-	2.24	8.96	97.6	3.58	0.42	-	-	-	0.84	2.15	2.37
	Averg	-	-	0.96	4.66	91.8	1.15	0.07	-	-	-	0.34	0.45	0.56
J zone	Min	-	-	-	-	-	-	-	-	-	-	-	-	-
	Max	2.43	-	16.2	15.5	93.9	99.2	18.1	6.42	13.7	1.94	0.36	-	-
	Averg	0.15	-	3.10	4.99	46.0	41.3	1.94	0.90	1.40	0.20	0.01	-	-
OB zone	Min	-	-	3.41	5.90	45.5	13.1	-	-	-	-	-	-	-
	Max	6.63	-	7.31	8.33	77.4	18.6	-	3.41	-	14.2	-	-	-
	Averg	4.01	-	4.77	6.77	62.6	16.0	-	1.14	-	4.73	-	-	-
K zone	Min	-	-	-	0.49	-	59.8	-	-	-	-	-	-	-
	Max	-	-	6.86	4.53	15.4	97.0	8.23	4.36	2.47	-	-	-	-
	Averg	-	-	2.38	2.20	8.56	82.1	2.15	2.10	0.49	-	-	-	-
IB zone	Min	-	-	1.30	0.26	6.67	42.0	-	-	-	-	-	-	-
	Max	-	3.48	12.9	8.42	43.5	80.0	2.60	11.5	8.89	-	-	-	-
	Averg	-	0.86	4.47	3.75	25.9	57.6	0.88	4.28	2.28	-	-	-	-
Q zone	Min	-	-	0.59	1.17	57.1	-	-	-	-	-	-	-	-
	Max	12.0	1.49	17.1	25.7	98.2	-	-	-	-	2.72	-	-	-
	Averg	1.20	0.15	5.28	10.8	82.3	-	-	-	-	0.27	-	-	-
UB zone	Min	-	-	-	2.14	26.0	-	-	-	-	-	-	-	-
	Max	-	-	3.39	4.49	92.9	70.7	-	11.8	-	-	-	-	-
	Averg	-	-	2.06	3.32	54.1	36.6	-	3.92	-	-	-	-	-

Remark: Mont: montmorillonite Chlo: chlorite Ill: illite Kaol: kaolinite
Qtz: quartz Cal: calcite Gyp: gypsum Py: pyrite Goet: goethite
Ab: albite An: anhydrite Apat: apatite He: hematite

4.2.1.2 Chiang Muan coal field.

The percent of mineral content of rocks in the Chiang Muan coal field is shown in Table 4.9 and Appendix C.

The predominant minerals are quartz, and kaolinite. The trace minerals are montmorillonite, illite, gypsum, pyrite, anhydrite, apatite, calcite, and hematite.

Quartz and kaolinite are dominant in all samples. Montmorillonite is dominant in interburden1, upper coal seam 1, lower massive coal seam, interburden3, lower split coal seam, and underburden. Illite is dominant in overburden, upper coal seam 1, interburden1, upper coal seam 2, lower massive coal, and interburden 3. Calcite is dominant in overburden, upper coal seam 1, upper coal seam 2, interburden 2, and lower massive coal. Gypsum is dominant in overburden, upper coal seam 1, interburden1, and upper coal seam 2. Pyrite is dominant in overburden. Anhydrite is dominant in overburden, upper coal seam 1, interburden1, upper coal seam 2, and interburden 2. Apatite is dominant in overburden, upper coal seam 2, interburden 2, interburden 3, and underburden. Hematite is dominant in overburden.

4.2.1.3 Mae Teep coal field.

The percent of mineral content of rocks in the Mae Teep coal field is shown in Table 4.10 and Appendix C.

The predominant minerals are quartz, kaolinite, and illite. The trace minerals are montmorillonite, chlorite, calcite, gypsum, siderite, and dolomite.

Table 4.9 Semi-quantitative XRD data of sediment samples from Chiang Muan coal field (%).

Zone		Qtz	Kaol	Ill	Mont	Gyp	Py	An	Apat.	Cal	He
OB	Min	37.8	0.73	0.40	-	-	-	-	-	-	-
	Max	97.1	32.9	1.95	-	0.26	1.00	0.51	0.40	60.1	1.17
	Averg	78.1	7.22	1.02	-	0.04	0.17	0.17	0.07	12.9	0.26
U1	Min	87.8	1.54	0.51	-	-	-	-	-	-	-
	Max	97.1	3.84	3.66	-	4.75	-	0.39	-	2.26	-
	Averg	92.4	2.69	2.08	-	2.38	-	0.20	-	0.26	-
IB1*	Min	92.1	3.68	1.66	0.74	0.74	-	1.10	-	-	-
	Max	92.1	3.68	1.66	0.74	0.74	-	1.10	-	-	-
	Averg	92.1	3.68	1.66	0.74	0.74	-	1.10	-	-	-
U2	Min	79.3	1.03	0.39	-	-	-	-	-	-	-
	Max	97.8	3.76	2.26	1.64	0.77	-	0.78	5.90	11.2	-
	Averg	91.2	2.11	1.02	0.41	0.19	-	0.19	2.06	2.79	-
IB2	Min	96.2	0.04	-	-	-	-	-	0.06	-	-
	Max	99.7	0.80	-	-	-	-	0.39	1.75	1.80	-
	Averg	98.0	0.40	-	-	-	-	0.10	0.85	0.61	-
LM*	Min	92.0	2.29	1.71	2.86	-	-	-	-	1.14	-
	Max	92.0	2.29	1.71	2.86	-	-	-	-	1.14	-
	Averg	92.0	2.29	1.71	2.86	-	-	-	-	1.14	-
IB3	Min	80.9	2.01	-	1.19	-	-	-	-	-	-
	Max	95.2	2.38	1.19	2.01	-	-	-	15.1	-	-
	Averg	88.1	2.19	0.60	1.60	-	-	-	7.51	-	-
LS*	Min	95.1	2.46	-	2.46	-	-	-	-	-	-
	Max	95.1	2.46	-	2.46	-	-	-	-	-	-
	Averg	95.1	2.46	-	2.46	-	-	-	-	-	-
UB	Min	94.6	0.77	-	0.94	-	-	-	-	-	-
	Max	98.1	0.94	-	1.15	-	-	-	3.45	-	-
	Averg	96.4	0.85	-	1.04	-	-	-	1.71	-	-

Remark: Qtz: quartz Kaol: kaolinite Ill: illite Mont: montmorillonite
Gyp: gypsum Py: pyrite An: anhydrite Apat: apatite Cal: calcite
He : hematite

* There is 1 sample.

Table 4.10 Semi-quantitative XRD data of sediment samples from Mae Teep coal field (%).

Zone		Mont	Chlo	Ill	Kaol	Qtz	Cal	Gyp	Sid	Do
OB	Min	-	-	-	1.75	11.4	-	-	-	-
	Max	13.2	15.2	4.88	30.5	87.8	26.3	2.17	26.5	69.7
	Averg	4.18	3.95	2.36	6.98	69.6	2.67	0.16	5.95	4.10
MS	Min	-	-	1.77	3.83	22.8	-	-	-	-
	Max	-	-	30.8	37.1	94.4	-	-	67.8	-
	Averg	-	-	9.64	15.4	62.1	-	-	12.8	-
UB	Min	-	-	-	2.41	21.1	-	-	-	-
	Max	-	-	1.61	9.76	97.5	75.1	0.31	-	-
	Averg	-	-	0.55	4.32	79.9	15.2	0.05	-	-

Remark: Mont: montmorillonite Chlo: chlorite Ill: illite Kaol: kaolinite
Qtz: quartz Cal: calcite Gyp: gypsum Sid: siderite Do: dolomite

Quartz, kaolinite, and illite are dominant in all samples. Montmorillonite, Chlorite, and dolomite are dominant in overburden. Calcite and gypsum are dominant in overburden and underburden. Siderite is dominant in overburden and coal seam.

4.2.1.4 Wang Nua coal field.

The percent of mineral content of rocks in the Wang Nua coal field is shown in Table 4.11 and Appendix C. The predominant minerals are quartz (54.7-95.7 %), kaolinite (0.73-43.2 %), and illite (2.16-6.62 %). The trace mineral is gypsum (0.19-2.87 %).

Table 4.11 Semi-quantitative XRD data of sediment samples from Wang Nua coal field (%).

	Ill	Kaol	Qtz	Gyp
Min	2.16	0.73	54.7	0.19
Max	6.62	43.2	95.7	2.87
Averg	4.53	20.4	74.3	0.77

Remark: Ill: illite Kaol: kaolinite Qtz: quartz Gyp: gypsum

4.2.1.5 XRD analysis in selected coal

The percent of mineral content from 21 oxidized coal are list in Table 4.12.

Mae Moh coal field

The minerals of coal from Q zone are dominant in quartz, kaolinite, illite, gypsum and apatite.

The minerals of coal from K zone are dominant in quartz, kaolinite, illite, dolomite, apatite, bassanite, and goethite.

The minerals of coal from J zone are dominant in quartz, calcite, dolomite, and gypsum. Kaolinite and illite were dominant in J1/1 and J1/3.

Chiang Muan coal field

The minerals of coal from U2 zone are dominant in quartz, kaolinite, illite, gypsum and pyrite.

The minerals of coal from U1 zone are dominant in quartz, kaolinite, gypsum. Illite and pyrite were dominant in U1-2 and U1-3.

Table 4.12 Semi-quantitative XRD data of selected coal samples from Mae Moh, Chiang Muan, Mae Teep, Wang Nua, and Ngao coal fields (%).

Area	Zone	Ill	Kaol	Qtz	Cal	Do	Gyp	Py	Apat	Bas	Goet
Mae Moh	J1/1	6.15	8.19	66.3	-	7.16	12.2	-	-	-	-
Mae Moh	J1/3	6.92	3.98	38.0	16.6	15.5	19.0	-	-	-	-
Mae Moh	J1/5	-	-	4.71	14.8	3.19	77.3	-	-	-	-
Mae Moh	J1/7	-	-	-	16.1	36.5	47.4	-	-	-	-
Mae Moh	J2/1	-	-	4.07	11.9	6.13	77.9	-	-	-	-
Mae Moh	K1	-	-	-	-	-	13.6	-	13.1	73.3	-
Mae Moh	K3	4.67	-	-	-	7.02	-	-	-	80.8	7.51
Mae Moh	K4	9.95	9.95	62.7	-	-	-	-	17.4	-	-
Mae Moh	Q1	-	-	48.1	-	-	32.5	-	19.4	-	-
Mae Moh	Q4	11.6	34.9	-	-	-	-	-	53.5	-	-
Chiang Muan	U1-1	-	4.86	5.25	-	-	89.9	-	-	-	-
Chiang Muan	U1-2	2.29	3.64	58.8	-	-	26.2	9.07	-	-	-
Chiang Muan	U1-3	2.76	7.11	74.2	-	-	10.6	5.33	-	-	-
Chiang Muan	U2-1	2.53	9.31	40.7	-	-	44.1	3.36	-	-	-
Chiang Muan	U2-2	3.09	3.71	63.8	-	-	18.1	11.3	-	-	-
Chiang Muan	U2-3	1.87	3.72	30.2	-	-	57.4	6.81	-	-	-
Chiang Muan	U2-4	2.88	6.49	43.2	10.3	-	27.4	9.73	-	-	-
Mae Teep	MTC1	17.2	11.0	55.2	16.6	-	-	-	-	-	-
Mae Teep	MTC6	7.56	9.46	56.9	-	9.48	16.6	-	-	-	-
Wang Nua	WN	-	-	59.6	-	-	40.4	-	-	-	-
Ngao	Ngao	-	-	-	5.35	1.35	93.3	-	-	-	-

Remark: Qtz: quartz Kaol: kaolinite Ill: illite Gyp: gypsum
Py: pyrite Apat: apatite Cal: calcite Do: dolomite
Bas: bassanite Goet: goethite

Mae Teep coal field

The minerals of selected coal from Mae Teep coal field are dominant in quartz, kaolinite, and illite. Calcite is dominant in MTC1, but dolomite and gypsum were dominant in MTC6.

Wang Nua coal field

The minerals of coal from Wang Nua coal field are dominant in quartz and gypsum.

Ngao coal field

The minerals of coal from Ngao coal field are dominant in calcite, dolomite, and gypsum.

4.2.2 Mineralogy

The minerals identified by XRD analysis include quartz, kaolinite, illite, montmorillonite, chlorite, siderite, calcite, dolomite, goethile, apatite, gypsum, anhydrite, pyrite, feldspar, and hematite.

4.2.2.1 Quartz

Quartz is a relatively abundant mineral phase in most coals. Quartz is considered primarily as a syngenetic mineral, not commonly identified as an epigenetic phase (Renton, 1982). Quartz grains which morphologically vary from rounded to subangular are primarily detrital (Davis and others, 1984), being either water-washed or wind blown into the swamp during peat accumulation (Ward, 1989).

Biogenically derived silica has been suggested as a potential source for chert lenses in Tertiary coal. However other authors, for example Davis and others (1984), have suggested that dissolution of biogenic silica would result in it being flushed from the peat and/or contribute the formation of authigenic clays. While few examples of authigenic quartz have been reported in coals, silica precipitation and preservation may occur where the silica flux rates exceed the rate of soluble organic acid production during humification, where high rates of organic acid neutralization takes place, or where the evaporative processes exceed the flow of water through the peat (Upchurch and others, 1983).

Two possible origins are suggested. First, in a depositional environment dominated by fluvial and lacustrine processes, quartz grains would be largely water-washed detritus periodically deposited into the swamp during peat accumulation; being wind blown detritus would be rare.

The second origin could be chemical, by direct precipitation from solution, either chemically or biogenically mediated, followed by recrystalization to quartz during diagenesis.

Preservation of biogenically derived or directly precipitated silica will indeed require specialized circumstances. Reduced mobility of aqueous silica in the wetland may be related to a weakly alkaline pH in the depositional environment. The high Ca content of coals and preservation of shell fragments within many of the intraseam partings indicates a neutral to weakly alkaline depositional environment with limited activity by humic acids, a common feature of Ca rich coals (Teichmuller and Teichmuller, 1982).

Preservation of biogenically precipitated silica may take place through overloading of the silica cycle: by direct influx an external source, limited dissolution by inorganic acids, failure of the cycling system through cessation of metabolic activity and/or restricted removal of silica rich pore water during peatification and coalification (Upchurch and others, 1983).

4.2.2.2 Carbonates

Carbonates rank as the second or third most abundant minerals (Renton, 1982). In coal, siderite probably forms during the early stages of coalification whereas calcite, dolomite and ankerite, which occur primarily in cleats and fractures, formed in the later diagenetic stages, after the coal had undergone most of its rank advance (Ward, 1989). Calcite, the most abundant carbonate, can be deposited in both fresh water and marine environments. Siderite appears to be the most useful carbonate mineral in determining depositional environment, forming mainly in acidic fresh water environments (Renton, 1982).

The carbonates identified by XRD in the samples collected in this study, consist solely of calcite. In addition to calcite, Ward (1991) has identified both aragonite and siderite in some of the intra-seam partings but agrees that calcite is the principle carbonate mineral present in the non-coal samples. Neither aragonite nor siderite were identified by XRD in this investigation. Several of the intra-seam parting contain shell fragments which are interpreted as non-marine (Corsiri and Crouch, 1985). Ward (1991) associated aragonite with these fossil rich horizons, however, in this study only calcite was observed in the fossiliferous zones.

The EDS spectra of most carbonate grains observed mainly Ca however variable amounts of Mg was identified, and few grains contained trace amounts of Mn and Fe. The blocky morphology of the grains is similar to those from the calcite seat-earth underlying the thick fresh water Holocene peat in the Okeechobee Depression of the Florida Everglades (Sawyer and Griffin, 1983).

The persistent calcite, along with the high concentration of Ca dissolved in pore waters and attached to function groups inorganic molecules (Ward, 1991), suggests that the depositional basin waters ere neutral to alkaline, Ca-rich and probably high in total dissolved carbonates. Runoff into the depositional environment would create alkaline conditions favoring biogenic precipitation of calcite by fresh water gastropods and algae (Sawyer and Griffin, 1983). The preservation of shell fragments throughout the section would indicate long term alkaline conditions and limited dissolution by humic acids (Teichmuller and Teichmuller, 1982).

In reaction 4-1, which summarizes carbonate equilibrium, it s evident that processes which increase the amount of CO_2 in solution increase the concentration of carbonic acid and result in calcite dissolution. Processes which remove CO_2, supersaturating the solution with respect to calcite, will result in precipitation.

$$\begin{array}{l} \quad H_2O + CO_2 \\ \qquad \uparrow\downarrow \\ CaCO_3 + H_2CO_3 \leftrightarrow Ca^{2+} + 2HCO_3^- \end{array} \qquad (4\text{-}1)$$

The removal of CO_2 from solution and calcite precipitation may have been facilitated by vegetation, during photosynthesis or, by intermittent evaporation during periods of limited water influx (Krauskopf, 1967).

The above reaction (4-1) reflects the effect of pH on calcite precipitation or dissolution. In acidic conditions where most of the carbonate exists as H_2CO_3, calcite dissolution is favored. In neutral to alkaline conditions, the interaction of hydroxyl ions (OH^-) with carbonic acid (H_2CO_3) increases the bicarbonate (HCO_3^-) concentration and displaces the calcite equilibria in favor of precipitation (Krauskopf, 1967).

The carbonates mentioned above and the cryptocrystalline masses of calcite found in fractures are both thought to represent authigenic mineral phases. Their timing of emplacement, however, is probably slightly different. Formation of blocky calcite probably took place pre-compaction, during sedimentation and/or slightly thereafter. The cryptocrystalline calcite which appears to be confined to veins and fractures, likely formed during or after compaction when cracks, developed in the peat or sediment, would allow solution migration and the precipitation of minerals.

In many of the carbonate grains limited amounts of Mg, Mn, and Fe have been identified. Ionic substitution for Ca in the calcite structure is not uncommon, particularly at elevated temperatures and/or where the concentration of competing ions is high (Krauskopf, 1967). The lack of siderite is expected due to the high concentration of dissolved sulfide, near neutral pH and significant bacterial activity for sulfate reduction.

4.2.2.3 Clay minerals

Clay minerals are probably he most common inorganic phases present in all types of coals. Renton (1982) has shown that they constitute, on average, 60-70% of the mineral assemblage in low temperature ash. Of the various species which can be present, kaolinite and illite are the most common, followed by the mixed layer clays and chlorite. The processes which result in the inclusion of clay minerals in to any coal can include; detrital, both water and air direct precipitation of clay minerals either from dissolved constituents in the swamp waters or in pore spaces within the peat (Ward, 1989; Ward and Christie, 1994). Kaolinite is the most common clay mineral to occur syngenetically (Renton, 1982).

The formation of kaolinite could result from weathered rhyolite, which is derived from the Phrae-Lampang mountains. Kaolonite favors acidic conditions with good drainage and low cation (Na^+, K^+, Ca^{2+}, and Mg^{2+}) activities (Garrels and Christ, 1965; Curtis, 1983; Rimmer and Davis, 1986) whereas higher pH values and high concentrations of total dissolved solids favor the formation of illite (Renton, 1982; Rimmer and Davis, 1986). Andrejko and others (1983) also identified kaolonite, along with minor illite and montmorillinite, as the dominant clay mineral in fresh water influenced wetlands whereas illite and montmorillinite are more common in wetlands influenced by marine waters.

Phyllosilicate clay minerals have widely varying chemical compositions due to partial or complete replacement of Al^{3+} by ions such as Fe^{3+}, Fe^{2+}, Cr^{3+}, and Mg^{2+} in the octahedral layer as well as partial replacement of Si^{4+} by Al^{3+} in the tetrahedral layer. This substitution results in a negative charge imbalance in the clay structure which is compensated by the adsorption of cations onto the clay surface. Ions in solution are exchanged with the surface of the clay minerals and, depending upon their type and abundance in the peat, they can have a significant affective on pore water chemistry. The cation exchange capacity varies according to the degree of substitution in any clay and is greatest in vermiculities and smectites, least in kaolonite and intermediate in illite (Faure, 1991).

Ward (1991) has suggested that minor amounts of kaolonite could be authigenic; however no evidence given. With regard to mineral proportions, in this study kaolonite is only slightly more abundant than illite and more abundant that the swelling clays and chlorite.

The mixed layer clays identified in a number of samples may represent the degradation products of illite. According to McBride (1994) the degradation of illite to a mixed layer clay is not pH sensitive. Alternatively, they may represent syngenetic phases formed in an alkaline depositional environment with restricted drainage and/or a high concentration of alkaline earth ions (McBride, 1994).

Since the clays appear to be detrital origin, they provide little information about the pH of he depositional environment. It may be possible that some of the kaolonite is authigenic, particularly in coal samples where few other clay minerals are present. The high proportion of kaolonite would suggest that the depositional environment at this time may have been acidic and low in total dissolved solids. The favors the formation of authigenic kaolinite and restricting the development of other minerals.

4.2.2.4 Sulfide minerals

Pyrite and marcasite are dominant sulfide minerals in coal. They occur almost as frequently as the carbonate minerals. The presence of abundant syngenetic pyrite in coal is indicative of a marine environment or a transgressive sequence where the coals are overlain by marine rocks. Both suggest that the availability of sulfate ions during deposition or early diagenesis may be the controlling factor for pyrite formation.

Pyrite in wetlands can only form where there is bacterial activity since, on the basis of reaction kinetics, there is insufficient energy for the reduction of SO_4^{2-} to S^{2-}. Berner (1970) summarized the major processes involved in the formation of sedimentary iron sulfide in anoxic marine sediments. The three major streps for the formation of pyite are:

1) bacterial reduction of SO_4^{2-} to H_2S
2) reaction of H_2S with Fe to form iron monosulfide;

$$H_2S + Fe_2 \leftrightarrow FeS^- + 2H^-$$

3) reaction of iron monosulfide to form pyrite;

$$FeS^- + S^0 \leftrightarrow FeS_2$$

The most important factors influencing these reactions are: 1) the availability of metabolizable organic matter for bacterial reduction of sulfate, 2) the availability of sulfate and iron, and 3) the production of elemental sulfur. The availability of elemental S is an extremely important part of this pathway. In the models by Rickard (1969) and Berner (1972), the initial sulfide mineral is not pyrite but a series of metastable iron monosulfides which transform to pyrite with the addition of elemental sulfur during early diagenesis (Berner, 1984). Another very important part of the pathway is bacterial activity, which has been shown to be controlled by pH. At pH values of 4.5 or less, bacteria are essentially inactive; in pH values above 4.5 the activity increases to a maximum around pH 7 (Baas Becking and Moore, 1961).

More recently, Howarth and Teal (1979) showed that small euhedral pyrite crystals were formed by the direct precipitation of iron and polysulfides without the iron monosulfide precursor phases. Salt marshes with high organic contents, rapid sulfate reduction and low pH are environments where this type of pyrite formation occurs (Gibling, 1988). Low pH is emphasized in keeping the solution undersaturated in iron monosulfides and supersaturated with respect to pyrite (Morse and others, 1987). Lower pH's however are not favorable to rapid bacterial sulfate reduction.

Luther and others (1982) studying pyrite textures in marsh sediments identified both framboidal and euhedral pyrite crystals and suggested that the single crystals formed by direct precipitation and the framboids by slow conversion from griegite. Gibling (1988) found that pyrite formation in salt mashes was very rapid and that a significant portion of the pyrite inventory in the upper 10 centimeters of the sediments can accumulate in just a few months. Her model involved partial oxidation of pyrite, the formation of polysulfided which precipitate as pyrite without the iron monosulfided as intermediates.

While early formed iron minerals may preserve a record of their depositional setting, alteration during diagenesis can often modify or erase the record of earlier environments. For example, if fresh water peats are overlain by marine peats or sediments both the organic and inorganic sulfur content of the subsequent coals will increase (Davis and Raymond, 1983). In this situation the downward diffusion of sea water and corresponding increase in pH and sulfate concentration, will likely increase rates of bacterial activity, sulfate and iron reduction and foster the precipitation of biogenic sulfides. While sulfides are not absent from fresh water coals, (Cohen and others, 1983) the lower pH and reduced activity of sulfate in fresh water environments limit their extensive development.

The presence of pyrite in almost all samples suggests near neutral pH conditions existed in the peat throughout the depositional period. The direct relation of pyrite to organic material provides good evidence that its precipitation was bacterially mediated; the organic material providing an energy source for bacterial sulfate reduction and neutral pH supporting a high degree of bacterial activity.

The mineralogy of the coal and interbedded sediments indicates a continual supply of both Fe and S to depositional area. The iron necessary for the formation of pyrite was likely derived from weathering of the surrounding highlands. Gastropods identified in the section indicate that the depositional environment was dominated by fresh water yet sulfur contents in some coal samples exceed 10%. This suggests a marine influence either during peat accumulation or shortly thereafter. While some of the sulfur may have come from the degradation of plant debris, as has been suggested for low sulfur, fresh water coal (Casgrande and others, 1977). Another source may be from weathering of gypsiferous horizon external to the coal basin. The third possibility is that the sulfur may be of volcanic origin. The southern portion of the Mae Moh basin is overlain by Pleistocene basalt and numerous Tertiary intrusion s have been identified in northern Thailand (Barr and MacDonald, 1981). Current geothermal gradients beneath in northern Thailand range between 50-93°C/km (Barr and others, 1980) and hot springs are numerous. Neogene geothermal activity as hot springs and/or ground water charged with sulfur of volcanic origin discharging into the lacustrine basin during peat accumulation, may account for the unusually high proportion of sulfur minerals present in these coals (Hart, 1995).

Peat accumulation probably took place in a brackish environment, the pH moderated by the influx of Ca^{2+} and HCO_3^- rich ground and surface water. The framboids and euhedral pyrite crystals likely formed by direct precipitation of iron with bacterially reduced sulfide similar to the method outlined by Luther and others (1982), Cohen and others (1983), and Giblin (1988). These sulfides were the first to form, probably very close to the sediment-water interface during the early stages of peat accumulation. Cohen and others (1983) suggest that framboid formation occurs primary in open, liquid filled pore spaces in close association with organic material. Single pyrite crystals were found to coincide with the occurrence of minute bacteria found on the outside of red mangrove rootlets. These sulfides correspond to the first period of sulfur emplacement (Davis and Raymond, 1983) when water circulation is unrestricted and small single crystals and pyrite framboids are incorporated into the peats. According to Spears (1987) this pyrite is considered early diagenetic, pre compaction or more commonly of syngenetic origin.

The larger solid masses of pyrite and the replacement of organic material probably took place somewhat after the single crystals and framboids but prior to coalification. The large solid pyrite spheres represent complete infilling of previously formed framboids as the sulfate and iron-rich water continued to circulate freely through the relatively porous peat. Pyrite replacement of cell lumens likely occurred in response to bacterial degradation of the organic material, bacterial sulfate reduction and the formation of sulfide fostering pyrite deposition was syngenetic, and most of the accumulation probably took place during the early stages of peat accumulation.

4.2.2.5 Sulfates minerals

A wide variety of sulfate minerals have been identified in coals and associates sediments. The most common Ca sulfate minerals identified are gypsum ($CaSO_4 \cdot 2H_2O$), bassanite ($CaSO_4 \cdot 1/2H_2O$) and anhydrite ($CaSO_4$).

Gibling and Ratanasthien (1980) identified thin beds gypsum throughout basins in north-western Thailand and indicate that deposition took place in lacustrine environments during intermittent periods of high salinity. Ratanasthien and others (1992) suggest that deposition of high sulfur coals containing gypsum in the central and eastern portion of northern Thailand may have taken place in a brackish environment.

The scattered euhedral crystal identified most commonly in the sediments associated with the coal likely developed in response to periodic wetting and drying of elevated flood plain or overbank deposits. Evaporation in the exposed unlithified sediment would result in hypersaline pore waters and gypsum precipitation when the surrounding sediment was soft enough to allow for uninhibited crystal development. Gypsum has also been identified in lignite horizons. Although the occurrence is somewhat less, it would suggest that periodic drying, or at least increases in water salinity, occurred though out the depositional environment.

4.2.2.6 Phosphates

Apatite is a mineral that results from phosphatization and it is an accessory mineral of acid crystalline rocks. Apatite is of considerable importance since it represents the principal primary source of phosphorus, an element essential to most forms of life. The common of apatite varieties is represented by the isomorphous series with end-member: fluorapatite ($Ca_5(PO_4)_3.F$), chlorapatite ($Ca_5(PO_4)_3.Cl$), hydroxyapatite ($Ca_5(PO_4)_3.OH$), and carbonate-apatite ($Ca_5(PO_4,CO_3,OH)_3.(F,OH)$) (Deer and others, 1992). Fluorapatite is the most stable form of the group and commonly persists as a detrital mineral in sediments, which was found in Mae Moh and Chiang Muan's beds, is relatively unstable under leaching conditions (Loughnan, 1969). 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 interburden 2 and the overburden.

4.3 Geochemistry

4.3.1 Mae Moh coal field

4.3.1.1 Major oxide

The major oxide of coal and sediment from Mae Moh coal field are reported in the Table 4.13 and Appendix D.

The major oxide can be divided in to 2 group of the pattern. First group consists of SiO_2, Al_2O_3, TiO_2, Fe_2O_3, CaO, and P_2O_5 (Figure 4.4). The other consists of MnO, K_2O, MgO, Na_2O, and SO_3 (Figure 4.5). The graph shows that when the first group is increasing pattern the other group will be decreasing pattern. The pattern of SiO_2, Al_2O_3, TiO_2, MgO, Fe_2O_3, K_2O, and P_2O_5 show similarity of pattern of each other. And the pattern of MnO, CaO, Na_2O, and SO_3 also shows similarity of pattern of each other. The SiO_2 content is decreasing in the middle part of J zone and K zone. The CaO content is high in the middle part to the lower part of J zone, K zone, and interburden. The Al_2O_3 and TiO_2 content are high in red bed, I zone, transitional zone, the upper part of J zone, interburden, Q zone, and underburden. The K_2O content is low in lower part of J1 zone, J4 zone, J5 zone, J6 zone, K4 zone, and Q coal zone. The MnO content is very low in Q zone. The major oxides in sediments are higher concentration than the major oxides in coals, especially SiO_2, Al_2O_3, CaO, and Fe_2O_3. But the concentration of SO_3 in coals is higher than the concentration of SO_3 in sediments.

Table 4.13 Geochemical analysis of major oxide of Mae Moh coal field.

ZONE		Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	SO_3
		(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
RB	Min	13.9	0.37	5.62	2.17	1.04	0.04	0.06	0.12	44.5	0.64	0.19
	Max	20.7	5.97	8.65	3.93	1.76	0.10	0.29	0.22	67.7	0.87	6.35
	Averg	16.1	2.16	7.41	2.97	1.45	0.07	0.17	0.15	57.5	0.79	1.41
I ZONE	Min	5.01	0.28	1.87	0.62	0.78	0.01	0.18	0.02	9.25	0.10	0.32
	Max	21.1	5.12	9.47	2.67	1.63	0.18	0.31	0.13	74.6	0.81	2.58
	Averg	14.1	1.74	4.36	1.88	1.24	0.06	0.24	0.07	47.7	0.54	1.24
TZ	Min	11.5	0.23	2.91	1.61	0.84	0.02	0.21	0.08	35.6	0.48	0.21
	Max	23.9	12.1	7.09	3.67	5.71	0.13	0.35	0.18	72.3	0.87	2.87
	Averg	16.4	3.39	4.63	2.36	2.15	0.06	0.27	0.11	57.8	0.73	1.12
J ZONE	Min	0.27	0.41	0.26	0.02	0.03	0.01	0.12	0.01	0.33	0.01	0.10
	Max	26.5	49.9	12.8	6.11	3.39	0.33	0.69	0.57	63.8	0.91	9.43
	Averg	9.87	11.5	5.01	2.04	1.29	0.06	0.27	0.15	22.4	0.33	2.71
OB	Min	9.70	9.93	5.76	2.16	1.83	0.10	0.20	0.12	41.7	0.46	0.81
	Max	11.3	12.1	6.37	2.73	2.24	0.11	0.20	0.16	43.4	0.53	0.93
	Averg	10.4	10.9	6.00	2.37	2.00	0.11	0.20	0.14	42.6	0.49	0.88
K ZONE	Min	0.56	0.25	0.63	0.26	0.02	0.01	0.06	0.01	3.89	0.02	0.43
	Max	8.13	37.0	9.70	2.28	1.18	0.64	0.21	0.45	19.1	0.34	1.84
	Averg	2.83	11.44	3.59	0.80	0.54	0.13	0.14	0.15	8.32	0.14	1.10
IB	Min	6.14	15.13	6.19	0.56	1.06	0.13	0.19	0.14	9.58	0.25	0.84
	Max	14.3	38.7	8.88	2.73	2.46	0.21	0.27	0.28	37.6	0.53	1.50
	Averg	9.71	27.9	7.32	1.71	1.64	0.16	0.21	0.20	24.9	0.39	1.19
Q ZONE	Min	0.59	0.14	0.47	0.20	0.02	0.01	0.03	0.01	4.44	0.06	0.47
	Max	22.7	1.93	5.76	3.86	1.24	0.17	0.26	0.08	71.7	0.83	0.94
	Averg	13.5	0.48	2.18	1.87	0.73	0.02	0.17	0.05	46.4	0.53	0.63
UB	Min	8.28	0.53	3.28	1.03	1.18	0.02	0.19	0.08	21.8	0.39	0.61
	Max	17.0	27.9	7.51	4.23	2.27	0.22	0.20	0.22	55.3	0.81	0.84
	Averg	11.6	14.7	5.54	2.43	1.59	0.14	0.19	0.14	36.6	0.55	0.76
Total	min	0.27	0.14	0.26	0.02	0.02	0.01	0.03	0.01	0.33	0.01	0.10
	max	26.5	49.9	12.8	6.11	5.71	0.64	0.69	0.57	74.6	0.91	9.43
	Averg	10.6	9.33	4.71	1.95	1.24	0.07	0.23	0.13	30.8	0.41	1.81

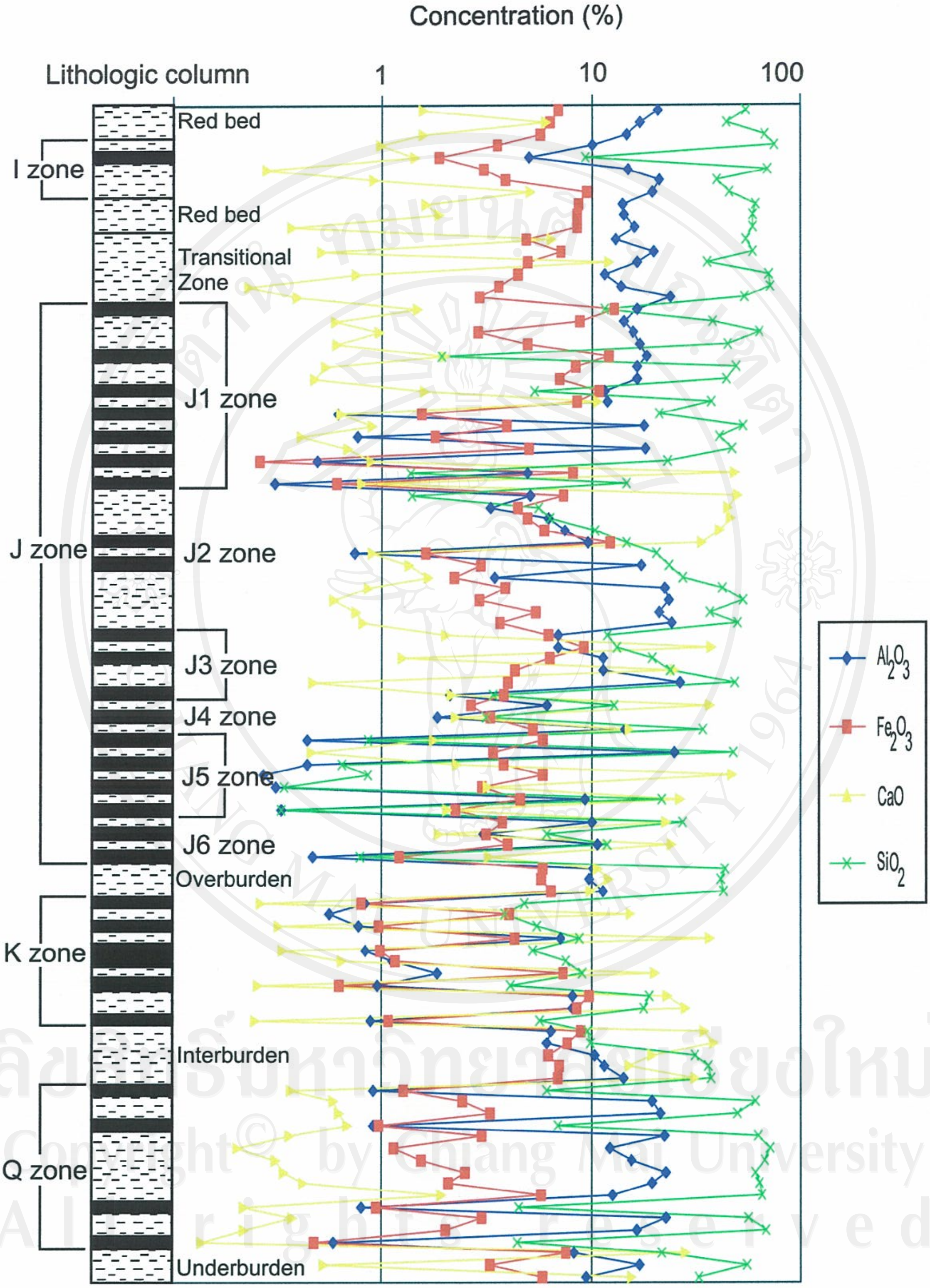


Figure 4.4 The graph of major oxide of Al-Fe-Ca-Si from Mae Moh coal field with lithologic column (not in scale).

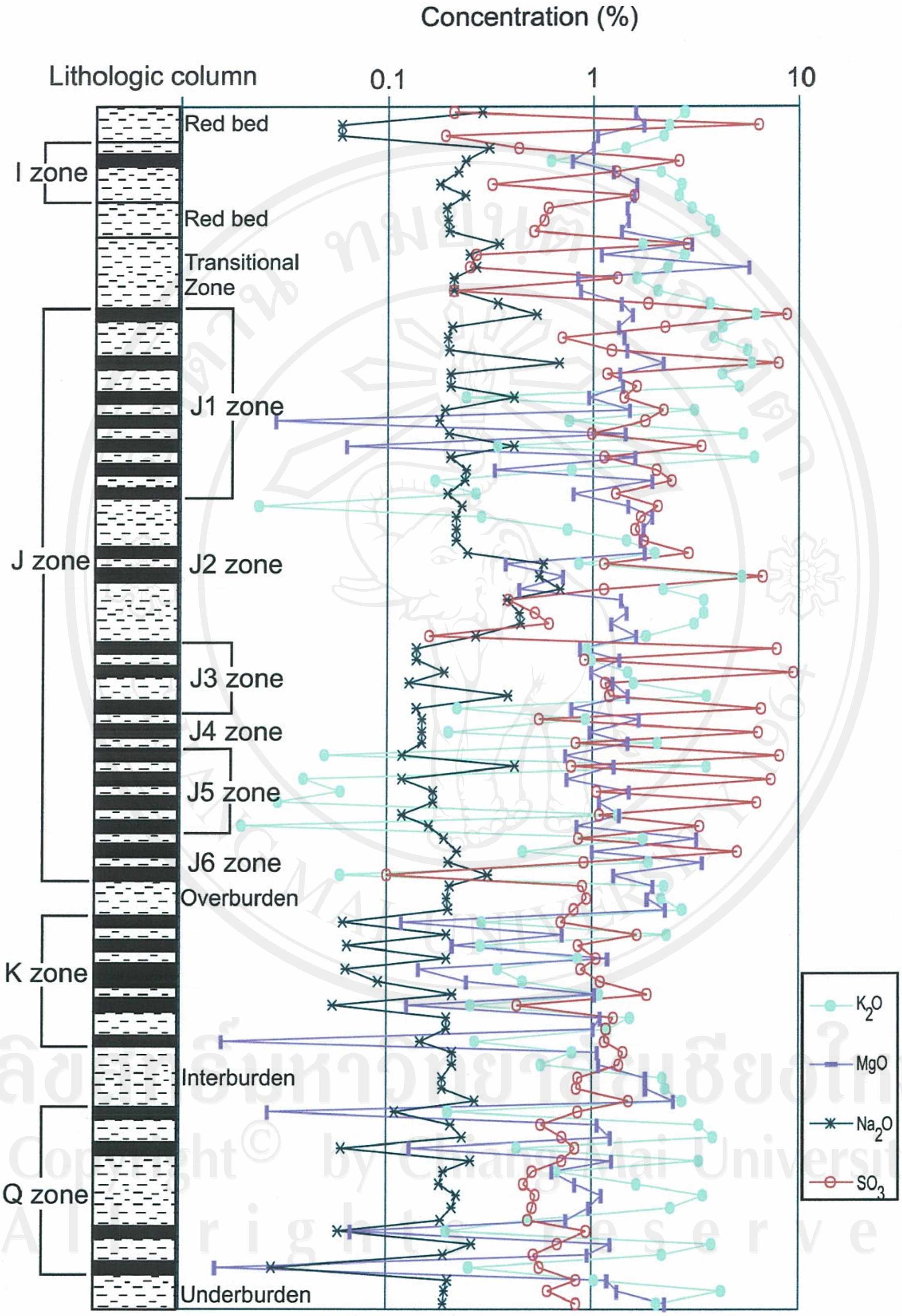


Figure 4.5 The graph of major oxide of K-Mg-Na-S from Mae Moh coal field with lithologic column (not in scale).

4.3.1.2 Trace elements

The trace elements of coal and sediment from Mae Moh coal field are reported in Table 4.14 and Appendix D.

The graphs of trace elements of Mae Moh coal field are shown in Figure 4.6 and 4.7. The Figure 4.6 shows the good correlation of V, Cr, Co, and Cu. The graph at Figure 4.7 shows the good correlation of Zn, Ba, Pb, As and Zr. The trace elements of Ni and Zr are high concentration in sediment. While the trace elements of Ba, V, Co, Zn, and As are high concentration in coal. The barium concentration is high in J zone coal.

Barium concentration is high in the lower part of J zone. Chromium concentration is very low in overburden and K zone. Zirconium concentration is low in the sediment samples of J zone. Arsenic concentration is very low at the sediment sample between J1 coal and J2 coal but high concentration in coals. Zinc concentration is low in the transitional zone, the middle part and lower part of J zone. Nickel concentration is low in Q zone. Vanadium concentration is high in J zone. Cobalt concentration is low in transitional zone and sediment in lower part of J zone. Nickel concentration is high in J5 coal and sediment from the interburden. Copper concentration is low in transitional zone and lower part of J zone. Zirconium concentration is low in transitional zone, middle and lower part of J zone, and interburden. Lead concentration is low in transitional zone and coal from K zone.

The trace element of V and Ba shown significant at J zone (Figures 4.6 and 4.7). The vanadium show association with basic igneous rock and volcanic origin, while barium have association with granitic rock (Table 4.15) (Andrews-Jones (1968) and Plant and Raiswell (1983)). The pattern of V, Cr, Co, Ba, and Pb from Mae Moh

Table 4.14 Geochemical analysis of trace elements of Mae Moh coal field.

Zone		V	Cr	Co	Ni	Cu	Zn	As	Zr	Ba	Pb
		ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
RB	Min	32.2	19.6	4.54	29.9	15.8	139	21.4	3.89	184	45.2
	Max	95.8	63.1	18.5	58.4	34.9	227	34.5	90.9	924	70.1
	Averg	64.9	39.9	14.0	43.8	26.9	181	30.3	43.3	371	51.4
I ZONE	Min	1.93	9.20	6.07	30.4	11.0	143	68.0	4.25	27.9	38.6
	Max	83.4	37.0	30.5	94.1	42.9	237	68.0	14.5	75.9	65.0
	Averg	37.2	19.2	14.0	45.9	27.1	184	68.0	8.31	44.4	51.3
TZ	Min	21.6	11.0	4.42	13.8	13.0	70.0	19.5	3.06	15.6	21.4
	Max	43.4	16.5	11.6	52.9	20.5	114	19.5	4.69	280	21.4
	Averg	29.9	14.5	7.9	25.3	16.5	94.9	19.5	4.05	138	21.4
J ZONE	Min	1.89	2.39	3.85	5.51	3.14	30.0	0.42	0.26	104	17.6
	Max	273	121	59.3	128	49.4	365	472	118	1150	55.9
	Averg	82.4	42.3	17.9	51.9	28.2	164	126	28.2	376	36.3
OB	Min	65.9	0.31	16.7	76.8	36.4	216	27.8	46.8	158	44.5
	Max	70.8	3.6	17.0	79.8	37.6	226	38.8	54.5	169	45.7
	Averg	68.0	2.5	16.9	78.5	37.1	222	35.1	50.4	163	44.9
K ZONE	Min	40.0	0.01	15.6	8.14	31.0	66.7	2.19	1.23	126	10.3
	Max	71.4	46.0	19.8	98.2	46.5	318	358	110	268	49.0
	Averg	52.9	18.6	17.8	52.4	37.6	210	169	48.6	194	30.7
IB	Min	48.09	6.52	16.1	86.2	31.6	262	5.39	2.52	125	46.8
	Max	66.1	30.2	16.9	102	33.7	316	18.5	42.4	150	50.3
	Averg	56.6	18.5	16.4	94.6	32.7	283	12.2	25.9	138	48.1
Q ZONE	Min	50.3	8.98	15.8	3.79	33.6	40.7	14.0	42.7	139	22.3
	Max	87.7	153	20.8	74.0	44.7	228	251	157	221	48.8
	Averg	77.5	30.7	17.1	43.9	39.3	152	101	105	175	38.0
UB	Min	53.9	5.21	16.4	40.4	32.2	116	2.56	22.8	131	40.7
	Max	96.3	57.5	16.7	95.9	46.3	297	77.0	119	188	48.5
	Averg	71.5	28.5	16.5	74.2	38.2	218	36.4	63.5	166	44.9
Total	Min	1.89	0.01	3.85	3.79	3.14	30.0	0.42	0.26	15.6	10.3
	Max	273	153	59.3	128	49.4	365	472	157	1150	70.1
	Averg	69.5	32.0	16.8	52.0	30.7	175	108	41.3	273	38.7

Remark V: vanadium Cr: chromium Co: cobalt Ni: nickel Cu: copper

Zn: zinc As: arsenic Zr: zirconium Ba: barium Pb: lead

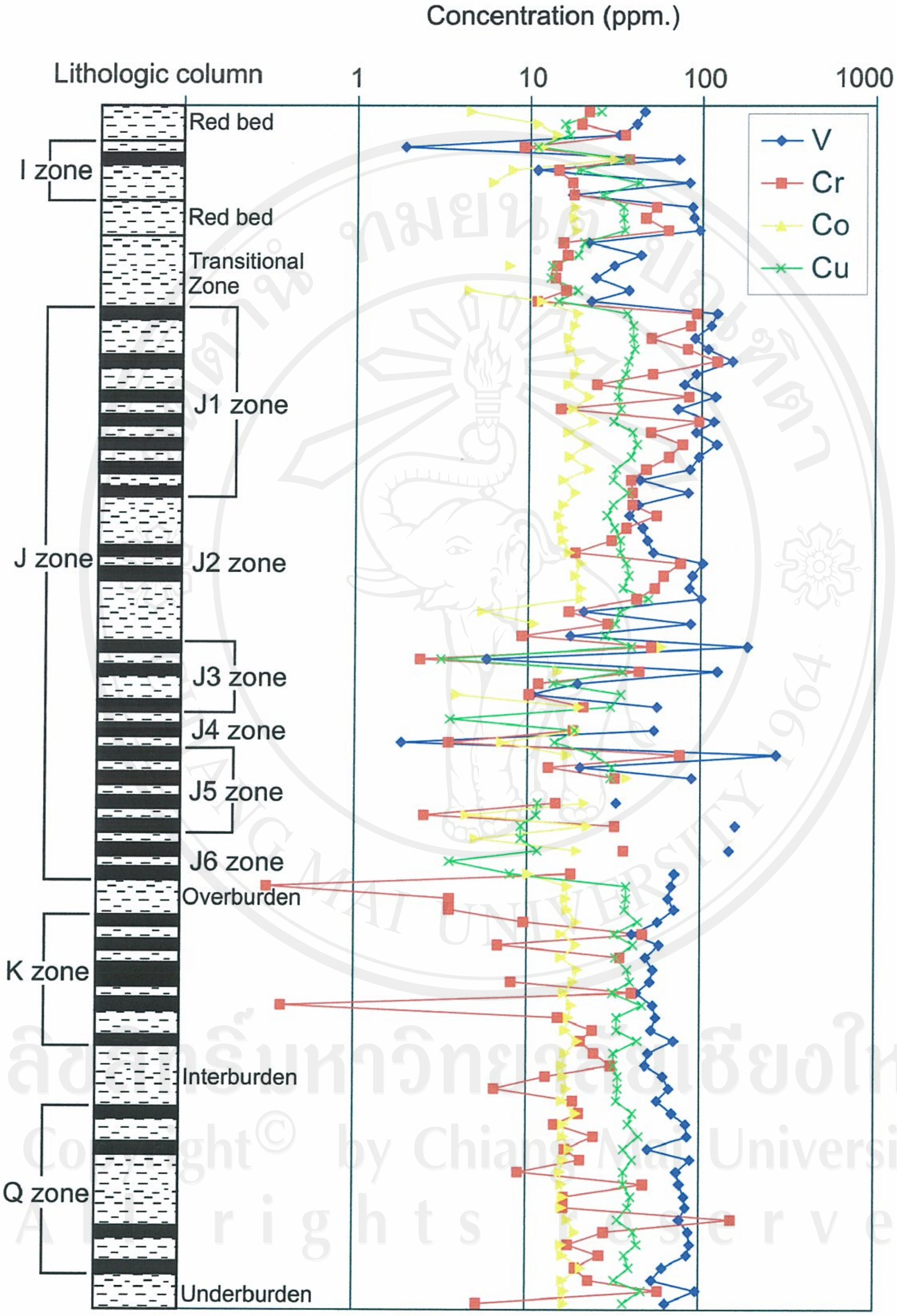


Figure 4.6 The graph of trace elements of V-Cr-Co-Cu from Mae Moh coal field with lithologic column (not in scale).

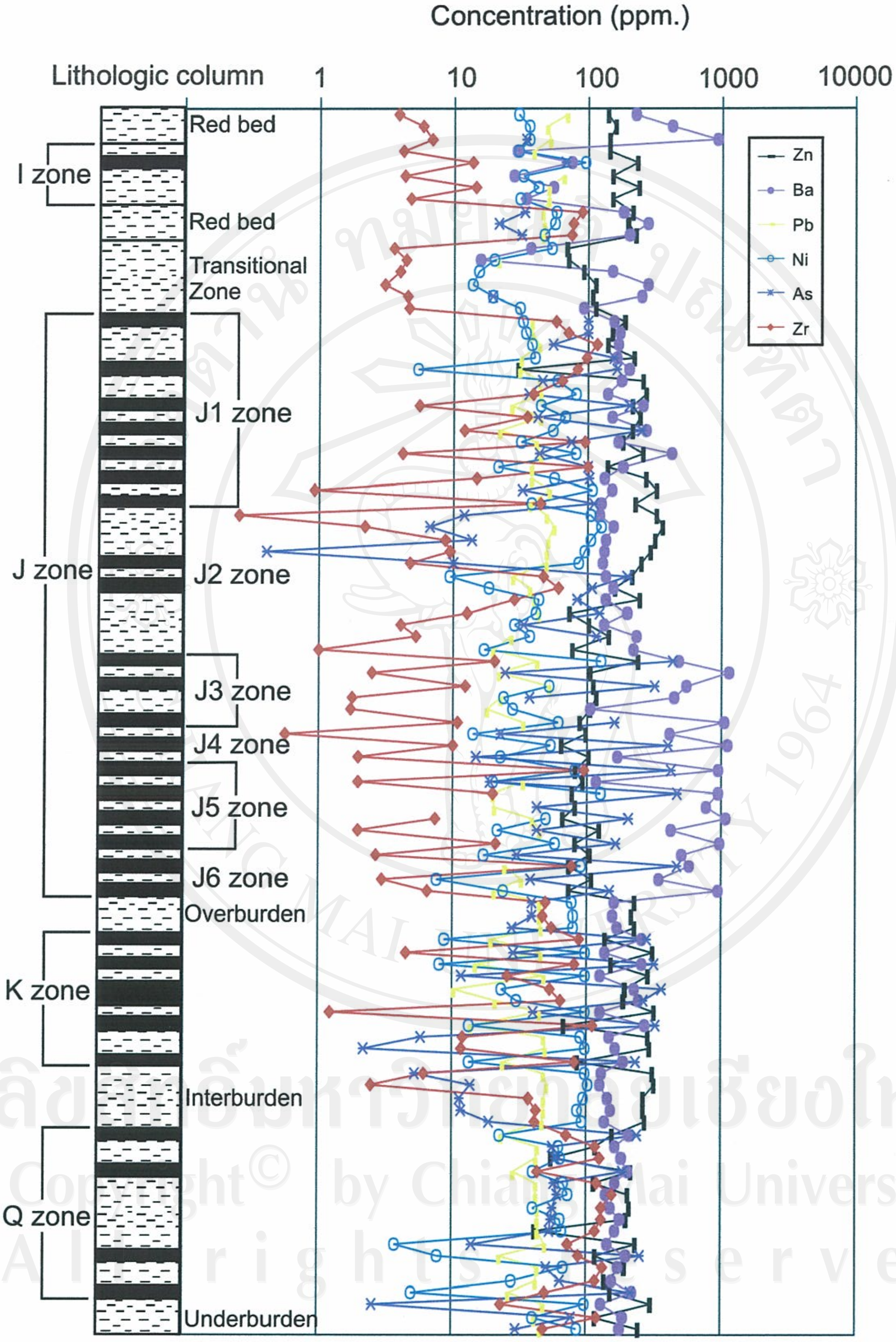


Figure 4.7 The graph of trace elements of Zn-Ba-Pb-Ni-As-Zr from Mae Moh coal field with lithologic column (not in scale).

Table 4.15 Selected geochemical associations of elements (modified from Andrews-Jones, 1968 and Plant and Raiswell, 1983)

Rock type occurrence	**Association**
1. Igneous associations	
Ultrabasic rocks	Cr-Co-Ni-Cu-Fe-Mg-Ca
Basic rocks	Ti-V-Sc-Fe-Mn-Ca
Alkaline rocks	Ti-Nb-Ta-Zr-Re-F-P-U-K-Na
Carbonatites	Re-Ti-Nb-Ta-P-F-U-K-Na
Granite rocks	Ba-Li-W-Mo-Sn-Zr-Hf-U-Th-Ti-F-K-Na
Pegmatites	Li-Rb-Cs-Be-Re-Nb-Ta-U-Th Zr-Hf-Sc-F-K
2. Granite-related mineralization	
Scheelite-cassiterite deposits	W-Sn-Mo-F
Fluorite-helvite deposits	Be-F-B
3. Hydrothermal sulfide ores	
General associations	Cu-Pb-Zn-Mo-Au-Ag-As-Hg-Sb Se-Te-Co-Ni-U-V-Bi-Cd
Porphyry copper deposits	Cu-Mo-Re
Complex sulfides	Hg-As-Sb-Se-Ag-Zn-Cd-Pb
Low-temperature sulfides	Bi-Sb-As
Base metal deposits	Pb-Zn-Cd-Ba
Precious metals	Au-Ag-Cu-Co-As
Precious metals	Au-Ag-Te-Hg
Associated with basic rocks	Ni-Cu-Pt-Co
4. Sedimentary associations	
Black shales	U-Cu-Pb-Zn-Cd-Ag-Au-V-Mo-Ni-As-Bi-Sb
Phosphorites	U-V-Mo-Ni-Ag-Pb-F-Re
Evapolites	Li-Rb-Cs-Sr-Br-I-B-K-Na
Laterites	Ni-Cr-V
Manganese oxides	Co-Ni-Mo-Zn-W-As-Ba-V
Placers and sands	Au-Pt-Sn-Nb-Ta-Zr-Hf-Th-Re
Red Beds, continental (mineralized)	U-V-Se-As-Mo-Pb-Cu
Red beds, volcanic origin	Cu-Pb-Zn-Ag-V-Se
Proxites	Nb-Ti-Ga-Re
5. Elements with Similar geochemistry	K-Rb; Rb-Cs; Al-Ga; Si-Ge; Zr-Hf; Nb-Ta; Re; S-Se; Br-I; Zn-Cd; Rb-Tl; Pt-Pd-Rh-Ru-Os-Ir

correlated with trace elements in common rock in Figure 4.8 indicated that the source of trace elements could come from weathered rhyorite flanked the Mae Moh basin.

It can be concluded that the source of trace elements of Mae Moh coal field could come from weathered rhyolite flanked the Mae Moh basin. The higher concentration of Ba show some significant in J3 to J6 zone. The source of trace elements in J zone might come from the weathering of rhyolite rock and pumice deposit that found in intraformational conglomerate texture in claystone in J1, J2, and J5 coal zone. Mahatthanachai (1996) found the volcanic debris and volcanic glass in J zone. It means that there was volcanic activity at that time but there was no report about volcanic rocks in northern Thailand at this period. The pumice could come from the other place and was deposited in J zone. The pumice might be transported by water. The Figure 4.9 shows the good correlation between CaO with Na_2O, SO_3, V, and Ba. This correlation could be associated with marine at J zone. The correlation can be supported that the pumice could be transported by marine or big lacustrine. However, the other source of Ca in the others sequences could come from the limestone is surrounding the Mae Moh basin.

4.3.2 Chiang Muan coal field

4.3.2.1 Major oxide

The major oxide of coal and sediment from Chiang Muan coal field are reported in the Table 4.16 and Appendix D.

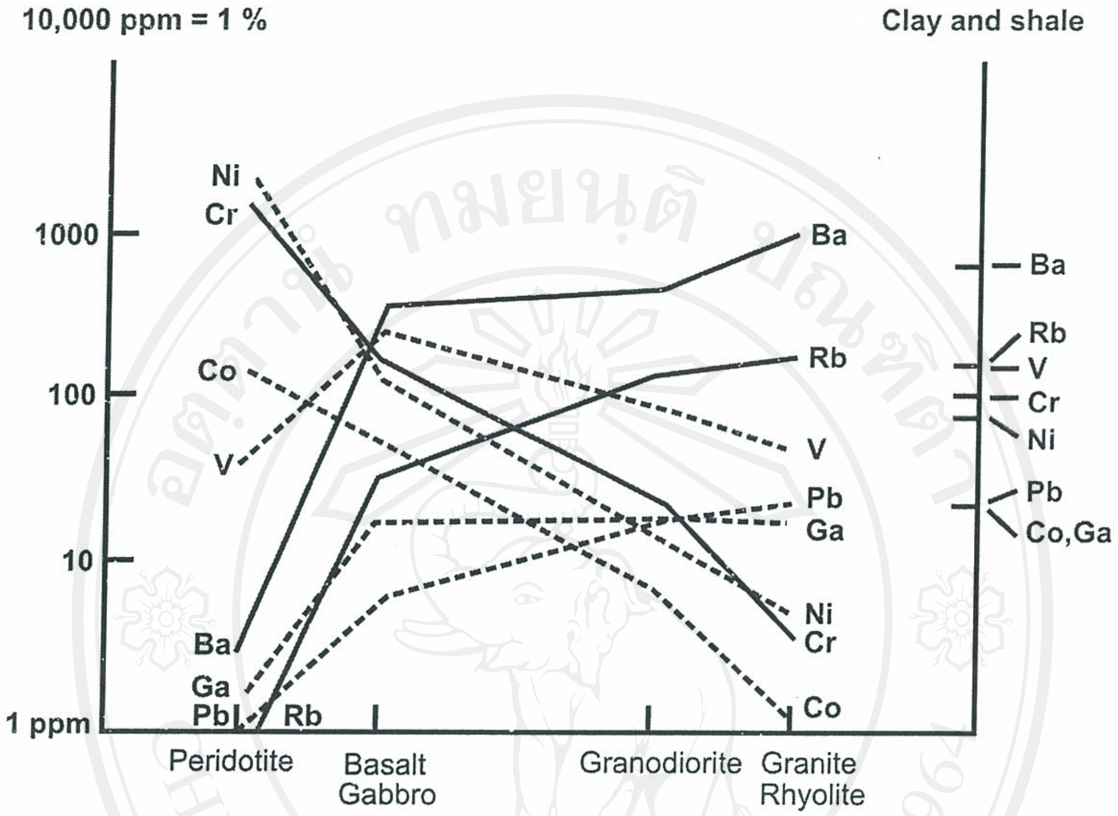


Figure 4.8 Trace elements in common rock types (modified from Wedepohl, 1969).

The major oxide graph pattern (Figure 4.10) shows that the pattern of SiO_2, Al_2O_3, Fe_2O_3, K_2O, and MgO show similarity of pattern. While the pattern of CaO and SO_3 show similarity pattern of this group.

The concentration of CaO is high in calcareous claystone at overburden zone. The SiO_2 content is very low in coal at LM zone. The Fe_2O_3 content is high in IB3 zone. The SO_3 content is high in U1 and U2. The K_2O content is low in IB2. The major oxides in sediments are higher concentration than the major oxides in. The concentration of K_2O in coal is very low at LS and LM zone.

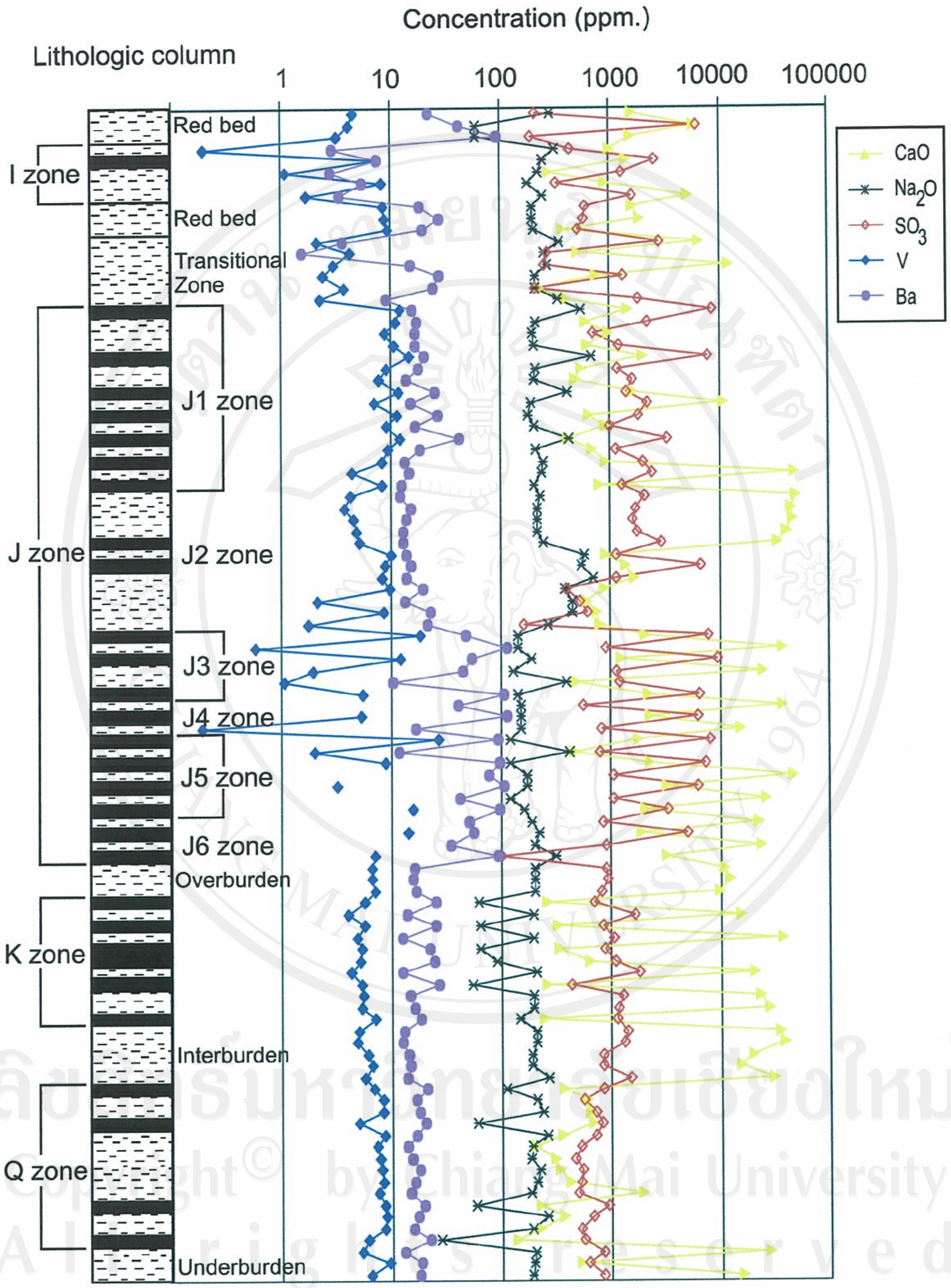


Figure 4.9 The graph of selected major and trace elements of Mae Moh coal field with lithologic column (not in scale).

Table 4.16 Geochemical analysis of major oxide of Chiang Muan coal field.

ZONE		Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	SO_3
		(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Q	Min	10.5	0.42	5.17	1.32	1.05	0.05	0.63	0.05	69.5	0.52	0.13
	Max	13.1	0.60	5.29	1.40	1.39	0.07	1.10	0.08	74.9	0.67	0.15
	Averg	11.8	0.51	5.23	1.36	1.22	0.06	0.87	0.07	72.2	0.60	0.14
OB	Min	9.65	1.11	3.37	1.33	0.56	0.04	0.12	0.04	33.5	0.42	0.16
	Max	20.5	25.4	7.77	2.92	1.16	0.24	0.24	0.16	71.5	0.74	2.49
	Averg	15.0	7.69	5.09	2.03	0.81	0.13	0.19	0.10	54.0	0.61	0.98
U1	Min	2.13	0.88	3.29	0.26	0.41	0.01	0.04	0.01	3.61	0.05	0.54
	Max	24.0	3.14	8.55	3.05	1.05	0.25	0.37	0.12	69.5	0.69	11.9
	Averg	13.1	1.75	6.40	1.70	0.86	0.06	0.20	0.06	38.4	0.39	5.26
IB1	Min	18.1	0.77	5.65	2.34	1.08	0.04	0.21	0.08	59.5	0.76	1.23
	Max	18.1	0.77	5.65	2.34	1.08	0.04	0.21	0.08	59.5	0.76	1.23
	Averg	18.1	0.77	5.65	2.34	1.08	0.04	0.21	0.08	59.5	0.76	1.23
U2	Min	4.97	0.33	2.83	0.62	0.63	0.01	0.12	0.01	8.25	0.09	0.17
	Max	26.9	4.74	7.70	3.42	1.79	0.10	0.35	0.14	69.2	0.71	6.10
	Averg	14.6	2.02	4.97	1.69	1.08	0.04	0.24	0.06	37.1	0.39	3.13
IB2	Min	7.02	0.45	2.57	0.65	0.60	0.03	0.07	0.02	65.3	0.50	0.10
	Max	12.9	2.72	5.64	1.05	1.06	0.13	0.12	0.07	82.7	0.72	0.31
	Averg	9.62	1.70	4.35	0.82	0.83	0.07	0.10	0.05	73.9	0.64	0.17
LM	Min	0.65	0.68	1.07	0.05	0.65	0.01	0.22	0.03	1.34	0.04	0.13
	Max	26.8	6.06	3.02	2.52	1.73	0.02	0.31	0.04	47.9	0.61	2.29
	Averg	13.7	3.37	2.05	1.29	1.19	0.02	0.27	0.04	24.6	0.33	1.21
IB3	Min	20.8	0.60	3.74	1.72	1.46	0.02	0.10	0.06	48.4	0.66	0.16
	Max	23.8	0.99	10.2	2.15	1.59	0.05	0.24	0.09	52.9	0.73	0.17
	Averg	22.3	0.80	6.96	1.94	1.53	0.04	0.17	0.08	50.7	0.70	0.17
LS	Min	2.88	0.86	1.54	0.17	0.53	0.01	0.26	0.01	4.92	0.07	0.18
	Max	24.4	1.88	3.65	1.76	1.60	0.02	0.45	0.03	50.2	0.61	2.74
	Averg	13.7	1.37	2.60	0.97	1.07	0.02	0.36	0.02	27.6	0.34	1.46
UB	Min	13.3	0.57	5.41	1.05	0.92	0.03	0.10	0.04	58.5	0.70	0.12
	Max	19.0	0.63	5.44	1.43	1.27	0.06	0.10	0.05	69.4	0.71	0.15
	Averg	16.1	0.60	5.43	1.24	1.10	0.05	0.10	0.05	64.0	0.71	0.14
Total	Min	0.65	0.33	1.07	0.05	0.41	0.01	0.04	0.01	1.34	0.04	0.10
	Max	26.9	25.4	10.2	3.42	1.79	0.25	1.10	0.16	82.7	0.76	11.9
	Averg	13.8	2.55	5.06	1.54	0.98	0.06	0.23	0.06	47.8	0.50	2.11

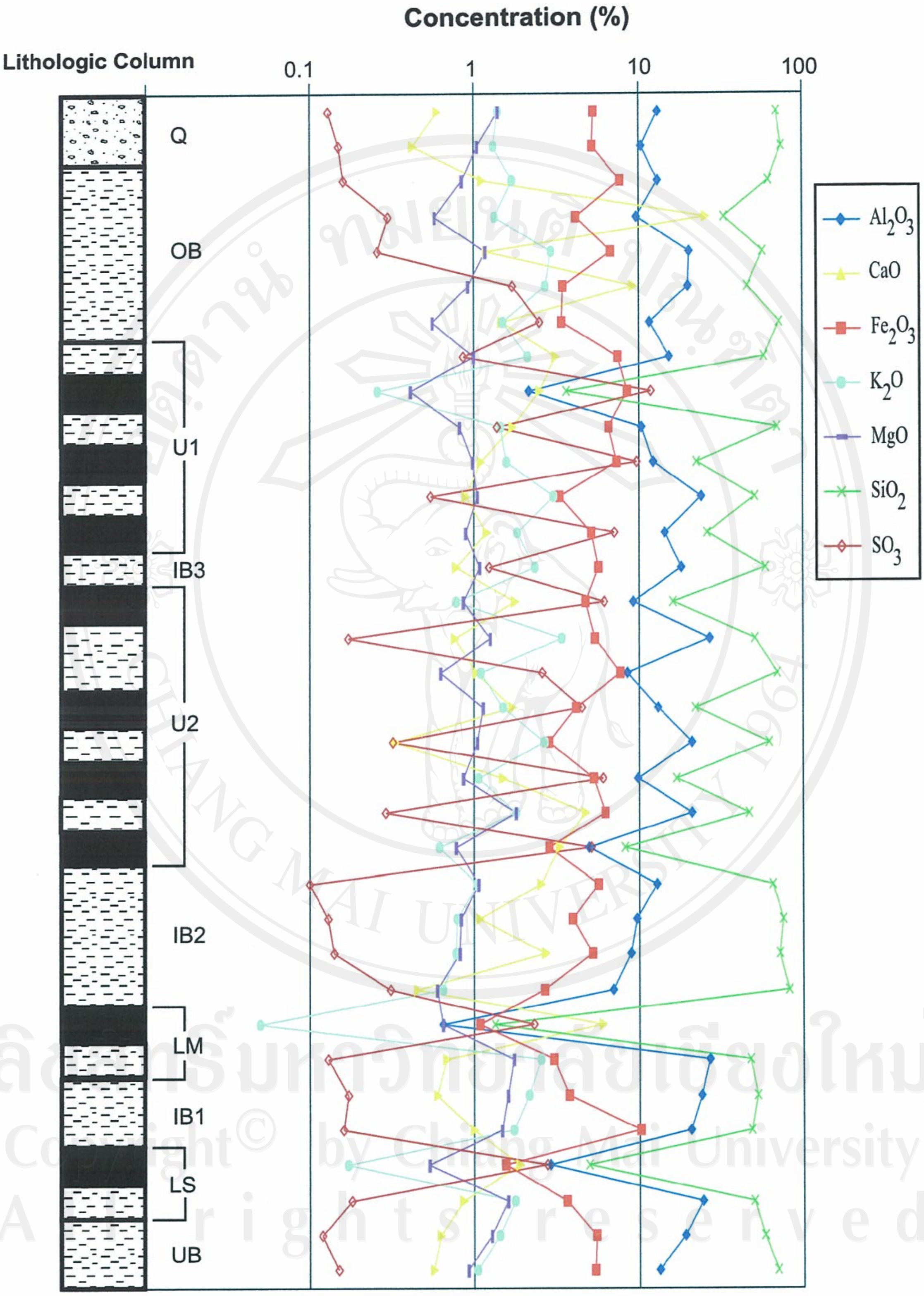


Figure 4.10 The graph of major oxide of Chiang Muan coal field with lithologic column (not in scale).

4.3.2.2 Trace elements

The trace elements of coal and sediment from Chiang Muan coal field are reported in the Table 4.17 and Appendix D.

The graphs of trace elements of Chiang Muan coal field are shown in Figures 4.11 and 4.12. The Figure 4.11 show the similarity of pattern of V, Cr, Ni, Cu, Ba, and Pb while the graph at Figure 4.12 show the similarity of pattern of Co, Zn, and Zr. Barium concentration is high value in overburden, LM, and LS zone. Cobalt concentration is low in U1, U2, and LS. Vanadium concentration is highest in coal from LS zone. Zirconium concentration is high in coal from upper coal seam 1 and low in sediment in lower split coal seam. Zinc concentration is low in lower massive coal seam. Chromium concentration is high in overburden and coal from upper coal seam 1 and lower split coal seam. Copper concentration is low in interburden2. The LS zone is high concentration of vanadium, chromium, nickel, and copper. The Figures 4.11 and 4.12 show that the concentration of trace elements in coals are higher than the concentration of trace elements in sediments at LS, LM, U2, and U1 zone.

The element of barium have association with granitic composition (Table 4.15) (Andrews-Jones, 1968 and Plant and Raiswell, 1983). Moreover, the trace element of V, Cr, Co, Ba, and Pb from Chiang Muan correlated with trace elements in common rock in Figure 4.8 indicated that the source of trace elements could come from the weathered volcanic rock surrounding Chiang Muan basin. The very high concentration of Ba in LS zone, LM, overburden show that there was strongly volcanic activity during deposition.

Table 4.17 Geochemical analysis of trace elements of Chiang Muan coal field.

Zone		V	Cr	Co	Ni	Cu	Zn	As	Zr	Ba	Pb	B	Mo	Sb
		ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Q	Min	23.8	11.5	5.9	25.1	10.9	122		2.89	58.6	38.5	32.0	3.74	
	Max	26.7	89.9	31.5	87.2	12.2	124		3.73	74.0	54.1	33.8	7.19	
	Averg	25.2	50.7	18.7	56.2	11.6	123		3.31	66.3	46.3	32.9	5.46	
OB	Min	5.61	5.23	4.76	22.0	13.7	159	9.02	4.66	26.5	50.7	22.2	16.9	41.5
	Max	53.1	40.0	22.1	53.1	62.4	226	9.02	8.37	1455	72.9	36.8	17.7	41.5
	Averg	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	Min	16.3	7.86	1.56	21.5	15.1	155	108	5.69	64.4	33.8	23.7	12.5	7.79
	Max	186	73.8	25.1	111	50.9	498	159	49.3	379	68.7	40.4	20.4	21.6
	Averg	86.3	39.0	16.7	66.4	34.0	247	138	20.2	203	52.7	30.9	16.7	14.7
IB1	Min	21.4	23.1	8.52	37.7	27.2	192		5.82	49.3	55.9	31.2		
	Max	21.4	23.1	8.52	37.7	27.2	192		5.82	49.3	55.9	31.2		
	Averg	21.4	23.1	8.52	37.7	27.2	192		5.82	49.3	55.9	31.2		
U2	Min	10.8	6.44	1.45	21.3	11.9	159	35.6	4.01	41.4	27.7	18.4	6.18	15.8
	Max	111	46.2	31.6	176	52.6	250	402	22.7	448	68.1	37.7	6.63	77.8
	Averg	49.9	21.7	15.6	62.9	35.5	205	154	9.50	199	44.8	27.4	6.40	36.7
IB2	Min	12.0	5.08	4.12	21.2	7.70	155		3.09	20.4	39.9	19.9	12.9	
	Max	27.7	40.8	41.0	44.7	9.31	172		3.87	71.9	54.8	31.0	12.9	
	Averg	18.9	16.7	18.5	28.4	8.43	165		3.33	38.6	46.1	25.7	12.9	
LM	Min	25.4	17.7	20.7	29.6	31.3	91.5	64.7	6.20	187	50.3	28.2	8.94	
	Max	30.7	22.8	20.7	57.3	32.3	256	64.7	11.5	1926	50.3	28.2	8.94	
	Averg	28.0	20.3	20.7	43.5	31.8	174	64.7	8.83	1056	50.3	28.2	8.94	
IB3	Min	31.3	10.9	11.0	42.6	21.3	181		2.67	62.2	59.8	17.2		86.4
	Max	37.4	75.4	13.3	83.0	35.7	206		4.38	92.5	61.9	20.0		86.4
	Averg	34.4	43.1	12.2	62.8	28.5	194		3.53	77.4	60.9	18.6		86.4
LS	Min	19.6	9.90	1.08	28.0	34.0	264	115	1.03	210	62.8	16.8	4.34	11.1
	Max	446	103	29.0	173	81.5	339	115	21.5	1588	62.8	16.8	4.34	24.3
	Averg	233	56.7	15.0	100	57.7	301	115	11.3	899	62.8	16.8	4.34	17.7
UB	Min	30.8	11.7	8.79	23.2	12.4	130		2.42	46.8	46.1	19.2	9.42	
	Max	32.4	13.1	8.79	30.6	17.7	137		3.34	127	47.9	23.4	9.42	
	Averg	31.6	12.4	8.79	26.9	15.1	133		2.88	86.8	47.0	21.3	9.42	
Total	Min	5.61	5.08	1.08	21.2	7.70	91.5	9.02	1.03	20.4	27.7	16.8	3.74	7.79
	Max	446	103	41.0	176	81.5	498	402	49.3	1926	72.9	40.4	20.4	86.4
	Averg	54.4	28.4	15.0	53.6	29.3	200	122	9.07	329	52.2	26.8	11.1	33.6

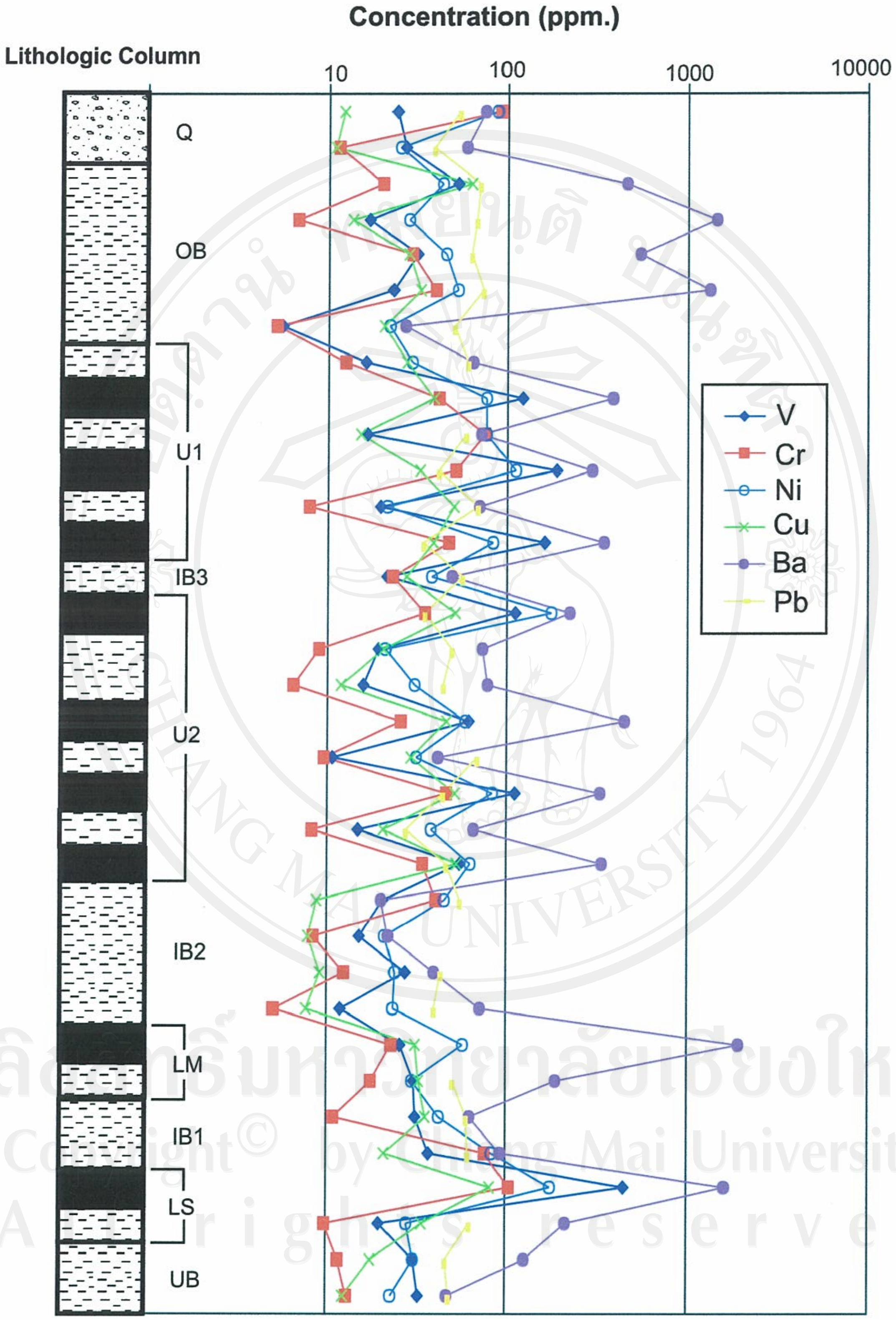


Figure 4.11 The graph of trace elements of V-Cr-Ni-Cu-Ba-Pb from Chiang Muan coal field with lithologic column (not in scale).

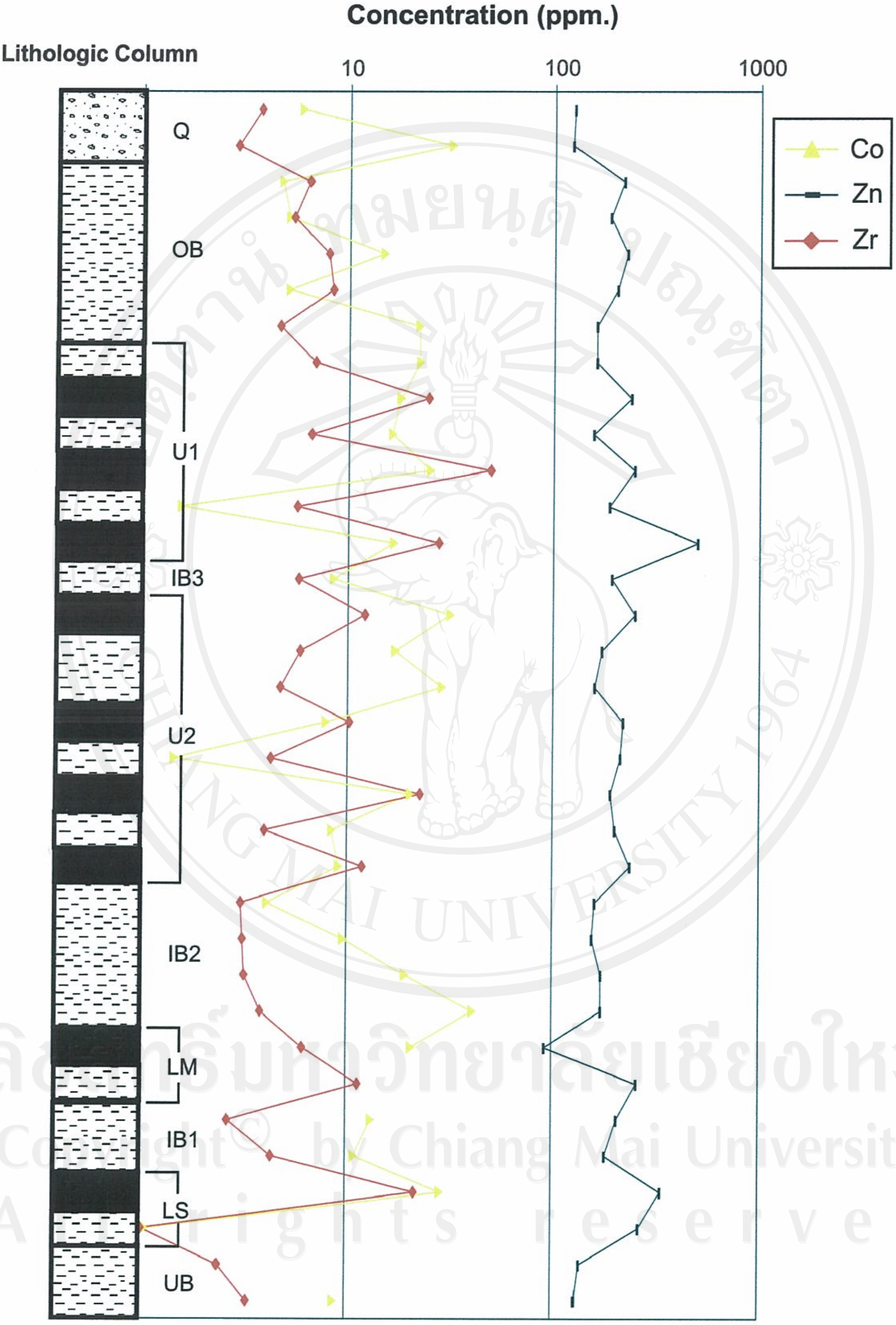


Figure 4.12 The graph of trace elements of Co-Zn-Zr from Chiang Muan coal field with lithologic column (not in scale).

4.3.3 Mae Teep coal field

4.3.3.1 Major oxide

The major oxide of coal and sediment from Mae Teep coal field are reported in the Table 4.18 and Appendix D.

The graph's pattern of major oxide (Figure 4.13) shows that the pattern of SiO_2, Al_2O_3, MgO, and K_2O and show similarity of pattern. While the pattern of CaO and Fe_2O_3 show similarity pattern of this group. The coal seam is low concentration of TiO_2, MgO, MnO, Na_2O, and P_2O_5. The underburden is low concentration of MnO. The K_2O concentration is very low in coal sample at coal seam. The major oxides in sediments are higher concentration than the major oxides in coals, especially SiO_2, Al_2O_3, CaO, K_2O, MgO and Fe_2O_3.

4.3.3.2 Trace elements

The trace elements of coal and sediment from Mae Teep coal field are reported in the Table 4.19 and Appendix D.

The graphs of trace elements of Mae Teep coal field are shown in Figures 4.14 and 4.15. Arsenic concentration is high in coal seam unit. Nickel concentration is low in middle part of coal seam. Lead concentration is low in upper part of coal seam. Copper concentration is high in underburden. Zinc concentration is high in overburden and underburden, but is decreasing from the upper part of coal seam and is increasing in middle part of coal seam. Zirconium concentration is lowest in sample number OB4 (Figure 3.5) at overburden. Vanadium concentration is lowest in calcareous mudstone at Overburden. Barium is high concentration in Mae Teep coal field. Barium and arsenic are high concentration in coal seam. At the coal seam, the

Table 4.18 Geochemical analysis of major oxide of Mae Teep coal field.

Zone		Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	SO_3
		(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
OB	Min	5.46	0.93	5.56	0.31	1.20	0.07	0.18	0.12	13.8	0.34	0.61
	Max	13.8	30.4	13.9	3.10	8.66	0.36	0.24	0.23	55.2	0.78	0.85
	Averg	11.3	4.18	9.00	2.45	1.83	0.15	0.20	0.16	47.5	0.65	0.69
MS	Min	0.65	0.22	0.75	0.13	0.01	0.01	0.01	0.01	2.02	0.06	0.46
	Max	20.3	4.23	41.3	4.58	1.66	0.55	0.31	0.46	49.9	0.76	5.15
	Averg	7.81	0.97	6.68	1.66	0.74	0.08	0.14	0.12	20.9	0.32	1.25
UB	Min	8.02	0.59	1.95	0.90	0.89	0.02	0.19	0.10	21.1	0.36	0.54
	Max	16.4	32.00	6.40	3.85	1.23	0.17	0.20	0.16	76.9	0.90	0.77
	Averg	12.3	7.10	4.09	1.84	1.08	0.08	0.19	0.13	60.1	0.72	0.59
Total	min	0.65	0.22	0.75	0.13	0.01	0.00	0.00	0.01	2.02	0.06	0.46
	max	20.3	32.00	41.3	4.58	8.66	0.55	0.31	0.46	76.9	0.90	5.15
	Averg	9.86	3.15	7.25	2.00	1.23	0.11	0.17	0.14	37.3	0.51	0.93

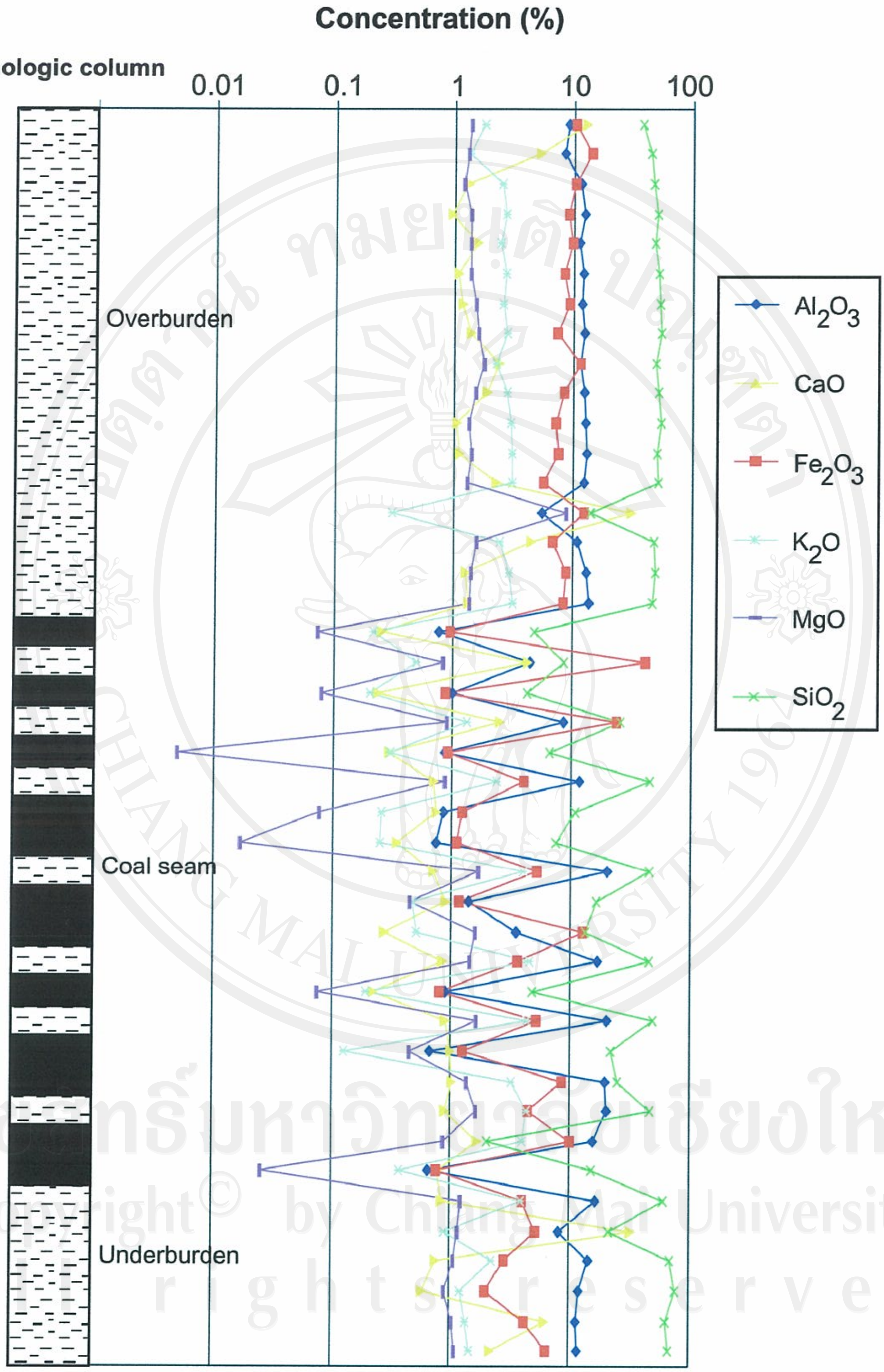


Figure 4.13 The graph of major oxide of Mae Teep coal field with lithologic column (not in scale).

Table 4.19 Geochemical analysis of trace elements of Mae Teep coal field.

Zone		V	Cr	Co	Ni	Cu	Zn	As	Zr	Ba	Pb
		ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
OB	Min	54.0	13.2	17.0	36.7	37.9	144	9.20	1.89	145	39.6
	Max	90.6	49.0	19.8	102	46.2	250	85.5	82.4	205	52.6
	Averg	84.5	38.8	18.3	55.4	43.1	179	54.1	57.9	171	43.4
MS	Min	65.4	39.1	16.6	9.43	40.0	9.22	10.8	12.1	176	10.3
	Max	129	82.0	28.0	83.3	84.1	296	359	199	299	56.1
	Averg	87.7	61.3	19.3	42.1	47.9	113	173	104	240	31.1
UB	Min	50.6	31.1	15.8	53.4	32.2	85.0	9.88	18.6	122	42.6
	Max	89.9	57.1	17.5	103	130	294	57.7	167	183	50.3
	Averg	74.9	46.5	16.5	69.3	74.9	150	32.7	106	159	45.7
Total	Min	50.6	13.2	15.8	9.43	32.2	9.22	9.20	1.89	122	10.3
	Max	129	82.0	28.0	103	130	296	359	199	299	56.1
	Averg	84.6	50.1	18.5	51.4	49.8	145	105	85.6	200	38.2

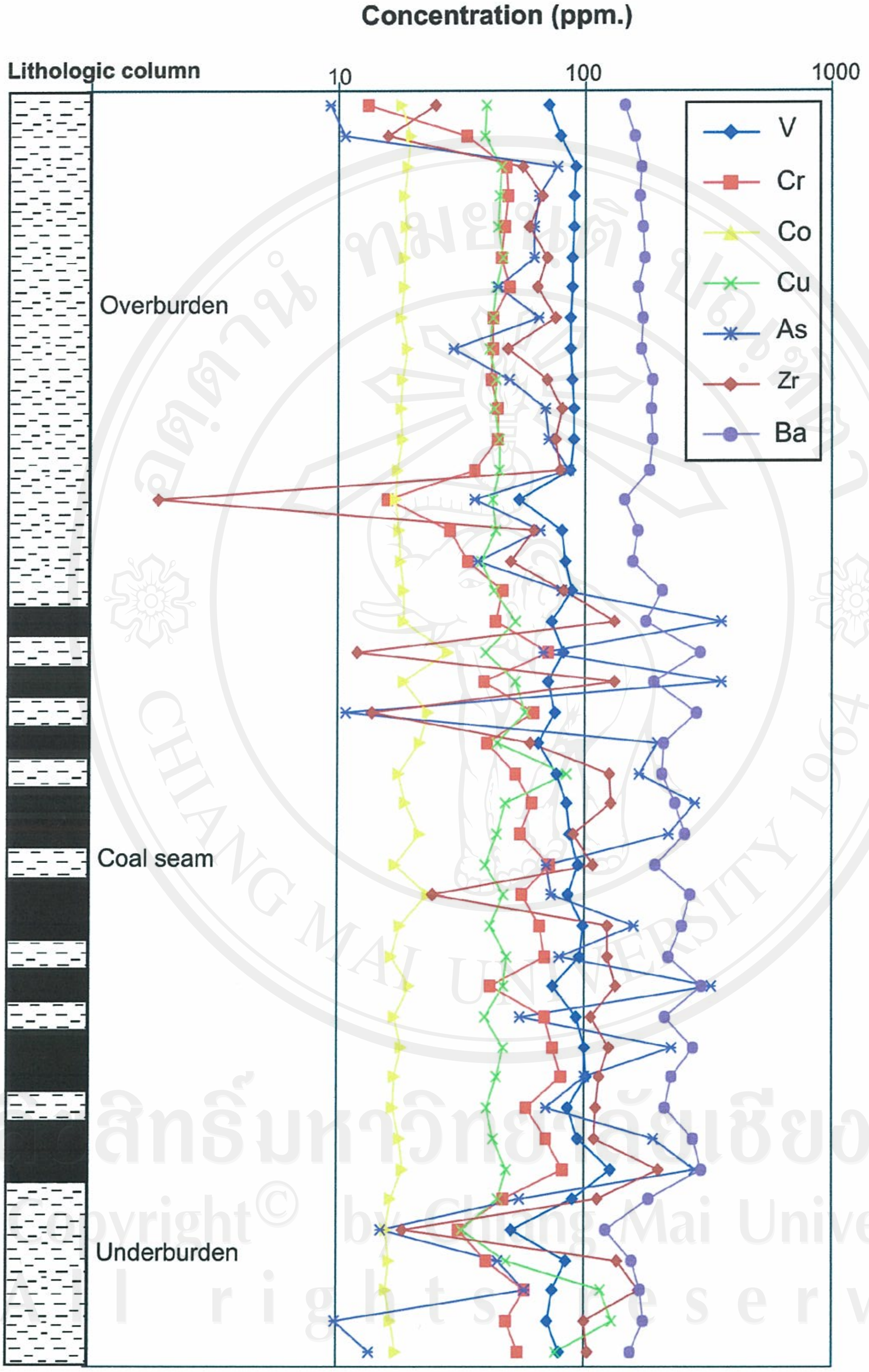


Figure 4.14 The graph of trace elements of V-Cr-Co-Cu-As-Zr-Ba from Mae Teep coal field with lithologic column (not in scale).

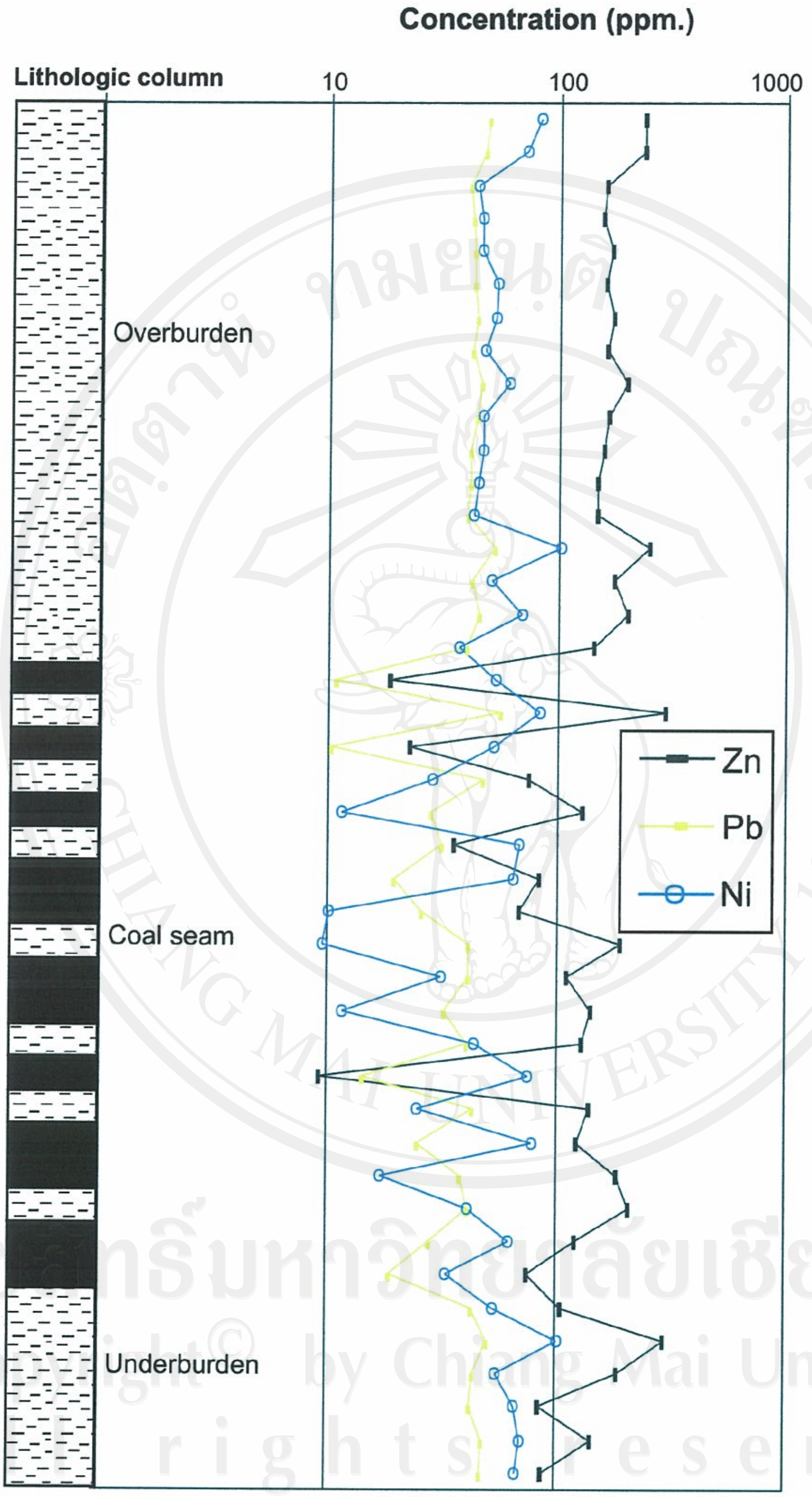


Figure 4.15 The graph of trace elements of Zn-Pb-Ni from Mae Teep coal field with lithologic column (not in scale).

concentration of trace elements of V, Cr, Cu, As, Zr, and Ba are high in coals, but the concentration of trace elements of Zn, Pb, and Ni are high in sediments.

The element of Ti, Fe, Mn, and Ca have association with basic igneous rock, while the element of Ti, P, K, and Na have association with alkaline igneous rock (Table 4.15) (Andrew-Jones, 1968 and Plant and Raiswell, 1983). It can be concluded that the source of major and trace element could be from the volcanic surrounding Mae Teep basin.

4.3.4 Wang Nua coal field

4.3.4.1 Major oxide

The major oxide of coal and sediment from Wang Nua coal field are reported in the Table 4.20 and Appendix D.

The graph's pattern of major oxide (Figure 4.16) shows that the pattern of SiO_2, Al_2O_3, TiO_2. MgO, K_2O, Fe_2O_3, P_2O_5, and Na_2O and show similarity of pattern. While the pattern of MnO, CaO, and SO_3 show similarity pattern of this group. The SiO_2, Al_2O_3, TiO_2, MgO, K_2O, Fe_2O_3, and Na_2O content are high in sediment and low in coal. While the CaO, and SO_3 content are high in coal.

4.3.4.2 Trace elements

The trace elements of coal and sediment from Wang Nua coal field are reported in the Table 4.21 and Appendix D. The graphs of trace elements of Wang Nua coal field are shown in Figure 4.17.

The element of Ba, Ti, Zr, K, and Na have association with alkaline igneous rock (Table 4.15) (Andrew-Jones, 1968 and Plant and Raiswell, 1983). The source of

Table 4.20 Geochemical analysis of major oxide of Wang Nua coal field.

Zone		Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	SO_3
		(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
OB	Min	13.3	0.19	3.84	1.47	0.72	0.01	0.18	0.09	39.8	1.22	0.55
	Max	20.9	0.33	6.83	2.53	0.86	0.02	0.19	0.11	71.2	1.37	0.65
	Averg	17.1	0.24	5.72	2.10	0.76	0.02	0.18	0.10	56.1	1.29	0.58
Coal	Min	0.40	0.49	1.31	0.36	0.40	0.01	0.05	0.06	12.0	0.05	1.08
	Max	0.67	0.75	2.06	0.58	0.59	0.02	0.06	0.09	12.7	0.21	1.54
	Averg	0.54	0.62	1.69	0.47	0.49	0.02	0.05	0.08	12.3	0.13	1.31
Total	Min	0.40	0.19	1.31	0.36	0.40	0.01	0.05	0.06	12.0	0.05	0.55
	Max	20.9	0.75	6.83	2.53	0.86	0.02	0.19	0.11	71.2	1.37	1.54
	Averg	11.6	0.37	4.37	1.55	0.67	0.02	0.14	0.09	41.5	0.90	0.82

Table 4.21 Geochemical analysis of trace elements of Wang Nua coal field.

Zone		V	Cr	Co	Ni	Cu	Zn	As	Zr	Ba	Pb
		(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
OB	Min	93.1	79.1	16.6	18.0	46.5	104	33.0	77.3	174	27.0
	Max	171	216	17.6	66.6	104	215	207	154	194	45.2
	Averg	148	186	17.6	20.7	75.4	199	149	83.9	184	32.9
coal	Min	172	122	20.9	30.0	59.4	10.1	312	46.7	219	11.7
	Max	191	154	22.4	38.5	59.4	146	348	74.6	436	15.2
	Averg	181	138	21.7	34.2	59.4	78.1	330	60.7	328	13.5
Total	Min	93.1	79.1	16.6	18.0	46.5	10.1	33.0	46.7	174	11.7
	Max	191	216	22.4	66.6	104	215	348	154	436	45.2
	Averg	142	139	18.8	39.6	64.1	145	175	91.5	230	30.0

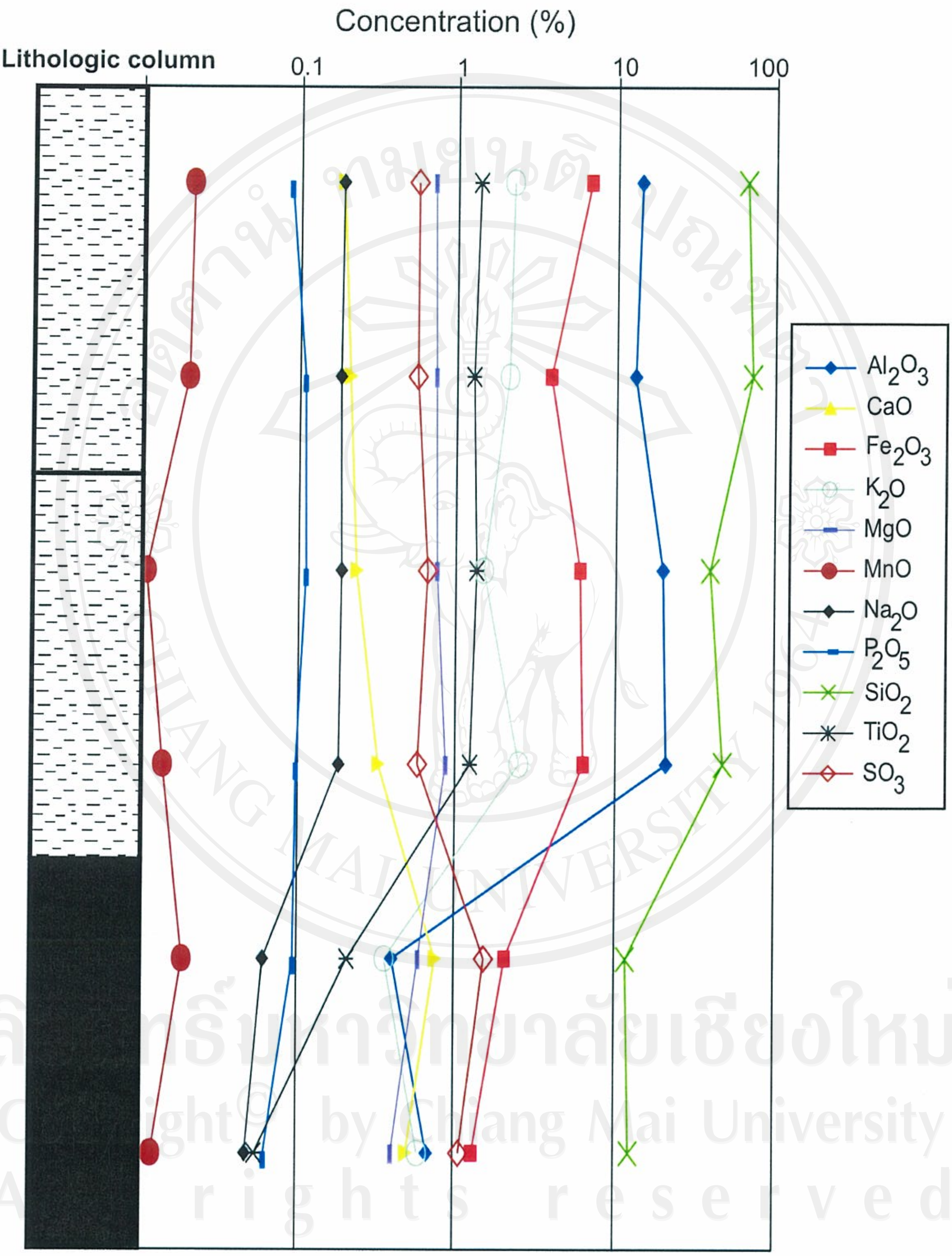


Figure 4.16 The graph of major oxide of Wang Nua coal field with lithologic column (not in scale).

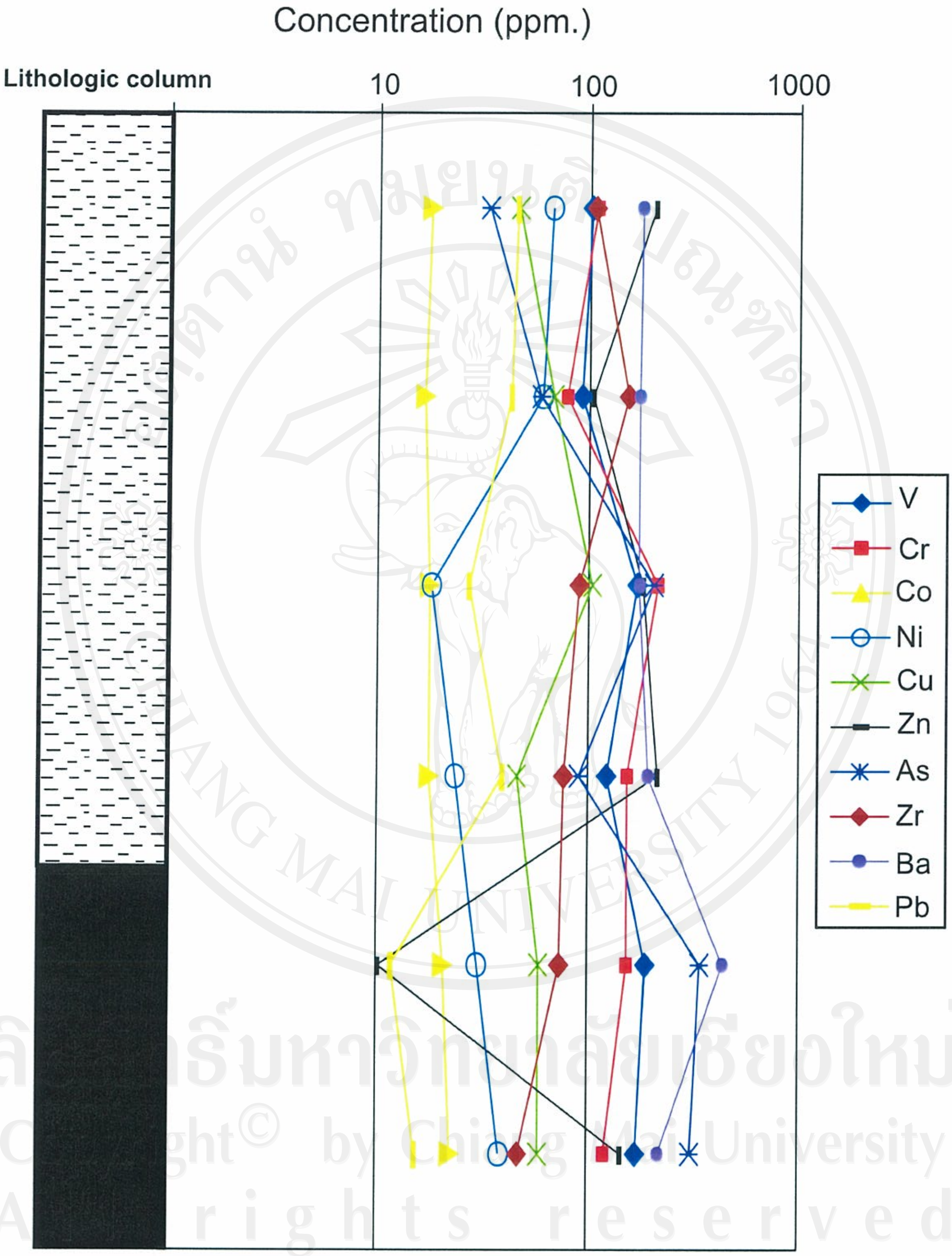


Figure 4.17 The graph of trace elements of Wang Nua coal field with lithologic column (not in scale).

major and trace element could be from the Triassic granite surrounding Wang Nua basin.

4.3.5 Ngao coal field

4.3.5.1 Major oxide

The major oxide of coal from Ngao coal field are reported in Table 4.22 and Appendix D.

4.3.5.2 Trace elements

The trace elements of coal from Ngao coal field are reported in Table 4.23 and Appendix D.

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.

Silicon occurs alone in quartz or with aluminum in the clay mineral kaolinite and with potassium, in illite. Calcium occurs primarily in calcite but may also occur in the gypsum, jarosite, and halotrichite or in organic combination. Titanium occurs from the weathered of igneous rock.

Iron and sulfur occur together primarily as pyrite but may also occur separately, associated with organic material on a molecular level. Hart (1995) concluded that the positive correlation of iron and sulfur supports the presence of pyrite. Moreover, the positive correlation graph of iron and sulfur of sample from Mae

Table 4.22 Geochemical analysis of major oxide of Ngao coal field.

Sample No.	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	SO_3
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
NGC1	1.04	0.68	0.90	0.58	0.13	0.01	0.04	0.03	11.4	0.17	1.05
NGC2	1.21	0.69	0.97	0.60	0.14	0.01	0.05	0.03	10.9	0.18	1.71
Min	1.04	0.68	0.90	0.58	0.13	0.01	0.04	0.03	10.9	0.17	1.05
Max	1.21	0.69	0.97	0.60	0.14	0.01	0.05	0.03	11.4	0.18	1.71
Averg	1.12	0.68	0.93	0.59	0.13	0.01	0.05	0.03	11.1	0.18	1.38

Table 4.23 Geochemical analysis of trace elements of Ngao coal field.

Sample No.	V	Cr	Co	Ni	Cu	Zn	As	Zr	Ba	Pb
	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
NGC1	73.3	15.1	19.7	28.4	36.5	216	131	22.3	168	34.7
NGC2	72.9	16.3	19.7	30.3	36.5	217	132	22.1	158	34.8
Min	72.9	15.1	19.7	28.4	36.5	216	131	22.1	158	34.7
Max	73.3	16.3	19.7	30.3	36.5	217	132	22.3	168	34.8
Averg	73.1	15.7	19.7	29.4	36.5	217	132	22.2	163	34.8

Moh coal field (Figure 4.18) also support. The presence of abundant syngenetic pyrite in coal in indicative of a marine environment or of a transgressive sequence where the coal is overlain by marine rocks. Both environments suggest that the availability of sulfate ions during deposition or early diagenesis may be the controlling factor for pyrite formation. The element of Ti, Fe, Mn, and Ca have association with basic igneous rock, while the element of Ti, P, K, and Na have association with alkaline igneous rock (Table 4.15) (Andrew-Jones, 1968 and Plant and Raiswell, 1983).

The geochemical distribution of trace elements can be divided into 2 parts, no environmental significance and environmental significance. The no environmental significance consists of Ce, Cs, Dy, Eu, Hf, In, La, Na, Nb, Nd, Rb, Sb, Sc, Sm, Sr, Ta, Tb, Ti, Y, Yb, and Zr. The environmental significance consists of As, Ba, Br, Cl, Co, Cr, Mn, Mo, Ni, Pb, Se, Th, Yb, and Zr (Hart, 1995). For this study the trace elements are in the environmental significance.

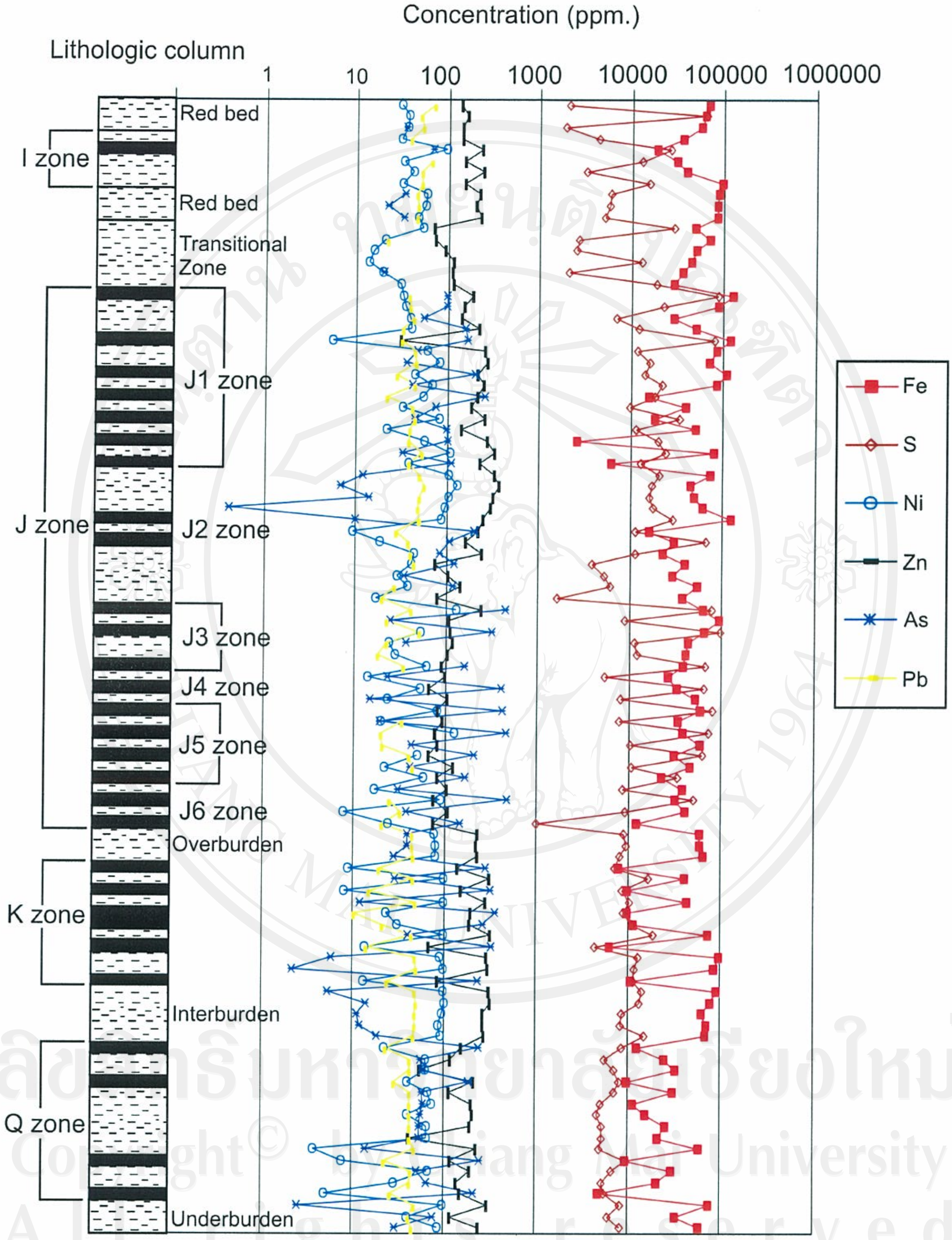


Figure 4.18 The graph of selected major element of Fe-S and trace elements of Ni-Zn-As-Pb from Mae Moh coal field with lithologic column (not in scale).

Arsenic

The reported organic/inorganic affinity of As in coals is as varied as the range of concentrations. Partitioning of the chalcophile elements, which includes As, between organic and inorganic phases is a function the availability of organic ligands and sulfides ions (Zubovic, 1976). In most wetlands the concentration of organic ligands would remain constant whereas the availability of sulfide ions would be erratic, dependent upon the influx of sulfate and the development of sulfate reducing bacteria. For most coals, the sporadic occurrence of pyrite indicates periodic sulfate influx since most peat swamps are conducive to the growth of sulfate reducing bacteria.

In coals, As mostly occurs in the mineral fraction and likely with pyrite (Finkelman, 1981; Benson and others, 1984; Palmer and Filby, 1984; Swaine, 1990). Minkin and others (1984) using an electron microprobe, identified As in solid solution within pyrite and believed that syngenetic pyrite was partially replaced by As bearing, epigenetic solutions, resulting in zones of high As content within single pyrite grains. As well, Finkelman (1981) identified As in both pyrite and chalcopyrite and Coleman and Bragg (1990) found that pyretic S and As varied sympathetically in US coals. Goodarzi and Van Der Flier-Keller (1991) showed that concentration variations of As, Fe and S were closely matched in the presence of arsenopyrite.

Goodarzi (1987, 1988) suggested an organic association for a portion of the As lignites and subituminous coals from western Canada and found a strong organic association for As in Texas lignites. Coleman and Bragg (1990) have suggested that low levels of As in U.S. coals may be organically associated. Querol and others (1992) have suggested that organic/inorganic affinity of As may be related to concentration, low As concentrations are mineral related whereas high concentrations may be organically associated.

At Mae Moh coal field, arsenic concentration ranges from 0.42 to 472 ppm, with average 108 ppm. Arsenic concentration is low at I zone coal. While the arsenic concentration is high in Q, K, and J zone coal.

At Chiang Muan coal field, arsenic concentration ranges from 9.42 to 402 ppm, with average 122 ppm. Arsenic concentration is high at U2 and U1 zone.

At Mea Teep coal field, arsenic concentration at coal seam ranges from 10.8 to 359 ppm, with average 173 ppm. The arsenic concentration from Wang Nua coal field ranges from 312 to 348 ppm, with average 330 ppm. The arsenic concentration from Ngao coal field ranges from 311 to 312 ppm, with average 312 ppm.

Barium

Barium has been reported in both organic and inorganic association. In low rank coals there is there is good evidence for organic association where the Ba is attached to carboxyl groups (Finkelman, 1981; Morgan and others, 1981; Benson and Holm, 1985; Miller and Given, 1986; 1987; Lyons and others, 1988; Mukherjee and others, 1993). In lignite from Ndagota, Karner and others, (1986) suggested both mineral and organic association for Ba. Mineral associations include barite (Gluskoter and others, 1977; Finkelman, 1981; Powell and others, 1990), carbonates (Hower and Bland, 1989; Hower and others, 1991; Spears and Martinez-Tarazona, 1993), feldspars (Finkelman, 1981) clay minerals (Palmer and Filby, 1984; Querol and others, 1992) and phosphates (Spears and Martinez-Tarazona, 1993).

At Mae Moh coal field, barium concentration ranges from 15.6 to 1150 ppm, with average 273 ppm. Barium is high concentration in coal from Q, K, and J zone. The highest concentration of barium is in coal at J zone.

At Chiang Muan coal field, barium concentration ranges from 20.4 to 1926 ppm, with average 329 ppm. The barium concentration is very high in LS, LM, and OB zone. The highest barium concentration is in the overburden.

At Mae Teep coal field, barium concentration ranges from 122 to 299 ppm, with average 200 ppm. The barium concentration of Mae Teep coal field is high at coal seam. The barium concentration of Wang Nua coal field ranges from 174 to 436 ppm, with average 230 ppm. The barium concentration of coal sample from Ngao coal field range from 158 to 168 ppm, with average 163 ppm.

Cobalt

Swaine (1990) indicate that Co can occur in both organic and inorganic association. The geochemical similarities of Fe, Co and Ni should lead to a linked mineral occurrence in coals which is indeed the case. The Co bearing mineral linnaeite $(Co, Ni)_3S_4$ has been identified in coals by a number of authors (Goldschmidt, 1935; Finkelman, 1981) and correlation data for amny coals indicate a Co-sulfide association (Van Der Flier-Keller and Fyfe, 1987; Querol and others, 1992). A clay mineral association has also been suggested (Finkelman 1981; 1982; Van Der Flier-Keller and Fyfe, 1987). Zubovic (1966), using float sink separates, reported a 58% organic association for Co and suggested that a partial organic affinity in coals may be related to the metal ion's chelate stability. Organic association has also been suggested by Ward (1980).

At Mae Moh coal field, cobalt concentration ranges from 3.85 to 59.3 ppm, with average 16.8 ppm. Cobalt is high concentration in coal from J and I zone.

At Chiang Muan coal field, cobalt concentration ranges from 1.08 to 41.0 ppm, with average 15.0 ppm. Cobalt is high concentration at U2 and IB2 zone.

At Mae Teep coal field, cobalt concentration ranges from 15.8 to 28.0 ppm, with average 18.5 ppm. Cobalt is high concentration at coal seam. The cobalt concentration from Wang Nua coal field is high in coal, which ranges from 16.6 to 22.4 ppm, with average 18.8 ppm. While . The cobalt concentration in coal from Wang Nua coal field is 19.7 ppm.

Chromium

The partitioning of Cr in coal varies from organic to inorganic. Zubovic and others (1961) based on float sink studies, identified an average organic affinity of 55% for Cr. An organic affinity for Cr has also been identified in British and German coals (Raask, 1985, reference therein). Chromium in vitrinite concentrates from England and Australia is primary organically bound (Lyons and others, 1988). Based on correlations with ash, an organic association was proposed for Cr in Indian coals from Meghalaya State (Mukherjee and others, 1993).

An inorganic, clay mineral association for Cr is suggested by Finkelman (1993). Van Der Flier-Keller and Fyfe (1987) suggest that Cr is also likely to be associated with heavy minerals in addition to clays. Goodarzi and Van Der Flier-Keller (1991) and Powell and others (1990) also report an inorganic association for Cr.

At Mae Moh coal field, chromium concentration ranges from 0.01 to 153 ppm, with average 32.0 ppm. Chromium is high concentration at Q and J zone.

At Chiang Muan coal field, chromium concentration ranges from 5.08 to 103 ppm, with average 28.4 ppm. Chromium is high concentration at LS and U1 zone.

At Mae Teep coal field, chromium concentration ranges from 13.2 to 82.0 ppm, with average 50.1 ppm. Chromium is high concentration in the coal seam.

At Wang Nua coal field, chromium concentration ranges from 79.1 to 216 ppm, with average 139 ppm.

At Ngao coal field, chromium concentration ranges from 15.1 to 16.3 ppm, with average 15.7 ppm.

Molybdenum

Molybdenum occurrence in coals can range from mostly inorganic to mostly organic (Swaine, 1990). According to Finkelman (1993) the probable mode of occurrence is unclear and suggests that Mo may be associated with sulfides or organics. Van Der Flier-Keller and Fyfe (1987) note an inorganic association for lignites in the N Ontario and a partial clay mineral association for bituminous coals from N.E. British Columbia. Zubovic and others (1961) found an average 40% organic affinity for Mo. Co-precipitation for Fe and Mn in sulfides was suggested by Finkelman (1981).

The trace element of Molybdenum in this study was analyzed only the sample from Chiang Muan coal field. The molybdenum concentration ranges from 3.74 to 20.4 ppm, with average 11.1 ppm. The molybdenum concentration is high at U1 zone.

Nickel

Zobovic and others (1961) calculated an average 58% organic affinity for Ni in samples from Eastern Interior region U.S. coals and Gluskoter and others (1977) suggested that Ni is distributes between sulfide minerals and the organic material in Illinois coals. Fractionation experiments by Miller and Given (1986) on samples from North Dakota lignites indicate that Ni is partially to largely complexed with the organic matter. Finkelman (1993) indicates the probable mode of occurrence for Ni is unclear and that it can occur with organic material, sulfides or clay minerals. Van Der Flier-Keller and Fyfe (1988) indicate a similar distribution while Lyons and others (1988), based on geochemical analyses of vitrinite concentrates, favor an organic association for Ni.

At Mae Moh coal field, nickel concentration ranges from 3.79 to 128 ppm, with average 52.0 ppm. The nickel concentration is very high in J zone.

At Chiang Muan coal field, nickel concentration ranges from 21.2 to 176 ppm, with average 53.6 ppm. The nickel concentration is high in LS, U2, and U1 zone.

At Mae Teep coal field, nickel concentration ranges from 9.43 to 103 ppm, with average 51.4 ppm. The nickel concentration is high in UB zone.

At Wang Nua coal field, nickel concentration ranges from 18.0 to 66.6 ppm, with average 39.6 ppm. The nickel concentration is high in sediment above coal layer. The nickel concentration of coal sample from Ngao coal field ranges from 28.4 to 30.3 ppm, with average 29.4 ppm.

Lead

Van Der Flier-Keller and Fyfe (1987) suggested a possible organic association for Pb in lignites from the Moose River Basin, Canada. Inorganic lead is most commonly identified in the sulfide minerals, either as galena or as a trace constituent in other sulfides, particularly pyrite (Kuhn and others, 1980; Harvey and Ruch, 1986; Miller and Given, 1987; Finkelman, 1993). The mineral clausthalite (PbSe) was identified by Goodarzi and Swaine (1993) in Western Canadian coals and small amounts of Pb can be found in some silicates, carbonates, phosphates and sulfates (Valkovic, 1983).

At Mae Moh coal field, lead concentration ranges from 10.3 to 70.1 ppm, with average 38.7 ppm. The lead concentration is high in I zone and red bed zone.

At Chiang Muan coal field, lead concentration ranges from 7.79 to 86.4 ppm, with average 33.6 ppm. The lead concentration is high in U2 zone.

At Mae Teep coal field, lead concentration ranges from 10.3 to 56.1 ppm, with average 38.2 ppm. The lead concentration is high in coal seam.

At Wang Nua coal field, lead concentration ranges from 11.7 to 45.2 ppm, with average 30.0 ppm. The lead concentration of coal from Ngao coal field is 34.8 ppm.

Vanadium

The organic/inorganic association of V in coals is extremely variable. The predominantly organic association for V is also indicated by Ruch and others (1974); Gluskoter (1975); Ward (1980); Karner and others (1986); Lyons and others (1988). Primarily inorganic association for V are indicated by Goodarzi (1987, 1988); Van

Der Flier-Keller and Fyfe (1987). The mineral constituents which most often contain trace proportions of V are carbonates and clay minerals (Kuhn and others, 1980; Valkovic, 1983; Harvey and Ruch, 1986; Finkelman, 1993).

At Mae Moh coal field, vanadium concentration ranges from 1.89 to 273 ppm, with average 69.5 ppm. The lead concentration is very high in J zone.

At Chiang Muan coal field, vanadium concentration ranges from 5.61 to 446 ppm, with average 54.4 ppm. The lead concentration is very high in LS, U2, and U1 zone.

At Mae Teep coal field, vanadium concentration ranges from 50.6 to 129 ppm, with average 84.6 ppm. The lead concentration is in coal seam.

The vanadium concentration of Wang Nua coal field ranges from 93.1 to 191 ppm, with average 142 ppm. The vanadium concentration of Ngao coal field ranges from 72.9 to 73.3 ppm, with average 73.1 ppm.

Zinc

Both organic and inorganic associations for Zn have suggested. Bases on float sink data Zubovic (1966) found that Zn always occurred with the inorganic material, a view that was supported by Ruch and others (1974). The primary Zn bearing in coals include sulfides (sphalerite or substitution for Fe in pyrite and chalcopyrite), and carbonates, either in smithsonite, or substituting in other carbonate minerals (Kuhn and others, 1980; Harvey and Ruch, 1986; Finkelman, 1993).

Zinc is also often associated with the clay minerals and/or hydrous oxides of Fe and Mn where Zn is adsorbed on to the clay or oxide surfaces. Organic associations are most commonly suggested for low rank coals however, Lyons and others (1988) found Zn in organic combination in coal from England and Australia. Where an organic association is suggested the mode of occurrence is mixed between organic and inorganic phases (Miller and Given, 1987; Goodarzi and Swaine, 1993; Van Der Flier-Keller and Fyfe, 1987).

At Mae Moh coal field, zinc concentration ranges from 30.0 to 365 ppm, with average 175 ppm. The zinc concentration is high in UB, Q, IB, K, J, and I zone. The highest concentration of zinc is in J zone.

At Chiang Muan coal field, zinc concentration ranges from 91.5 to 498 ppm, with average 200 ppm. The zinc concentration is high in all coal zone; LS, LM, U2, and U1 zone.

At Mae Teep coal field, zinc concentration ranges from 9.22 to 296 ppm, with average 145 ppm. The zinc concentration is high in underburden and coal zone.

The zinc concentration of Wang Nua coal field ranges from 10.1 to 215 ppm, with average 145 ppm. The vanadium concentration of Ngao coal field is 217 ppm.

4.4 Coal petrography

The coal petrography was study to determine the macerals in coal that can be divided into 3 group, huminite group, liptinite group, and inertinite group. For this study, the huminite group consists of densinite, gelinite, and texto-ulminite. The liptinite group consists of alginite, liptodetrinite, sporinite, cutinite, and resinite. Finally, the inertinite group consists mostly of semifusinite and funginite.

4.4.1 Mae Moh coal field.

Q zone

Major macerals are the huminite group with consist of densinite, gelinite, and texto-ulminite. These macerals comprise about 80-90 % of the total macerals in the zone. Second in abundance are the liptinite group which comprise 5-10 % with dominant macerals are alginite, liptodetrinite, and sporinite. The inertinite maceral group forms a minor constituent and is mostly semifusinite, which indicates an arid to semi arid condition of the basin.

The presence of semifusinite in Q zone coal indicates that water during deposition was shallow and that at other times conditions were dry. Indications of burning are present throughout the coal seams. Since alginites are rare in the Q zone, depositional sites were not waterlogged during the peat accumulation. Highly oxidized condition of water in the basin led to the formation of liptodetrinite bands by the destruction of all organic materials in the liptinite group.

K zone

Major macerals are huminite group which comprise 70-80 % with dominant macerals are texto-ulminite, gelinite, and densinite. Second in abundance are the liptinite group which comprise 5-20 % with dominant macerals are alginite, liptodetrinite, suberinite, cutinite, and sporinite (Figures 4.19 and 4.20). In this zone, sporinite are very rich and show degraded spore. The inertinite maceral group forms a minor constituent and is mostly semifusinite, which indicates an arid to semi arid condition of the basin. Framboidal pyrite is common as an authigenic mineral. Diatom is remained in this zone.

The sporinite-rich coal and tree trunk remains indicate the depositional area was a forest swamp. The water in the lacustrine depositional area was essentially freshwater. This is indicated by the dominance of thin-walled alginite and the present of sporinite. The siliceous diatom rich in the K-zone could be result from the input of volcanic ash into the basin from the distance volcanic eruption gave rise to diatom boom.

J zone

Major macerals are the huminite group which 60-70 % with dominant macerals are gelinite, texto-ulminite, and densinite. Second in abundance are the liptinite group comprise 20-25 % with dominant macerals are alginite, liptodetrinite, and sporinite. The inertinite maceral group forms a minor constituent and is mostly semifusinite and funginite and comprise less than 5 %.

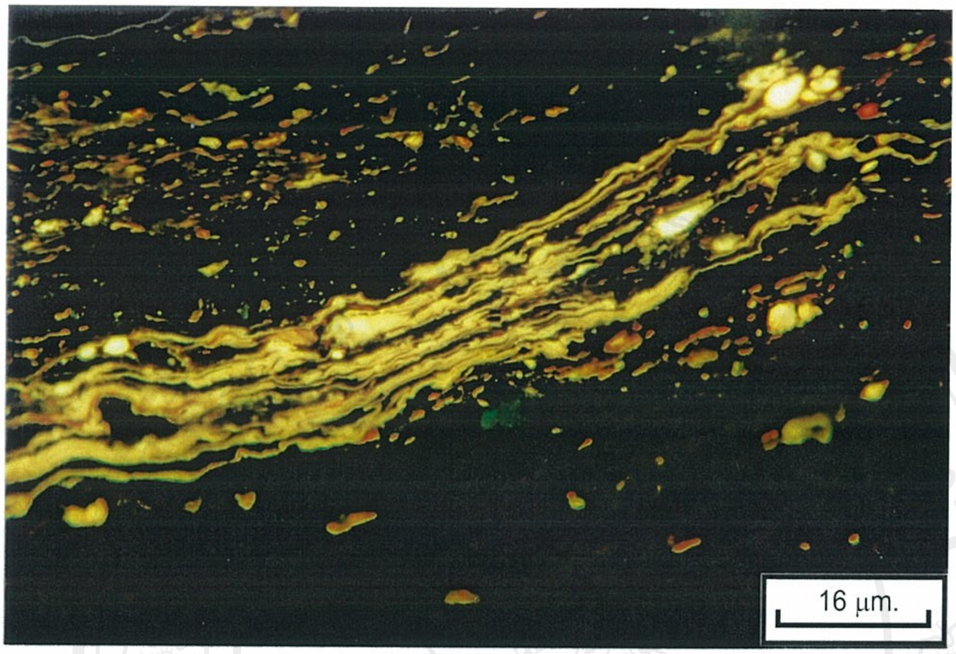


Figure 4.19 Photomicrograph showing association of alginite (*Pila* type-long yellowish and lamaginite-short greenish yellow) in K3 coal seam under oil immersion and fluorescenced.

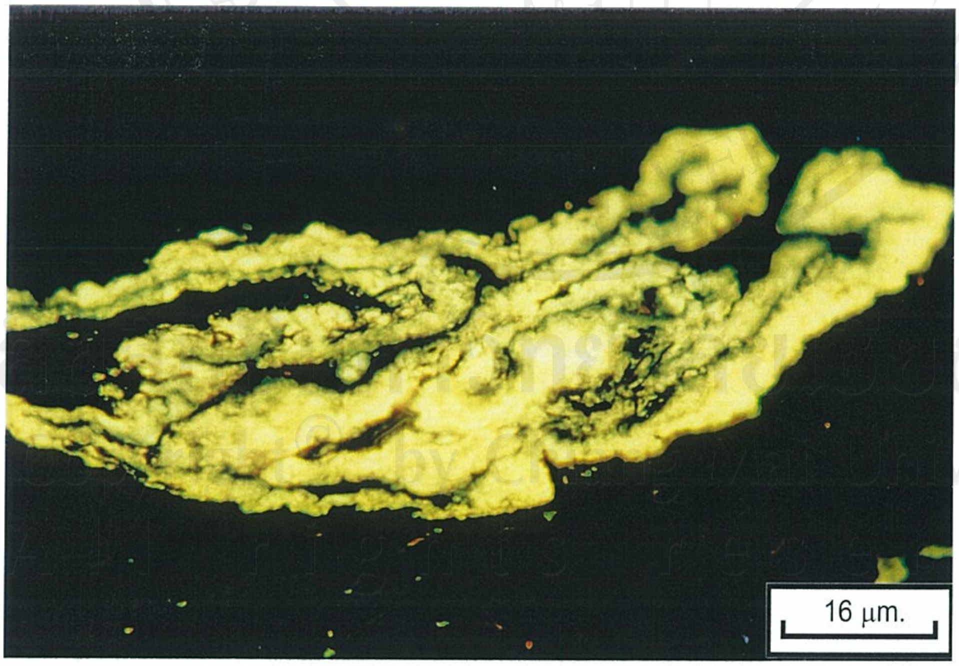


Figure 4.20 Photomicrograph showing association of cutinite in K3 coal seam under oil immersion and fluorescenced.

Some J coal seams are rich in semifusinite. This indicates that natural fires or strong oxidation of plant materials occurred before deposition. The dominant authigenic mineral is framboidal pyrite.

The association of alginite and cutinite in coal throughout the J zone indicates that water level during deposition was intermediate to shallow. The variation of alginite types, especially the presence alginite such as *Reinschia*, *Pila* algae, and *Botryococcus* sp. (Figure 4.21) could also indicate a change in water condition. Diatom is remained in this zone (Figure 4.22). The richness of framboidal pyrite resulted from the presence of *Desulfoviobrio desulfuricans* bacteria. This may indicate that water in the Mae Moh basin during this time became brackish and was at a high level. The presence of semifusinite indicates that there was at times shallow water and dry periods that likely led to natural fires before the deposition.

I zone

Major macerals are the huminite group which comprise 85-95% with dominant macerals are densinite and texto-ulminite (Figure 4.23). Second in abundance are the liptinite group which dominated by alginite, and sporinite.

The tree tunk remains, densinite, and texto-ulminites in I zone indicated the area of forest swamp. The replacement of in gastropod (*Margarya* sp.) and pyrite ball in I zone could be resulted from the presence of *Desulfoviobrio desulfuricans* bacteria.

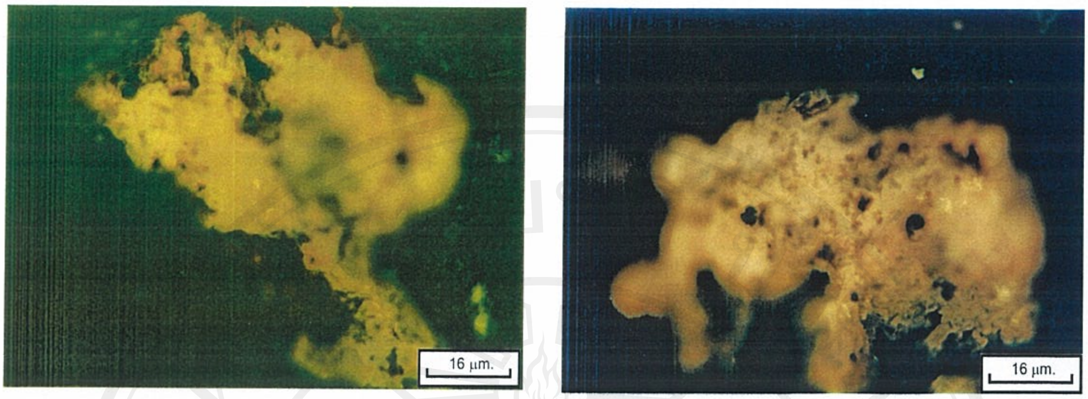
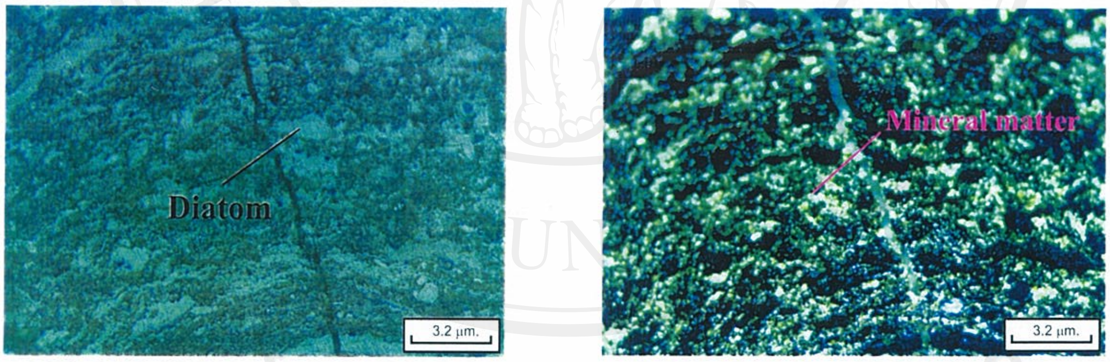
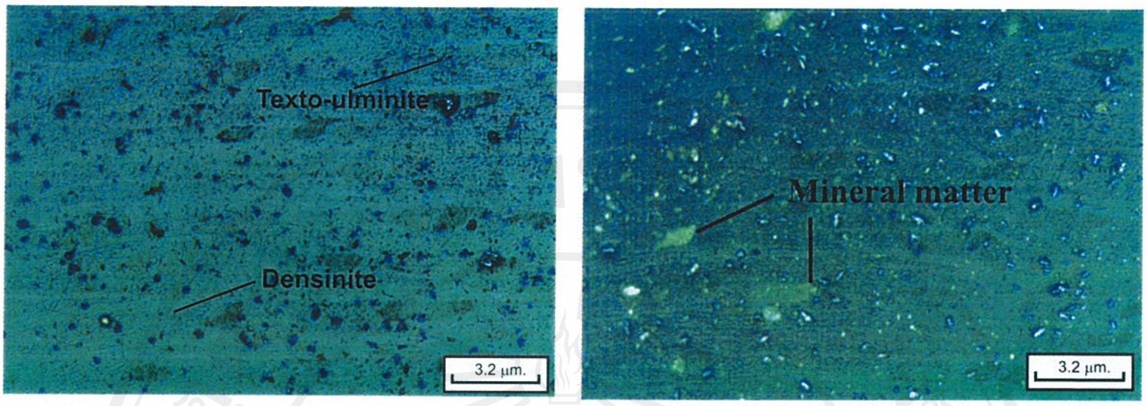


Figure 4.21 Photomicrograph showing alginite (*Botryococcus* sp.) in J6 coal seam from Mae Moh coal field under oil immersion and fluorescenced.



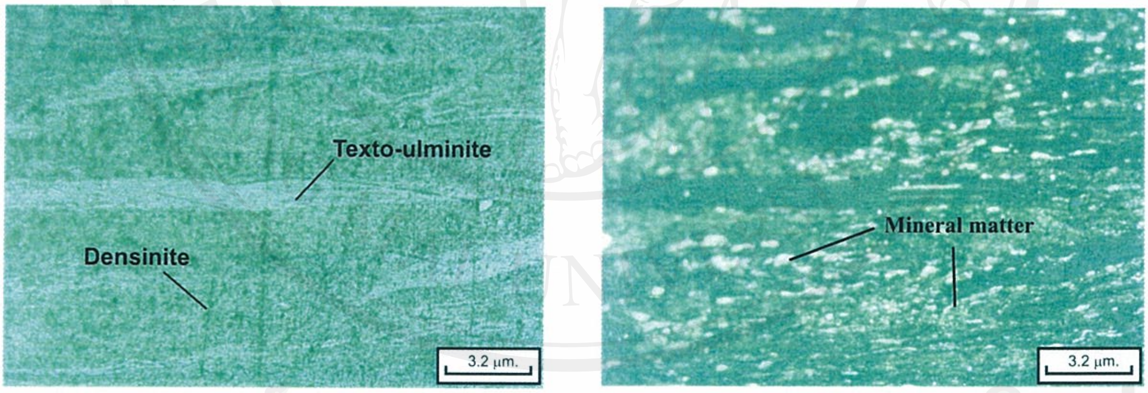
(a) (b)

Figure 4.22 Photomicrograph showing diatom in J6 coal from Mae Moh coal field under plane light (a) and cross polarizer (b).



(a) (b)

Figure 4.23 Photomicrograph showing densinite and texto-ulminite in I coal from Mae Moh coal field in plane light (a) and cross polarizer (b).



(a) (b)

Figure 4.24 Photomicrograph showing densinite and texto-ulminite in Lower split coal seam from Chiang Muan coal field in plane light (a) and cross polarizer (b).

4.4.2 Chiang Muan coal field.

LS zone

Major macerals are the huminite group which comprise 70-80 % with dominant macerals are gelinite, texto-ulminite, and densinite (Figure 4.24). Second in abundance are the liptinite group which comprise 10-15 % with dominant macerals are alginite, cutinite, and sporinite. The inertinite maceral group forms a minor constituent and is mostly semifusinite and funginite.

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.

LM zone

Major macerals are the huminite group which comprise 70-80 % with dominant macerals are densinite, gelinite, and texto-ulminite. Second in abundance are the liptinite group which comprise 10-20 % with dominant macerals are alginite and minor of sporinite. The inertinite maceral group forms a minor constituent and is mostly semifusinite.

The highly dissolved organic matter and gelinite indicated oxidation at the surface of peat deposit. The texto-ulminite and tree trunk remains indicate the area of herbaceous to 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 lacustrine depositional area was essentially freshwater. This indicated by the *Botryococcus* sp. and the present of sporinite.

U2 zone

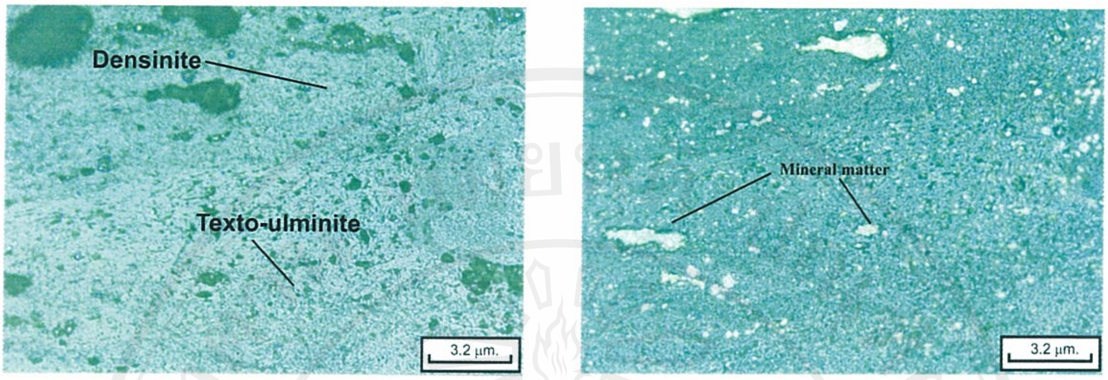
Major macerals are the huminite group which comprise 70-80 % with dominant macerals are densinite and collinite. Second in abundance are the liptinite group which comprise 10-20 % with dominant macerals are liptodetrinite and sporinite. The inertinite maceral group forms a minor constituent and is mostly semifusinite. The authigenic minerals are dominated by pyrite in form of framboidal pyrite. Moreover the pyrite was found in form of pyrite ball and pyritization in wood remains.

The densinite and collinite indicated that the depositional area was forest swamp. Highly oxidized condition of water in the basin led to the formation of liptodetrinite bands by the destruction of all organic materials in the liptinite group. The semifusinite indicated the dried up of the basin.

U1 zone

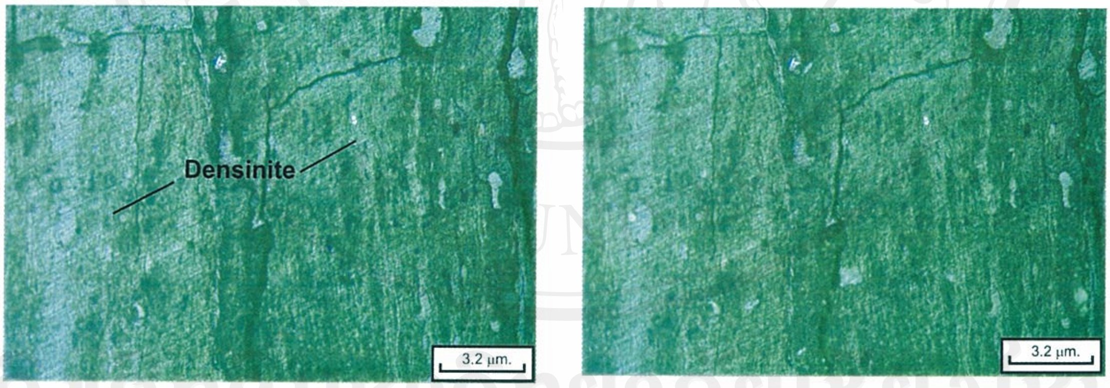
Major macerals are the huminite group which comprise 60-70 % with dominant macerals are densinite and texto-ulminite (Figure 4.25). Second in abundance are the liptinite group which comprise 15-25 % with dominant macerals are alginite, liptodetrinite, and sporinite. This zone is rich in spore that consists of young pollen. The inertinite maceral group forms a minor constituent and is mostly semifusinite. The authigenic minerals are dominated by pyrite in form of framboidal pyrite.

The texto-ulminite and tree trunk remains indicate the area of herbaceous to forest swamp. Highly oxidized condition of water in the basin led to the formation of liptodetrinite bands by the destruction of all organic materials in the liptinite group.



(a) (b)

Figure 4.25 Photomicrograph showing densinite and texto-ulminite in Upper coal seam 1 (U1) from Chiang Muan coal field in plane light (a) and cross polarizer (b).



(a) (b)

Figure 4.26 Photomicrograph showing densinite in coal from Mae Teep coal field in plane light (a) and cross polarizer (b).

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 lacustrine depositional area was essentially freshwater. This indicated by the *Botryococcus* sp. and the present of sporinite. The semifusinite indicated the dried up of the basin.

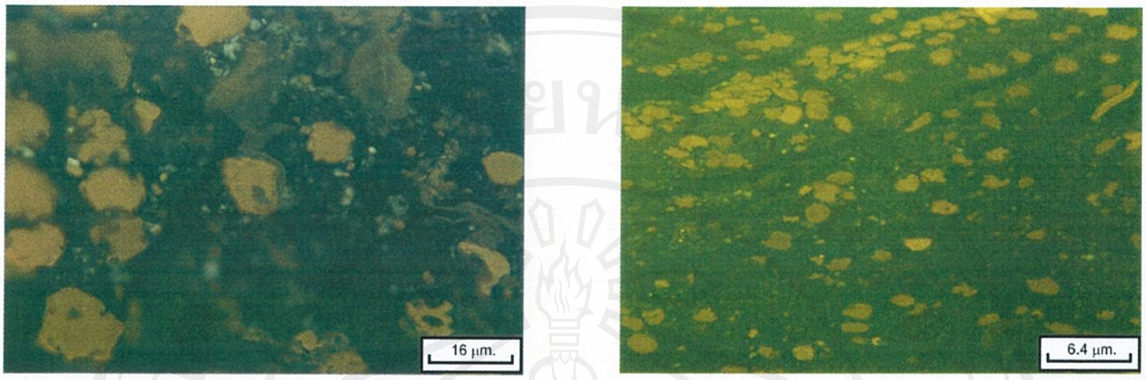
4.4.3 Mae Teep coal field.

Major macerals are the huminite group which comprise 70-80 % with dominant macerals are densinite and texto-ulminite (Figure 4.26). Second in abundance are the liptinite group which comprise 15-20 % with dominant macerals are alginite, liptodetrinite, sporinite, cutinite, and resinite (Figure 4.27). The inertinite maceral group forms a minor constituent and is mostly semifusinite. The authigenic minerals are dominated by pyrite in form of framboidal pyrite.

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 lacustrine depositional area was essentially freshwater. The semifusinite indicated the dried up of the basin.

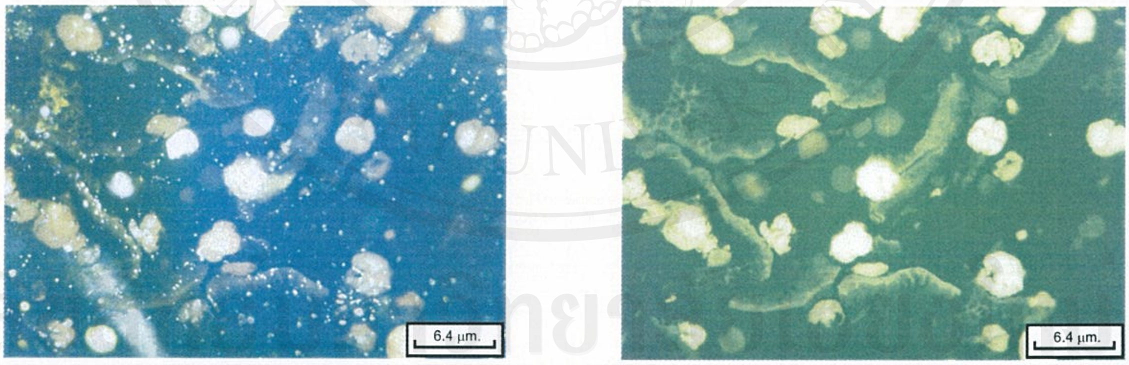
4.4.4 Wang Nua coal field.

Major macerals are the huminite group which comprise 70-80 % with dominant macerals are densinite, gelinite, and texto-ulminite. Second in abundance are the liptinite group which comprise 10-15 % with dominant macerals are liptodetrinite, sporinite, resinite, and suberinite (Figure 4.28). The inertinite maceral



(a) (b)

Figure 4.27 Photomicrograph showing sporinite in coal from Mae Teep coal field under oil immersion and fluorescenced (a) the sample was cut paralleled bed (b) the sample was cut perpendicular bed.



(a) (b)

Figure 4.28 Photomicrograph showing sporinite in coal from Wang Nua coal field under oil immersion (a) and fluorescenced (b).

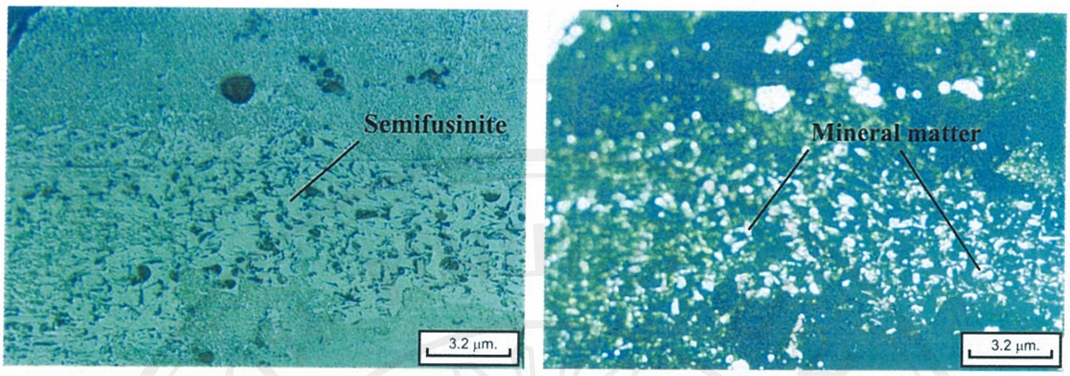
group forms a minor constituent and is mostly semifusinite and funginite. Pyrite is common as an authigenic mineral.

The tree trunk remains, densinite, and texto-ulminites indicated the area of forest swamp. Highly oxidized condition of water in the basin led to the formation of liptodetrinite bands by the destruction of all organic materials in the liptinite group. The semifusinite indicated the dried up of the basin.

4.4.5 Ngao coal field.

Major macerals are the huminite group which comprise 70-80 % with dominant macerals are densinite, gelinite, and texto-ulminite. Second in abundance are the liptinite group which comprise 10-15 % with dominant macerals are alginite and sporinite. The inertinite maceral group forms a minor constituent and is mostly semifusinite (Figure 4.29). The authigenic minerals are dominated by pyrite in form of framboidal pyrite.

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.



(a) (b)

Figure 4.29 Photomicrograph showing semifusinite in coal from Ngao coal field in plane light (a) and cross polarizer (b).

4.5 Sulfur isotope

4.5.1 Mae Moh coal field.

The sulfur isotopic analyses of the Mae Moh samples are listed in Table 4.24 and Table 4.25.

In the Q zone, the $\delta\ ^{34}S$ value of pyrite from the Q zone is +4.2 ‰. The $\delta\ ^{34}S$ value of Q zone coal is +14.4 ‰ for total sulfur.

In the K zone, the $\delta\ ^{34}S$ value of pyrite from the K zone is +10.9 ‰. The $\delta\ ^{34}S$ values of gypsum from the K zone are between +11.2 and +12.1 ‰. The $\delta\ ^{34}S$ values of K zone coal range from +1.89 to +2.62 ‰ for total sulfur.

In the J zone, the $\delta\ ^{34}S$ values of J zone coal range widely from -18.8 to +17.2 ‰ and from –23.2 to +9.4 ‰ for total sulfur and organic sulfur, respectively

In the I zone, the $\delta\ ^{34}S$ values of pyrite in *Margarya* sp. are very high and show a narrow range, from +30.6 to +34.2 ‰. The $\delta\ ^{34}S$ values of pyrite ball are narrow negative range, from –6.2 to –11.0 ‰. The $\delta\ ^{34}S$ values of I zone coal are +11.3 and 0.18 ‰ for total sulfur and organic sulfur, respectively.

In the red bed zone, Huai Luang Formation, the $\delta\ ^{34}S$ values of gypsum from the red bed are between +15.8 and +18.6‰.

4.5.2 Chiang Muan coal field.

The sulfur isotopic analyses of the Chiang Muan samples are listed in Table 4.26 and Table 4.27.

In the LS zone, the $\delta\ ^{34}S$ value of LS zone coal for total sulfur is +12.1 ‰.

In the LM zone, the $\delta\ ^{34}S$ value of LM zone coal for total sulfur is +10.3 ‰.

Table 4.24 δ ^{34}S of coal from Mae Moh coal field.

Sample No.	Description	Total sulfur		Evolved SO_2 from coal	
		δ ^{34}S (‰)	S content[a] (%)	δ ^{34}S (‰)	S content[b] (%)
I2	Coal from I zone	+11.3	2.93	+0.18	0.28
J1/1	Coal from J1/1 zone	+11.5	2.69	-19.21	2.88
J1/2	Coal from J1/2 zone	-3.26	4.26		3.01
J1/3	Coal from J1/3 zone	-9.56	5.80	-9.68	3.07
J1/4	Coal from J1/4 zone	-15.1	5.32		7.45
J1/5	Coal from J1/5 zone	+8.67	6.78	-5.13	2.85
J1/6	Coal from J1/6 zone	-14.6	6.19		3.06
J1/7	Coal from J1/7 zone	+8.74	4.98	+7.29	2.55
J2/1	Coal from J2/1 zone	-7.26	5.68	-7.28	3.17
J2/2	Coal from J2/2 zone	-7.57	6.25	-8.98	3.10
J3A	Coal from J3A bed	-18.8	6.54	-23.22	3.48
J3B1	Coal from J3B1 bed	-15.6	6.60		
J3B2	Coal from J3B2 bed	-4.50	6.63	-8.72	3.49
J4	Coal from J4 bed	-0.50	5.86		
J5A	Coal from J5A bed	+1.45	6.67	-1.11	3.52
J5B upper	Coal from J5B bed (Upper)	-3.33	6.73		
J5B lower	Coal from J5B bed (Lower)	+4.42	6.37	+1.76	1.73
J5C	Coal from J5C bed	+8.81	6.27		
J6A	Coal from J6A bed	-5.83	5.77		
J6B	Coal from J6B bed	+17.3	4.26	+9.37	0.27
K1A	Coal from K zone	+17.4	1.89		0.05
K2A	Coal from K zone	+14.8	2.62		0.26
Q	Coal from Q zone	+14.4	2.88		0.71

Remark: [a] Measured by Eschka method
[b] Sulfur content in original coal

Table 4.25 δ^{34}S of pyrite and gypsum from Mae Moh coal field.

Sample No.	Description	δ^{34}S (‰)
RB1	gypsum in NW pit	+16.1
RB2	gypsum in NW pit	+16.3
RB3	gypsum in NE pit	+18.6
RB4	gypsum in NE pit	+18.5
RB5	gypsum RB under I, NW Pit	+15.9
RB6	gypsum RB under I, NW Pit	+15.8
K1	gypsum in K zone	+12.2
K2	gypsum in K zone	+11.2
I1	pyrite in *Margarya sp.* from I zone	+32.3
I2	pyrite in *Margarya sp.* from I zone	+34.3
I3	pyrite in *Margarya sp.* from I zone	+30.7
I4	Pyrite from I zone	-6.17
I5	Pyrite from I zone	-11.0
K3A	mud ball in K3A	+10.9
Q4A	mud ball in Q4A	+4.23

Table 4.26 δ^{34}S of coal from Chiang Muan coal field, Mae Teep coal field, Wang Nua coal field, and Ngao coal field.

Sample No.	Description	Total sulfer		Evolved SO_2 from coal	
		δ^{34}S (‰)	S content[a] (%)	δ^{34}S (‰)	S content[b] (%)
U1-1	coal in U1 bed	-9.74	6.96	-12.48	3.47
U1-2	coal in U1 bed	-14.9	1.41		
U1-3	coal in U1 bed	-18.2	3.91		
U2-1	coal in U2 bed	+7.67	3.33	+3.70	1.38
U2-2	coal in U2 bed	+4.29	2.59		
U2-3	coal in U2 bed	+7.06	5.74		
U2-4	coal in U2 bed	+8.05	3.45	+2.81	0.75
LM2	coal in LM bed	+10.4	1.16	*	0.01
LS2	coal in LS bed	+12.2	2.26	*	0.01
Mae Teep	Mae Teep coal	+10.1	0.59		0.07
Wang Nua	Wang Nua coal	-5.86	1.78		1.18
Ngao	Ngao coal	-2.94	6.09		2.09

Remark: [a] Measured by Eschka method
[b] Sulfur content in original coal
* : sample is not enough for analysis

In the U2 zone, the $\delta^{34}S$ values of pyrite from the U2 zone are between -15.6 and –11.2 ‰. The $\delta^{34}S$ values of U2 zone coal are between +4.3 and +8.1 ‰ and from +2.8 to +3.7 ‰ for total sulfur and organic sulfur, respectively.

In the U1 zone, the $\delta^{34}S$ values of black gypsum from the U1 zone are –10.1 and –10.7 ‰, whereas the $\delta^{34}S$ values of colorless gypsum from the U1 zone have a narrow range from +4.7 to +5.4 ‰. The $\delta^{34}S$ values of U1 coal are between from –18.1 and –9.7 ‰ for total sulfur. In sample no. U1-1, the organic sulfur $\delta^{34}S$ value is –12.4 ‰.

The $\delta^{34}S$ values of total sulfur in coal from Mae Teep, Wang Nua, and Ngao coal field are +10.1, -5.86, and –2.94 ‰ respectively.

For the sulfur isotope study of gypsum and pyrite, the +4.2 ‰ $\delta^{34}S$ value of pyrite from the Q zone in the Mae Moh coal field is a low value. This value indicates that the source of sulfur should come from organic sulfur. The medium high $\delta^{34}S$ values of gypsum from the K zone are +12.1 and +11.2 ‰. These values are similar to values of non-marine sulfate (Nielsen, 1967). The medium high $\delta^{34}S$ value of pyrite from the K zone is +10.9 ‰. This value indicates that the source of sulfur came from organic sulfur. The pyrite could be from an organic-rich swamp that cause of the use of organic oxysulfur compounds in dissimilatory respiration by sulfur-reducing bacteria. This process would take place in a closed system (Altschuler and others, 1983). However, the fossils such as, from Q and K zones support deposition of gypsum and pyrite in a closed system of freshwater.

Table 4.27 δ ^{34}S of pyrite and gypsum from Chiang Muan coal field.

Sample No.	Description	δ ^{34}S (‰)
U1-1G	black gypsum in U1 bed	-10.1
U1-2G	black gypsum in U1 bed	-10.7
U1-3G	colourless gypsum in U1 bed	+4.67
U1-4G	colourless gypsum in U1 bed	+5.37
U2-1P	pyrite in U2 bed	-15.6
U2-2P	pyrite in U2 bed	-15.5
U2-3P	mud ball in U2 bed	-11.3

The high δ ^{34}S values of gypsum from the red bed zone in northwest pit, Mae Moh coal field are +16.1 and +16.3 ‰. The high δ ^{34}S values of gypsum from the red bed zone in northeast pit, Mae Moh coal field are between +15.8 and +18.6 ‰. These values are consistent with a gypsum source from marine sulfate (Claypool and others, 1980). The sediments in red beds were deposited in a fluvial environment (Chaodumrong, 1985; Uttamo and others, 1999). However, the δ ^{34}S values of gypsum indicate that there was marine incursion during sediment deposition. The marine incursion can be confirmed by the sulfur isotopic study from Tankaya (2001). The high δ ^{34}S values of gypsum from red beds are between +16.4 to +20.0 ‰. The similarity of the δ ^{34}S in this study and Tankaya (2001) show marine source.

The very high δ ^{34}S values of pyrite in the gastropod samples, *Margarya* sp., from I zone coal; Mae Moh coal field are +30.6, +32.3, and +34.2 ‰. These values could indicate a sulfur source from reduction of sulfate by bacteria to sulfide during coal deposition deposition (Faure, 1986). The very high δ ^{34}S values of pyrite samples strongly indicate a closed system of freshwater environment (Raiswell, 1982). The source of pyrite in the gastropod, *Margarya* sp., samples from I zone coal could be from reduction of freshwater sulfate by bacteria. But the low δ ^{34}S values of pyrite from pyrite ball from I zone are –6.2 and –11.0 ‰ show concluded that the source of sulfur was derived from a marine incursion (Figure 4.30). The δ ^{34}S values of pyrite ball in this study are similar to the δ ^{34}S values of -13.6 and –7.8 ‰, which was studied by Tankaya (2001). It can be concluded that the source of sulfur was also derived from a marine incursion. Moreover, the sulfur of the gypsum from red beds indicates marine sulfate. The I zone is the zone between red beds, so its sulfur could be derived from a sulfate marine source, which was found as gypsum in the red beds below this I zone. This is the other reason that pyrite can be formed after coal was deposited.

The very low δ ^{34}S values of pyrite, –15.6, -15.4, and –11.2 ‰, from the U2 zone in the Chiang Muan coal field indicate an open system relative to seawater sulfate (Hoefs, 1987). The very low δ ^{34}S values of black gypsum from U1 zone are -10.7 and –10.1 ‰. These values are close to the δ ^{34}S values in coal from the U1 zone. The source of sulfur could come from the oxidation of sulfide in coal to sulfate (Ohmoto and Rye, 1979). On the other hand, the δ ^{34}S values of colorless gypsum from the U1 zone are low positive values, +4.7 and +5.4 ‰. These values indicate non-marine sulfate (Holser, 1979).

The δ ^{34}S values in coal from Mae Moh and Chiang Muan coal fields show very wide range in total sulfur and organic sulfur (Figure 4.31). Smith and Batts (1974) suggested that the δ ^{34}S values of organic sulfur in low-sulfur coal are representative of the isotopic composition of sulfate in a freshwater environment in which the coal was deposited. These values are in the LM, LS, and U2 zones in the

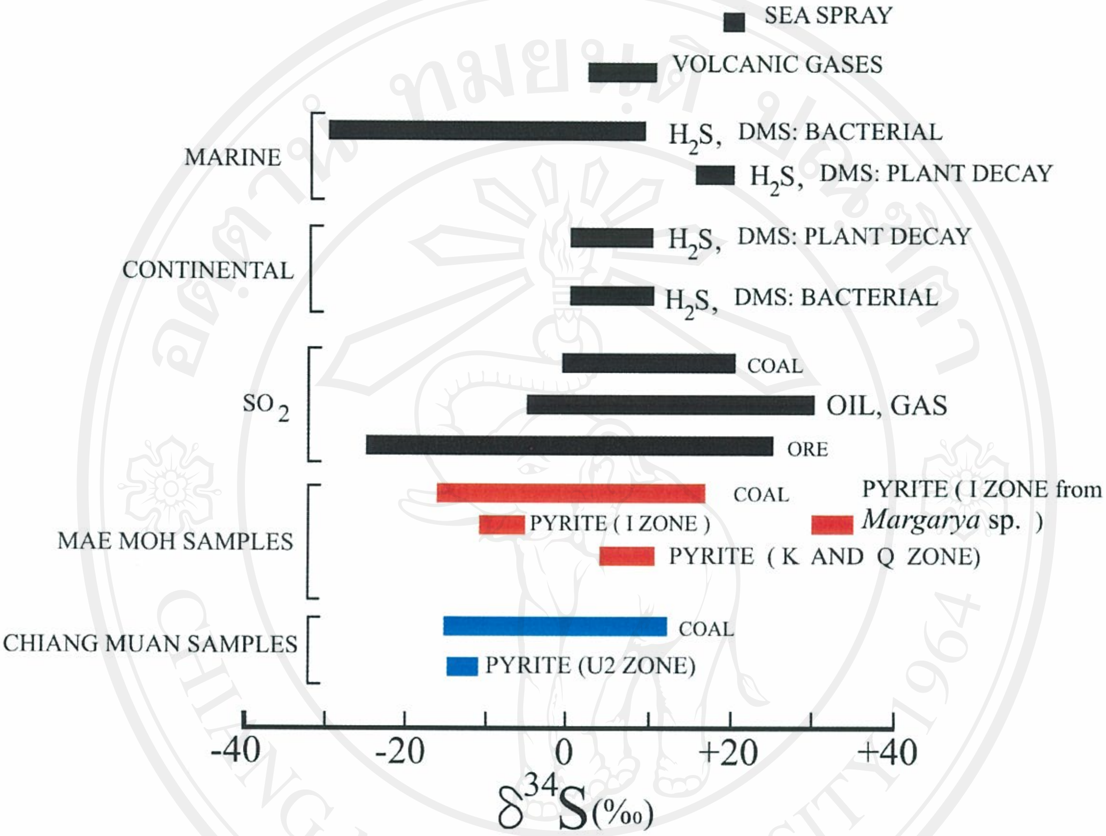


Figure 4.30 The sulfur in coal and pyrite from Mae Moh and Chiang Muan coal fields related to the different sources (modified from Nielsen and others, 1991).

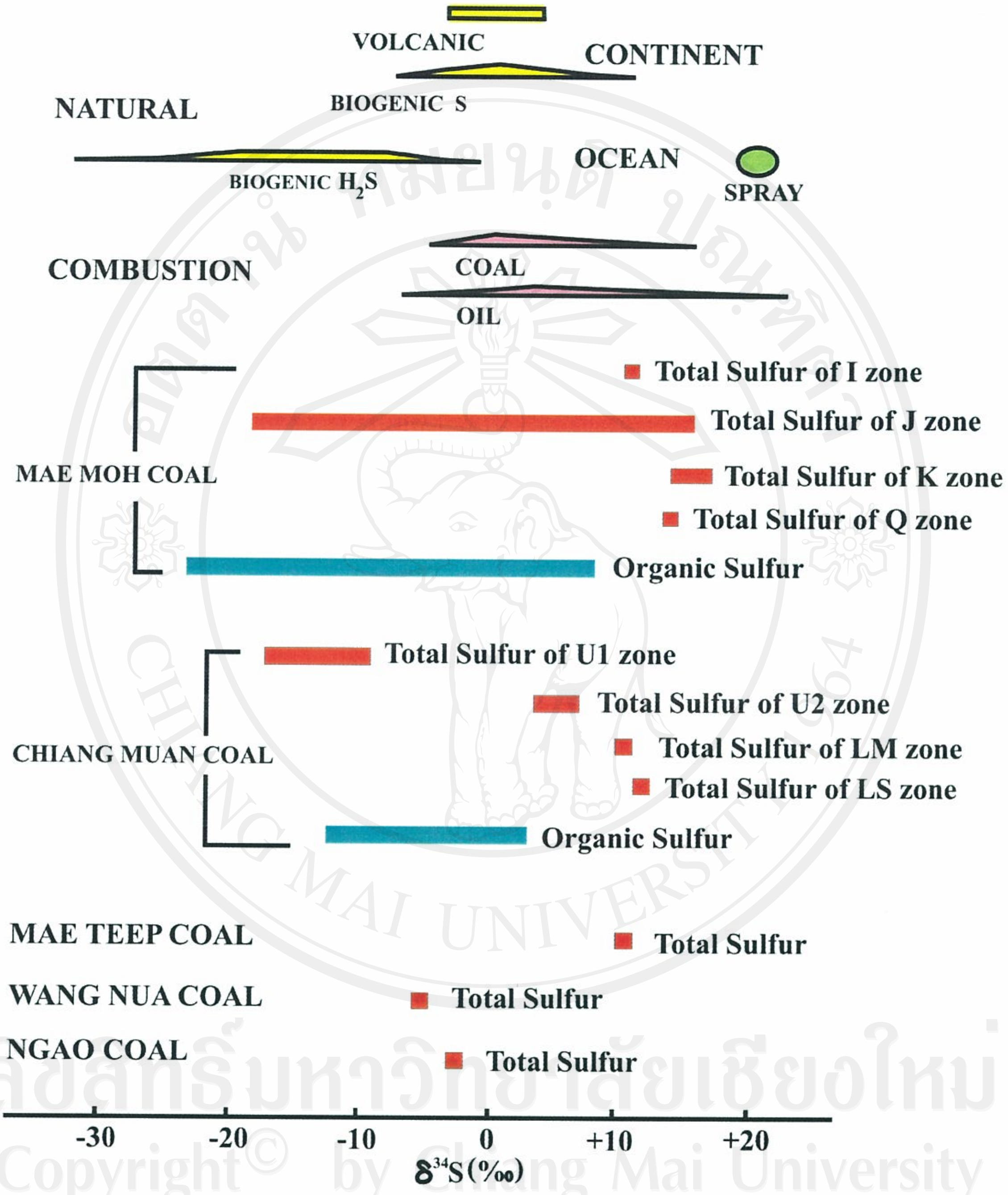


Figure 4.31 The total sulfur and organic sulfur in coal from Mae Moh and Chiang Muan coal fields related to the major source (modified from Nielsen and others, 1991).

Chiang Muan coal field, in coal from Mae Teep coal field, and also occur in the Q zone, K zone, the lower portion of the J zone, and I zone in the Mae Moh basin.

The very low $\delta\ ^{34}S$ values of total sulfur in high-sulfur coal in J1, J2, and J3 coal zone from the Mae Moh coal field (Figure 4.32), U1 zone from the Chiang Muan coal field (Figure 4.33), Wang Nua, and Ngao coal field indicate a marine incursion during plant growth and early deposition (Nielsen and others, 1991). These very low sulfur values indicate that the sea level changed during the depositional period. There was marine incursion in northern Thailand at the Middle Miocene. The cause of sea level change could be from the changing of the polarity of paleomagnetic. The paleomagnetic study of Middle Miocene Mae Moh and Chiang Muan coal field show the reverse paleomagnetic in the Middle Miocene (Benammi and others, 2002; Nagaoka and others, 2003). Additionally, volcanic debris in strata in the middle part of the J zone in the Mae Moh mine could have been another source of sulfur (Mahatthanachai, 1996). The basins between the Mae Moh basin and the Chiang Muan basin have to be investigated to confirm this high sea level change. Moreover,

there is the evidence of marine incursion during Miocene at Phrae Basin in northern Thailand. The Palynological study of PH1 and PH2 well samples from Phrae basin shows that the specimens of *Florschuetzia semilobata*, *Florschuetzia trilobata* and *Zonocostites ramonae* indicate marine influences on deposition (Waton, 1996).

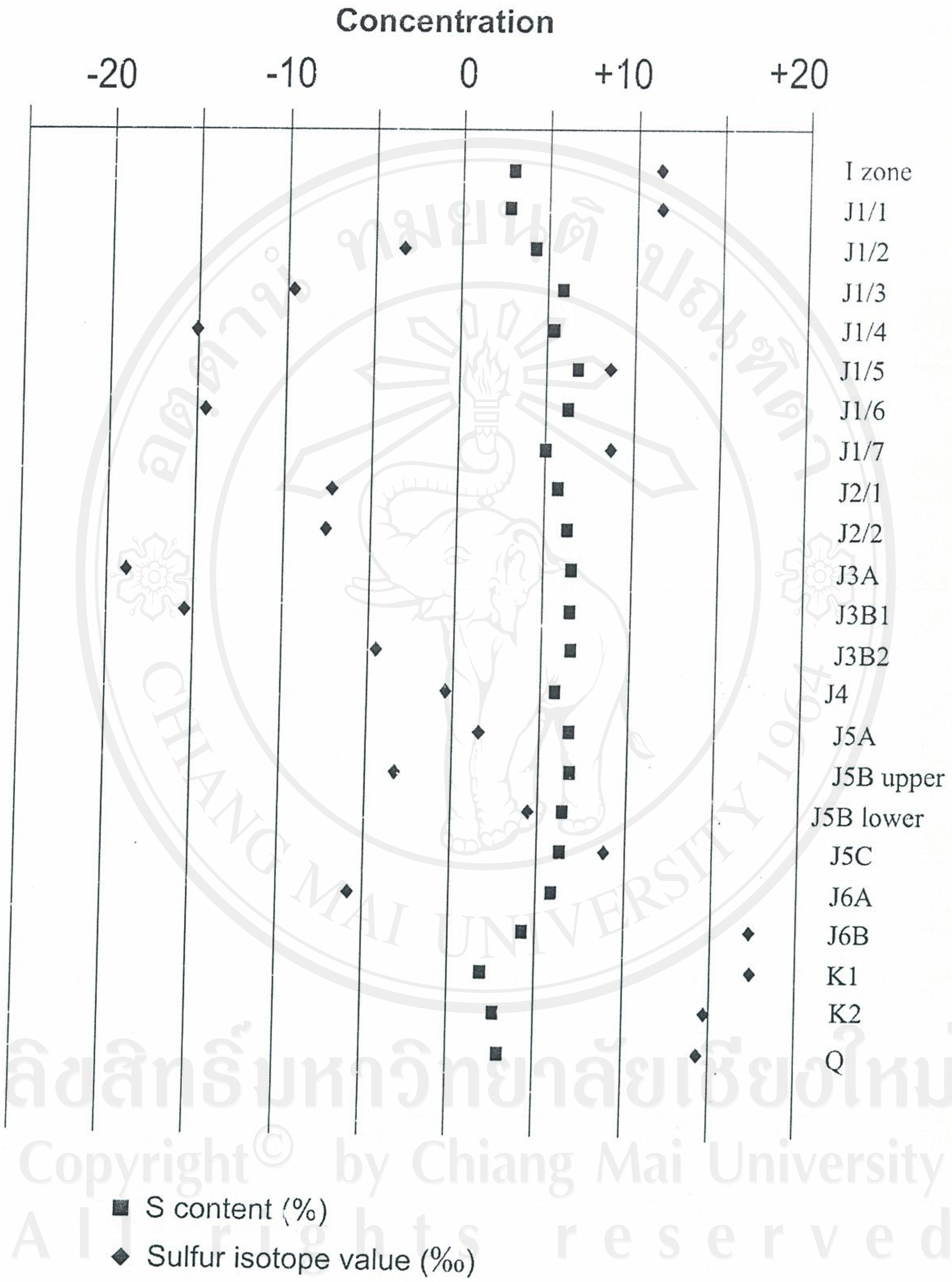


Figure 4.32 Graph of sulfur isotope values and sulfur content of total sulfur in coal from Mae Moh coal field.

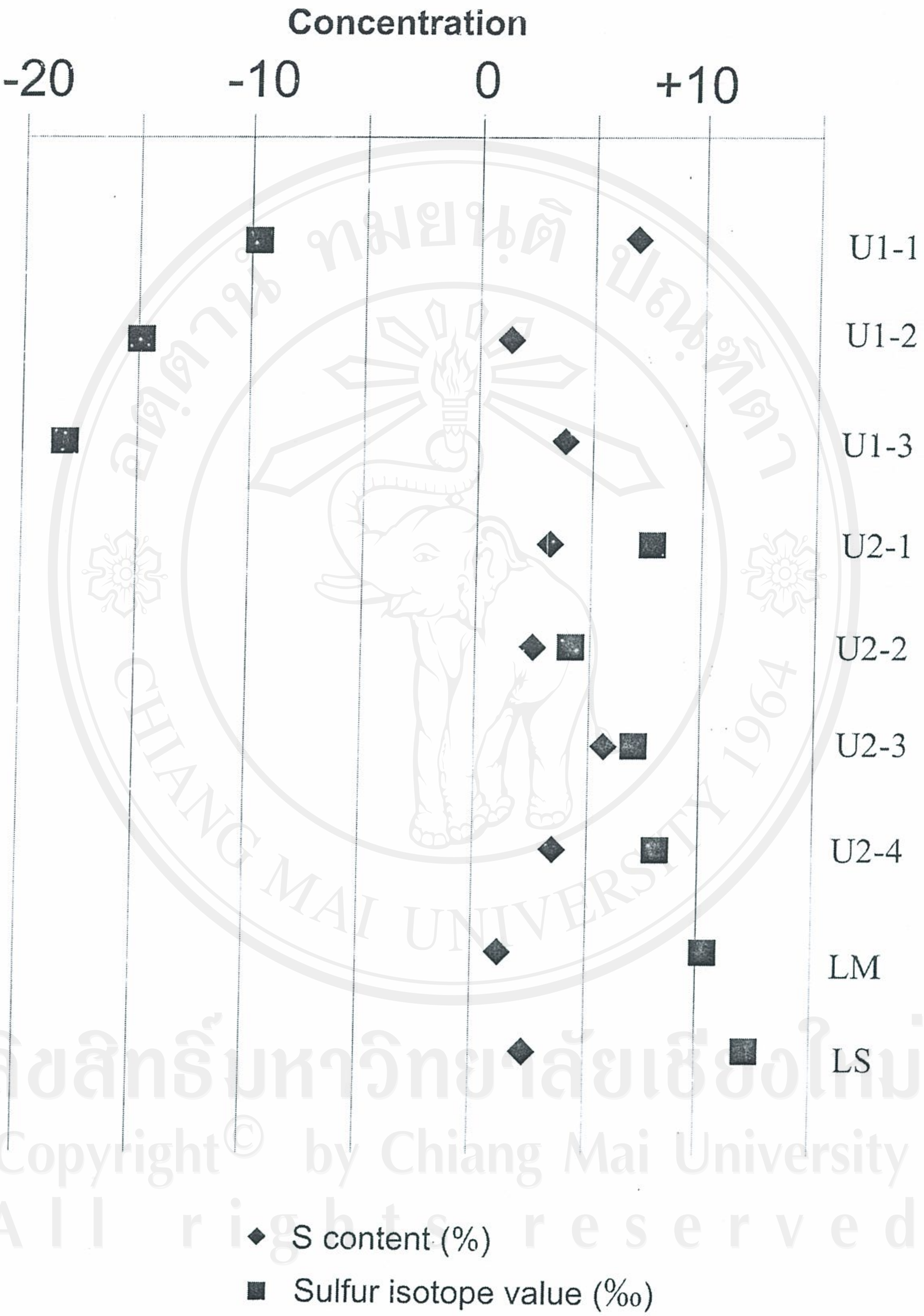


Figure 4.33 Graph of sulfur isotope values and sulfur content of total sulfur in coal from Chiang Muan coal field.

4.6 Carbon and oxygen isotope

4.6.1 Mae Moh coal field.

The carbon and oxygen isotope data of the Mae Moh samples are reported as δ (‰) relative to the Belemnitella american from the Cretaceous PeeDee Formation standard (PDB) in Table 4.28. The gastropod samples were collected from seperated zone such as underburden zone, K zone, J zone, and I zone. The plot between the δ ^{13}C values and the δ ^{18}O values are shown in the Figure 4.34.

4.6.2 Chiang Muan coal field.

The carbon and oxygen isotopic analyses of the Chiang Muan samples are listed in Table 4.29. The plot between the δ ^{13}C values and the δ ^{18}O values are shown in the Figure 4.35. All of Chiang Muan's samples were collected from same bed of claystone bed at the upper coal seam 1 (U1).

4.6.3 Wang Nua coal field.

The carbon and oxygen isotopic analyses of the Wang Nua samples are listed in Table 4.30. The plot between the δ ^{13}C values and the δ ^{18}O values are shown in the Figure 4.36. All of Wang Nua's samples were collected from the same bed of gray silty claystone.

Table 4.28 The δ^{13}C and δ^{18}O values of shells from the Mae Moh coal field.

Sample No.	Species	δ^{13}C (‰ PDB)	Averg δ^{13}C (‰ PDB)	δ^{18}O (‰ PDB)	Averg δ^{18}O (‰ PDB)
MM1	*Margarya* sp. in I	-5.4	-4.0±1.0	-3.9	-6.2±1.5
MM2	*Margarya* sp. in I	-2.7		-5.2	
MM3	*Margarya* sp. in I	-4.6		-5.7	
MM4	*Margarya* sp. in I	-3.9		-7.8	
MM5	*Margarya* sp. in I	-4.1		-7.4	
MM6	*Margarya* sp. in I	-3.1		-7.1	
MM7	*Bellamya* sp. in J4	-3.1	-3.4±0.4	-5.6	-5.4±0.6
MM8	*Bellamya* sp. in J4	-3.2		-5.9	
MM9	*Bellamya* sp. in J4	-3.8		-4.7	
MM10	*Melanoides* sp. in J4	-2.1	-1.7±1.4	-4.6	-4.9±0.3
MM11	*Melanoides* sp. in J4	-3.0		-5.3	
MM12	*Melanoides* sp. in J4	0.0		-4.8	
MM13	*Bellamya* sp. in J5	+3.0	+4.6±0.7	-3.5	-3.7±1.6
MM14	*Bellamya* sp. in J5	+4.9		-4.1	
MM15	*Bellamya* sp. in J5	+5.8		-3.7	
MM16	Planorbidae in K1	-1.8	-1.8±1.4	-8.0	-10.1±0.3
MM17	Planorbidae in K1	-1.0		-11.6	
MM18	Planorbidae in K1	-2.1		-9.5	
MM19	Planorbidae in K1	-2.5		-10.6	
MM20	Planorbidae in K1	-0.9		-11.9	
MM21	Planorbidae in K1	-2.5		-8.7	
MM22	*Bellamya* sp. in K2	+3.1	+3.5±0.7	-5.0	-4.5±1.4
MM23	*Bellamya* sp. in K2	+4.3		-2.8	
MM24	*Bellamya* sp. in K2	+2.9		-5.5	
MM25	*Bellamya* sp. in K3//K4	+5.3	+5.4±0.3	-6.6	-6.2±1.2
MM26	*Bellamya* sp. in K3//K4	+5.2		-4.9	
MM27	*Bellamya* sp. in K3//K4	+5.8		-7.3	
MM28	*Bellamya* sp. in UB	+3.2	+2.2±0.9	-6.3	-6.5±0.3
MM29	*Bellamya* sp. in UB	+1.4		-6.9	
MM30	*Bellamya* sp. in UB	+1.8		-6.4	

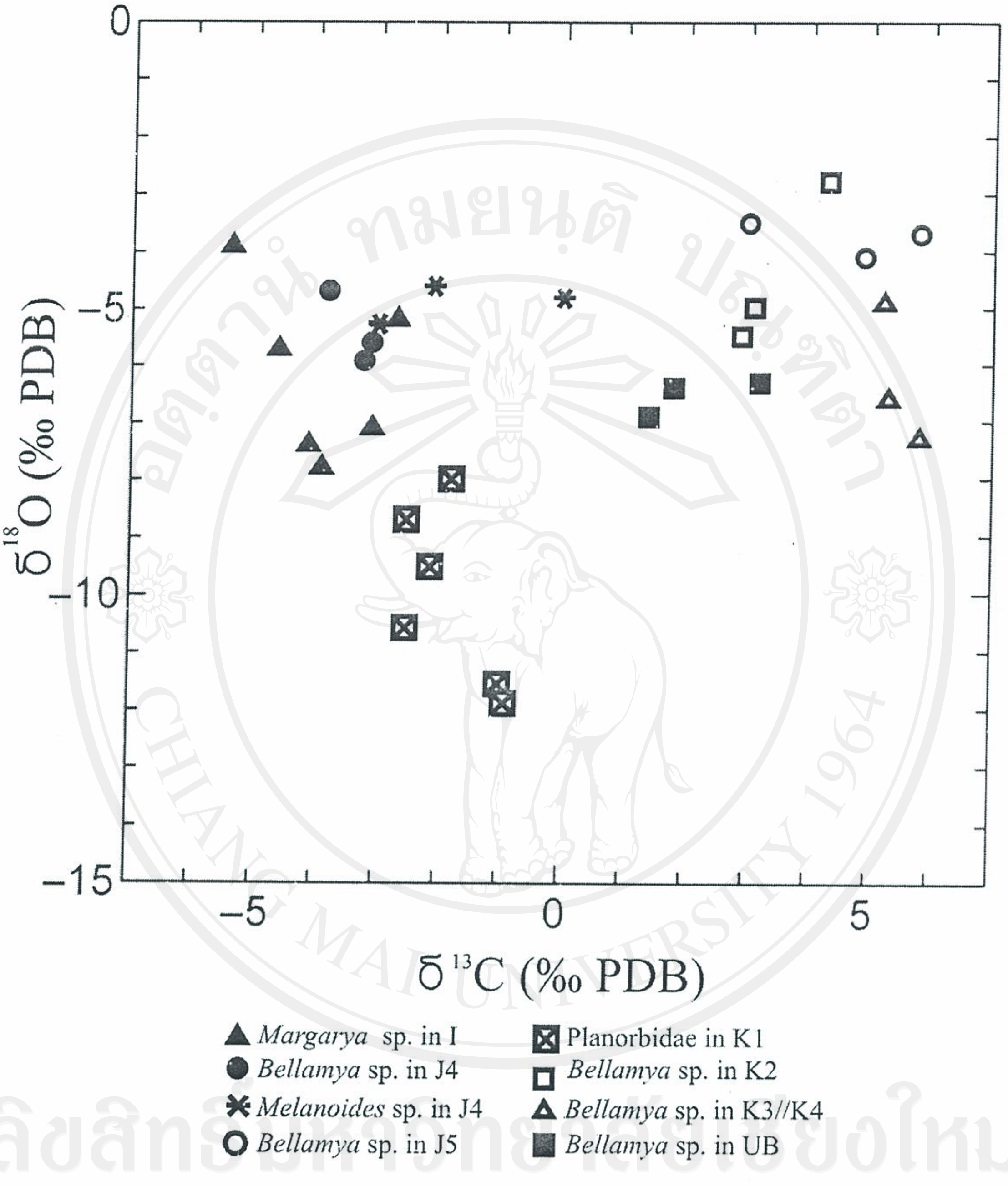


Figure 4.34 The plot of stable carbon and oxygen isotope of 30 shell samples from Mae Moh coal field.

Table 4.29 The δ ^{13}C and δ ^{18}O values of shells from the Chiang Muan coal field.

Sample No.	Species	δ^{13}C (‰ PDB)	Averg δ^{13}C (‰ PDB)	δ^{18}O (‰ PDB)	Averg δ^{18}O (‰ PDB)
CM1	*Brotia costula varicosa* sp.	-9.1	-8.9±0.2	-10.2	-10.0±0.3
CM2	*Brotia costula varicosa* sp.	-8.9		-10.3	
CM3	*Brotia costula varicosa* sp.	-8.8		-9.7	
CM4	*Bellamya* sp.	-11.2	-11.8±0.5	-9.5	-8.8±0.6
CM5	*Bellamya* sp.	-12.3		-8.4	
CM6	*Bellamya* sp.	-11.8		-8.5	
CM7	*Hyriopsis* sp.	-8.4	-8.5±0.6	-9.7	-9.3±1.1
CM8	*Hyriopsis* sp.	-7.5		-10.2	
CM9	*Hyriopsis* sp.	-8.4		-10.3	
CM10	*Hyriopsis* sp.	-9.1		-7.9	
CM11	*Hyriopsis* sp.	-8.9		-8.4	
CM12	*Melanoides* sp.	-9.9	-10.1±0.5	-9.9	-9.4±0.5
CM13	*Melanoides* sp.	-10.7		-9.0	
CM14	*Melanoides* sp.	-9.7		-9.3	
	Average	-9.6±1.4		-9.4±0.8	

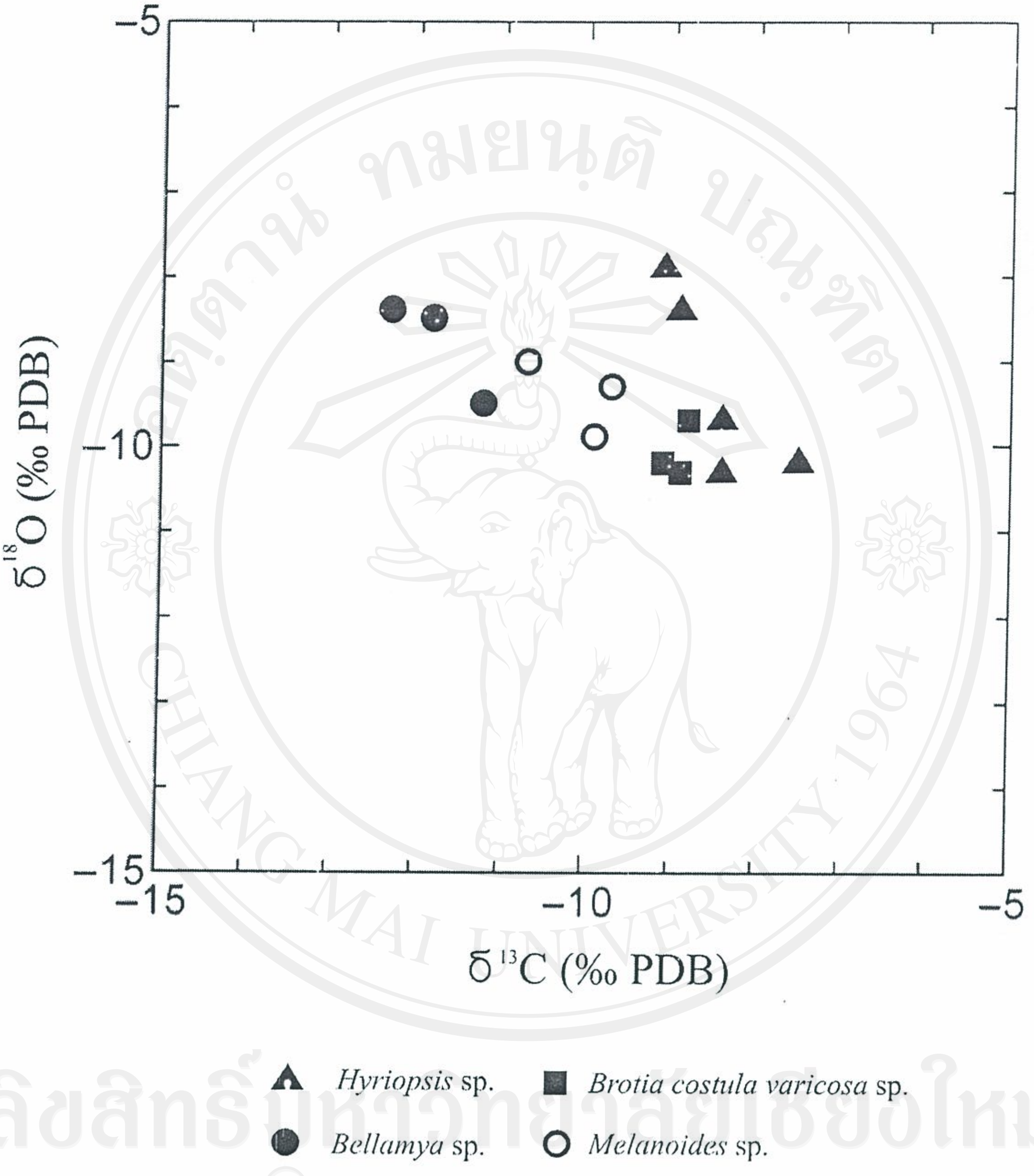


Figure 4.35 The plot of stable carbon and oxygen isotope of 14 shell samples from Chiang Muan coal field.

Table 4.30 The δ ^{13}C and δ ^{18}O values of shells from the Wang Nua coal field.

Sample No.	Species	δ^{13}C (‰ PDB)	Averg δ^{13}C (‰ PDB)	δ^{18}O (‰ PDB)	Averg δ^{18}O (‰ PDB)
WN1	*Brotia* sp.	-1.9	-2.9±0.9	-4.5	-5.1±0.5
WN2	*Brotia* sp.	-3.2		-5.5	
WN3	*Brotia* sp.	-3.6		-5.3	
WN4	*Margarya* sp.	-4.9	-4.5±1.1	-5.1	-6.3±1.3
WN5	*Margarya* sp.	-5.9		-5.7	
WN6	*Margarya* sp.	-5.2		-8.4	
WN7	*Margarya* sp.	-3.9		-7.3	
WN8	*Margarya* sp.	-3.6		-5.6	
WN9	*Margarya* sp.	-2.9		-5.6	
WN10	*Hyriopsis* sp.	-5.2	-5.1±0.1	-6.8	-6.6±0.2
WN11	*Hyriopsis* sp.	-5.0		-6.4	
WN12	*Hyriopsis* sp.	-5.0		-6.7	
	Average	-4.2±1.2		-6.1±1.1	

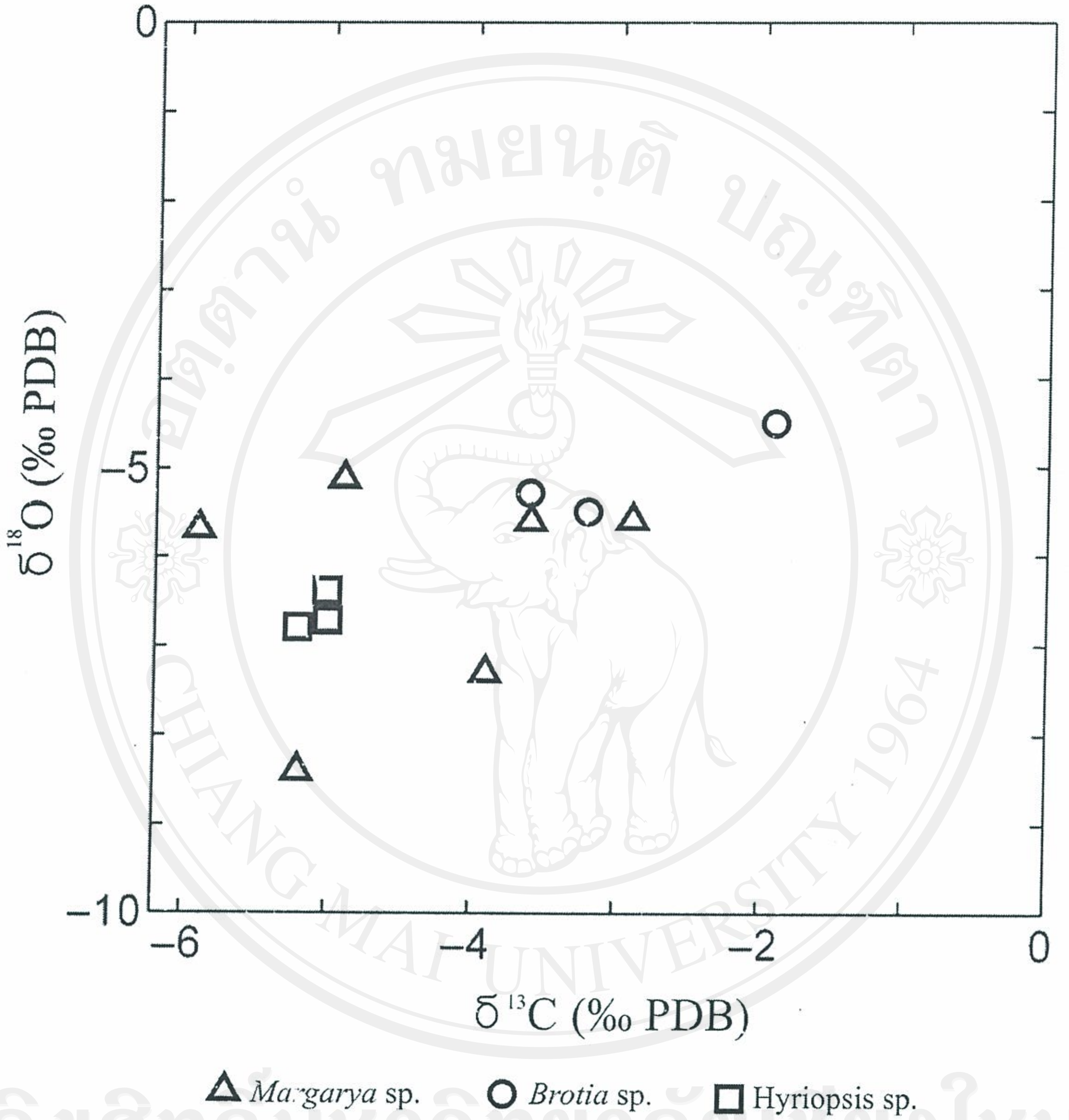


Figure 4.36 The plot of stable carbon and oxygen isotope of 12 shell samples from Wang Nua coal field.

The goal of oxygen isotopic study was to determine paleotemperature changes. Goodwin and others (2001) reported that the positive isotopic values correspond to cold temperatures, while negative isotopic values occur in portions of the shell deposited during warmer conditions. All of the samples from Mae Moh, Chiang Muan, and Wang Nua coal field are negative values. The values indicate that the gastropod and bivalve samples from Mae Moh, Chiang Muan, and Wang Nua coal field were deposited during warm condition.

The plot between carbon and oxygen isotope compositions of this study correlated with the carbon and oxygen isotope compositions marine Tertiary values from Keith and Weber (1964) are shown in Figure 4.37. Keith and Weber (1964) reported the $\delta\ ^{13}C$ value of Tertiary marine is -1.33 ± 2.9 ‰ and the $\delta\ ^{18}O$ value of Tertiary marine is -2.42 ± 2.39 ‰. The isotopic values of carbon and oxygen of *Bellamya* sp. and *Melanoides* sp. from J4 zone and *Bellamya* sp. from J5 zone of Mae Moh coal field close to the values of carbon and oxygen from Tertiary marine samples. The gastropod from J4 and J5 zone of Mae Moh coal field indicate brackish water that associated with marine environment.

The correlation between the stable isotope values of carbon and oxygen plot along with the lithologic zone of Mae Moh coal field is shown in Figure 4.38. The $\delta\ ^{18}O$ values are negative values. Goodwin and others (2001) reported negative isotopic values occur in portions of the shell deposited during warm conditions. It can be concluded that Mae Moh coal field had warm condition at Middle Miocene. The $\delta\ ^{13}C$ values are high and positive values in *Bellamya* sp. from J5, *Bellamya* sp. from K2, *Bellamya* sp. from mudstone between K3 and K4 zone, and *Bellamya* sp. from underburden can support the warm condition of Mae Moh coal field. The numerous

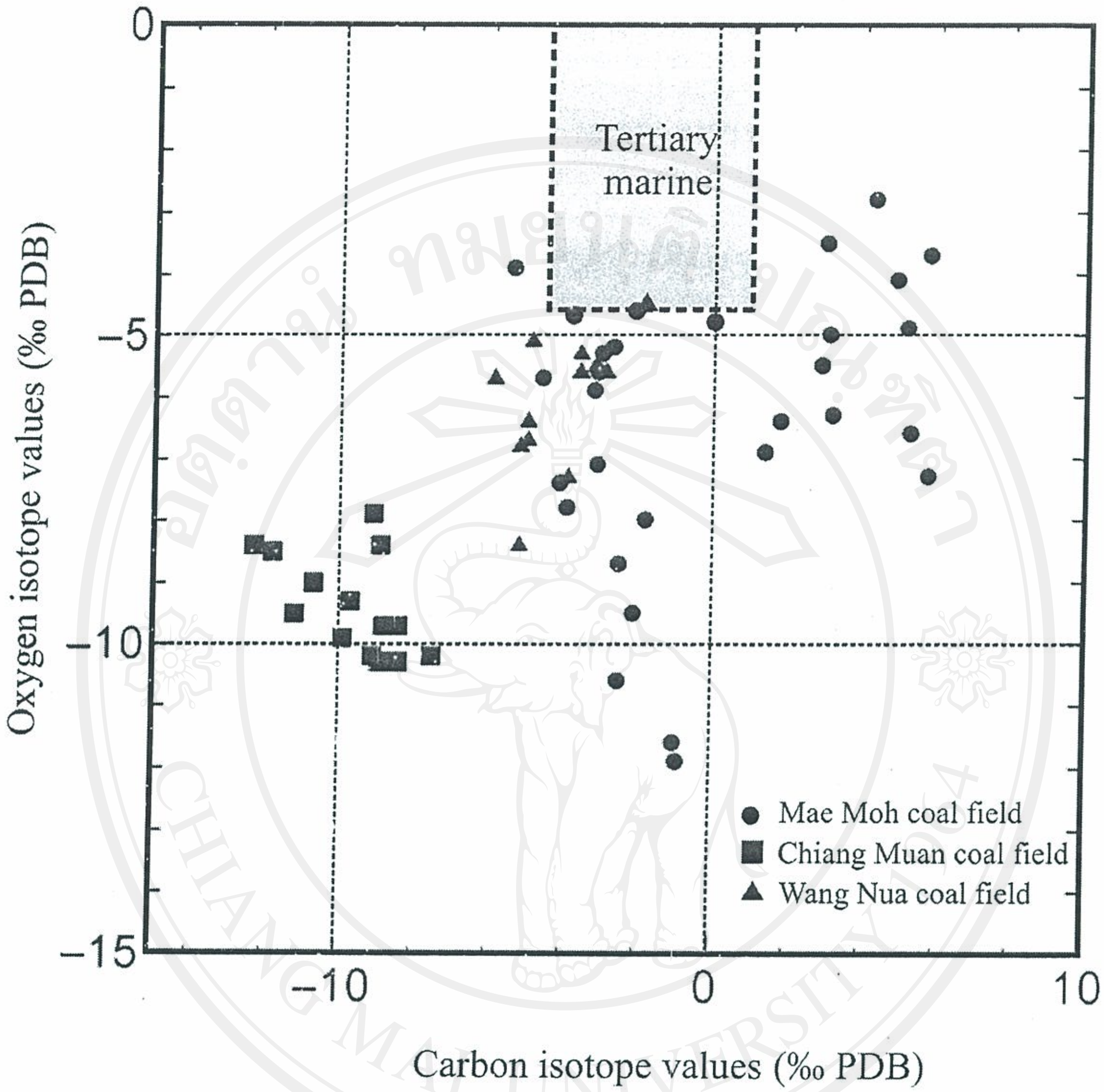


Figure 4.37 Plot of carbon isotope compositions and oxygen isotope compositions of shell from Mae Moh coal field (30 samples), Chiang Muan coal field (14 samples), and Wang Nua coal field (12 samples). In the rectangular area show Tertiary marine isotope composition from Keith and Weber (1964).

of vertebrate fossil bone fragments were found at K zone and the more than 10 meter thick bed of *Bellamya* sp. at claystone were found at layer between K3 and K4 of Mae Moh coal field. Appearance of fossils and gastropod bed indicated catastrophes, the cause of the lost of animals lives. The changing of temperature is one of cause of the catastrophes. However, the correlation between the stable isotope values of carbon and oxygen plot in Chiang Muan and Wang Nua coal field (Figures 4.39 and 4.40) show warm condition. The warm condition of oxygen isotope study is supported by the study of algae, pollen, and spore which concluded that Mae Moh and Chiang Muan coal fields were deposited in tropical condition (Songtham, 2003).

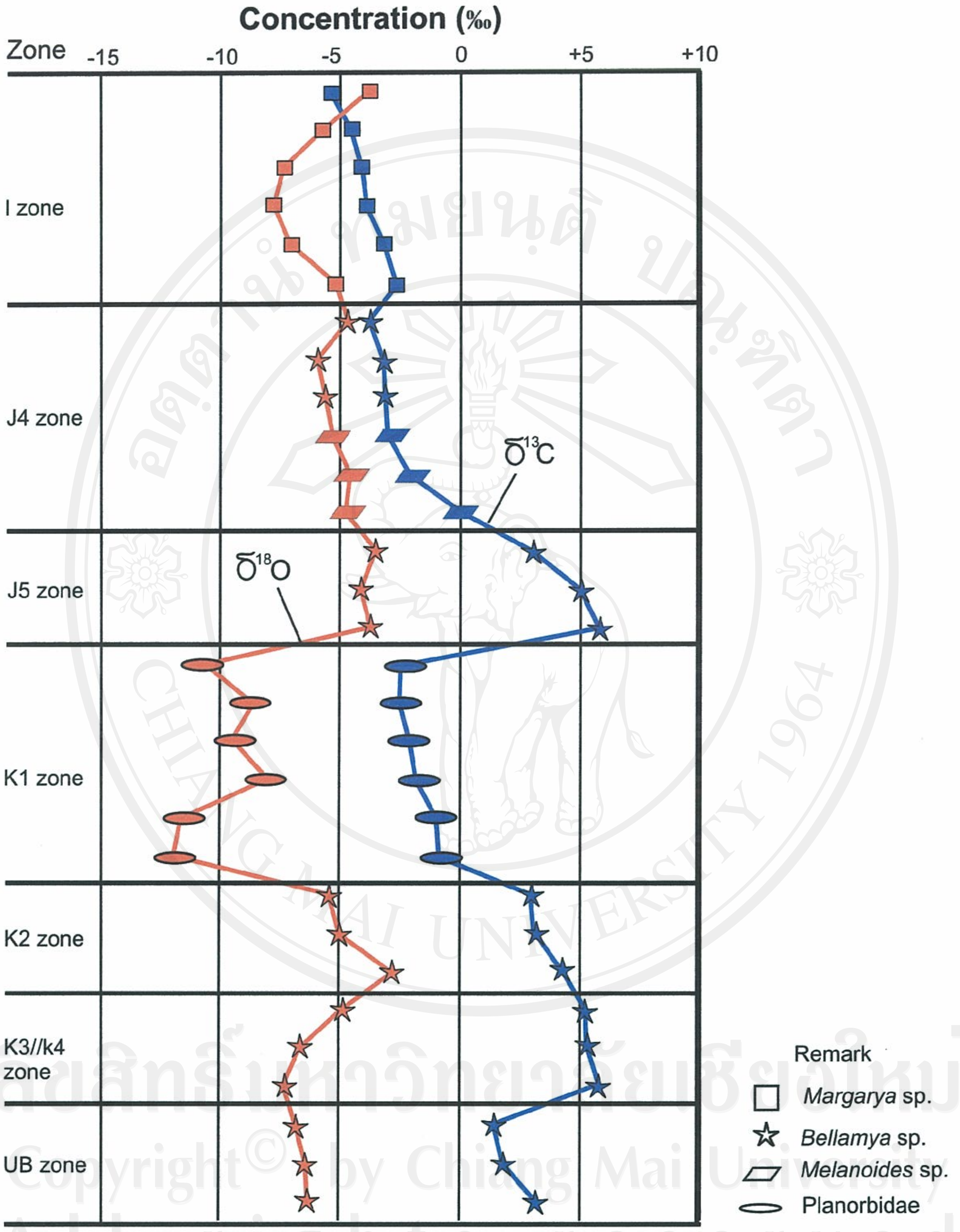


Figure 4.38 The graph of stable carbon isotope versus stable oxygen isotope of gastropod from Mae Moh coal field correlated with the lithologic zone.

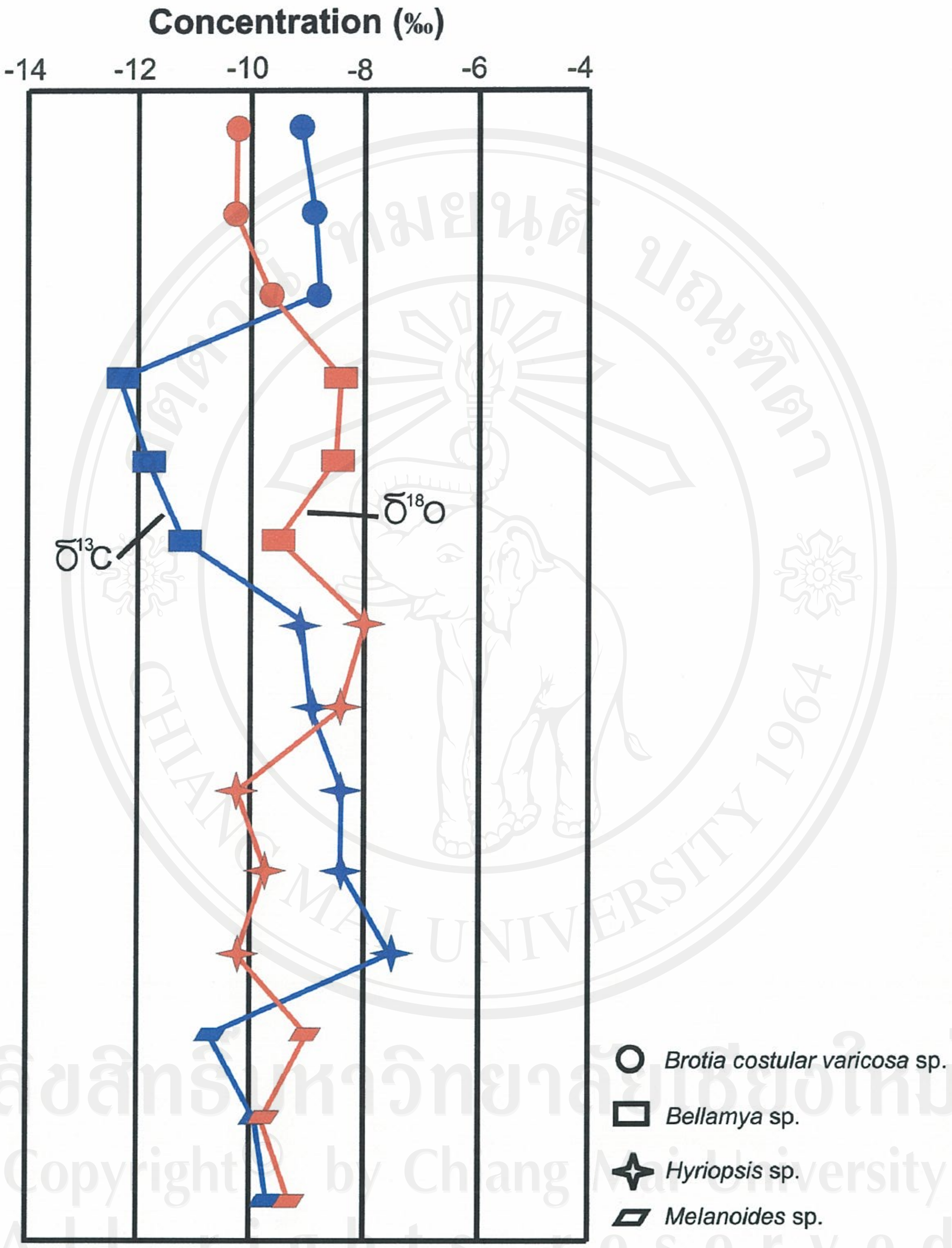


Figure 4.39 The graph of stable carbon isotope versus stable oxygen isotope of gastropod from Chiang Muan coal field.

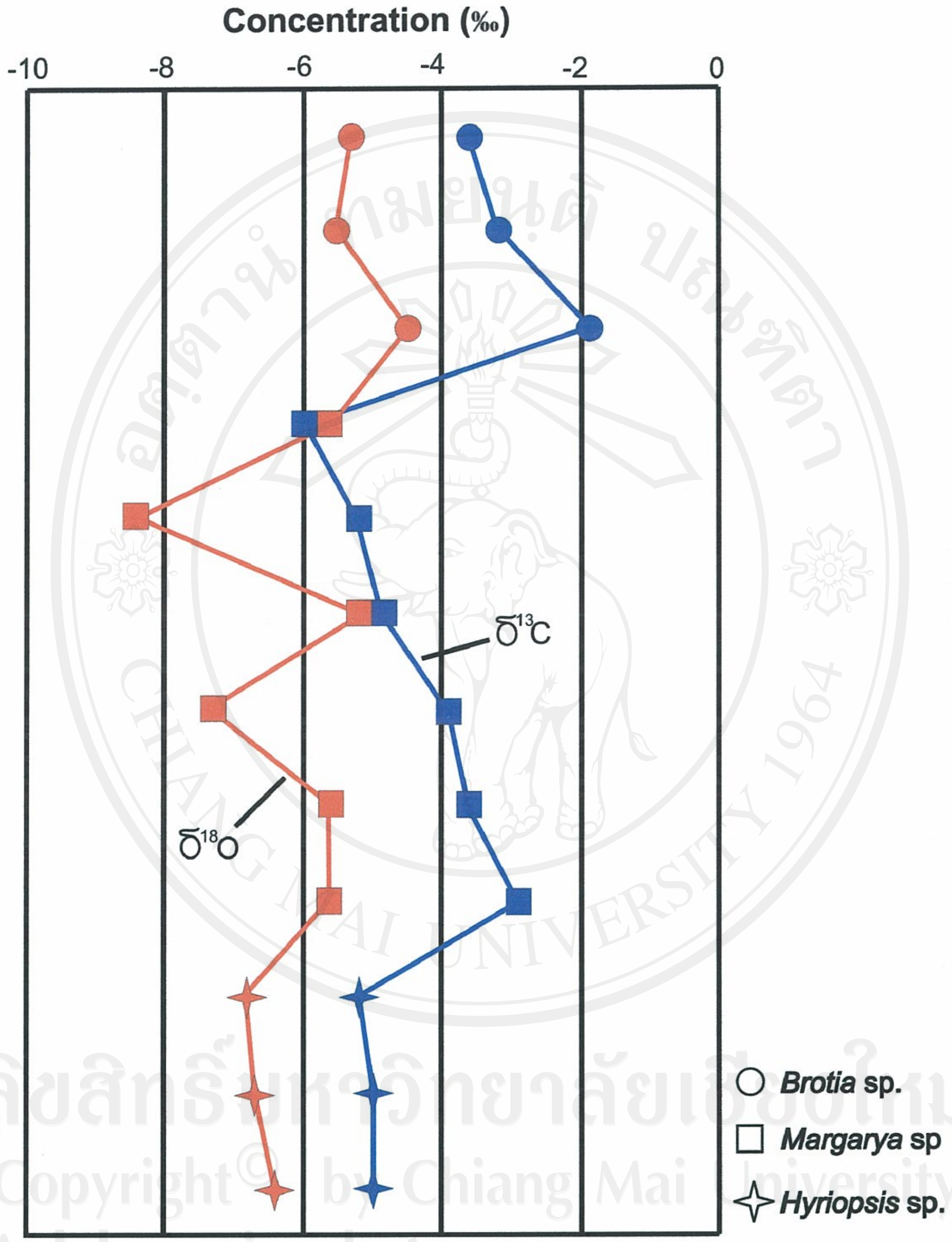


Figure 4.40 The graph of stable carbon isotope versus stable oxygen isotope of gastropod from Wang Nua coal field.

4.7 Carbon, hydrogen, nitrogen and sulfur in coal and sediment

4.7.1 Mae Moh coal field

The carbon, hydrogen, nitrogen and sulfur data of the Mae Moh samples are reported in Table 4.31 and Appendix E.

4.7.2 Chiang Muan coal field.

The carbon, hydrogen, nitrogen and sulfur data of the Chiang Muan samples are reported in Table 4.32 and Appendix E.

4.7.3 Mae Teep coal field.

The carbon, hydrogen, nitrogen and sulfur data of the Mae Teep samples are reported in Table 4.33 and Appendix E.

4.7.4 Wang Nua coal field

The carbon, hydrogen, nitrogen and sulfur data of the Wang Nua samples are reported in Table 4.34 and Appendix E.

4.7.5 Ngao coal field

The carbon, hydrogen, nitrogen and sulfur data of the Ngao samples are reported in Table 4.34 and Appendix E.

Table 4.31 The carbon, hydrogen, nitrogen, and sulfur in sediment and coal samples from Mae Moh coal field.

Sample from zone.		Elements (%)				C/S
		Carbon	Hydrogen	Nitrogen	Sulfur	
RB	Min	0.00	0.00	0.02	0.00	-
	Max	0.00	1.30	0.09	0.00	-
	Averg	0.00	0.58	0.05	0.00	-
I zone	Min	0.05	0.90	0.05	0.19	0.10
	Max	46.9	3.92	1.17	3.50	18.1
	Averg	11.8	2.07	0.33	1.62	6.17
TZ zone	Min	0.00	0.79	0.05	0.08	0.13
	Max	1.21	3.70	0.10	2.26	1.83
	Averg	0.25	1.82	0.07	0.77	0.92
J Zone	Min	0.38	0.00	0.02	0.19	0.32
	Max	55.2	4.85	1.48	20.8	35.1
	Averg	16.7	2.16	0.52	4.26	5.45
OB	Min	3.87	0.00	0.21	0.00	-
	Max	5.80	0.00	0.27	0.00	-
	Averg	5.07	0.00	0.24	0.00	-
K zone	Min	7.74	6.53	0.42	0.00	31.0
	Max	55.8	8.85	2.02	1.68	224
	Averg	36.3	7.60	1.35	0.47	87.0
IB	Min	3.47	0.00	0.17	0.00	-
	Max	11.3	4.70	0.43	0.06	181
	Averg	5.85	0.94	0.25	0.01	36.3
Q zone	Min	0.00	0.00	0.08	0.00	0.40
	Max	51.4	10.30	1.70	1.66	47.3
	Averg	14.4	3.20	0.55	0.38	26.7
UB	Min	4.48	0.00	0.24	0.00	-
	Max	8.50	0.00	0.30	0.76	5.88
	Averg	5.88	0.00	0.26	0.25	1.96

Table 4.32 The carbon, hydrogen, nitrogen, and sulfur in sediment and coal samples from Chiang Muan coal field.

Sample from zone		Elements (%)				C/S
		Carbon	Hydrogen	Nitrogen	Sulfur	
OB	Min	0.00	0.86	0.04	0.24	0.02
	Max	3.38	2.67	0.06	1.53	12.4
	Averg	0.69	1.89	0.05	0.73	4.15
U1	Min	0.00	1.15	0.05	0.63	0.02
	Max	37.5	3.13	1.01	8.31	4.63
	Averg	12.6	2.01	0.38	3.51	2.75
IB1		0.07	1.3	0.06	1.11	0.07
U2	Min	0.02	0.8	0.04	0.18	0.02
	Max	42.5	3.44	1.05	6.41	30.4
	Averg	16.6	2.25	0.46	1.59	9.68
IB2	Min	0.00	0.63	0.02	0.10	-
	Max	0.00	1.53	0.04	0.20	-
	Averg	0.00	1.12	0.03	0.14	-
LM	Min	2.76	2.05	0.10	0.00	-
	Max	25.8	16.9	1.09	0.10	29.1
	Averg	14.3	9.48	0.60	0.05	14.6
IB3	Min	0.00	1.64	0.04	0.05	-
	Max	0.45	2.07	0.04	0.35	8.73
	Averg	0.23	1.86	0.04	0.20	4.37
LS	Min	2.70	1.97	0.09	0.34	8.00
	Max	55.8	16.9	1.29	1.48	37.7
	Averg	29.3	9.44	0.69	0.91	22.9
UB	Min	0.00	1.19	0.03	0.04	-
	Max	0.42	1.91	0.04	0.05	8.75
	Averg	0.21	1.55	0.04	0.05	4.38

Table 4.33 The carbon, hydrogen, nitrogen, and sulfur in sediment and coal samples from Mae Teep coal field.

Sample from zone		Elements (%)				C/S
		Carbon	Hydrogen	Nitrogen	Sulfur	
OB	Min	1.51	0.00	0.08	0.00	15.1
	Max	10.7	1.44	0.37	0.66	50.9
	Averg.	6.59	0.08	0.26	0.07	32.1
MS	Min	1.99	0.00	0.20	0.00	37.4
	Max	58.9	8.52	2.24	0.47	225
	Averg.	33.1	4.32	1.14	0.04	131
UB	Min	0.01	0.00	0.06	0.00	-
	Max	2.13	1.42	0.11	0.00	-
	Averg.	0.47	0.34	0.09	0.00	-

Table 4.34 The carbon, hydrogen, nitrogen, and sulfur in coal samples from Wang Nua and Ngao coal field.

Sample from		Elements (%)				C/S
		Carbon	Hydrogen	Nitrogen	Sulfur	
NGAO coal field		41.2	3.68	1.24	4.19	9.82
Wang Nua coal field	Min	39.9	3.41	1.04	0.00	-
	Max	42.1	4.23	1.06	0.00	-
	Averg.	41.1	3.77	1.11	0.00	-

Sulfur and organic carbon relationships in modern and ancient sediments have been used to characterize depositional environments (Berner, 1970; 1972; 1982; 1984; 1989; Berner and Raiswell, 1983; 1984). The sulfur and organic carbon relationship could be a useful indicator for depositional environments, since the biogeochemical cycle of sulfur in sediments is inseparable from that of carbon, and the relationship depends on the depositional environment (Berner, 1989). The sulfur in marine sediments is primarily contained in pyrite, and the mechanisms of formation of which have been extensively investigated (Berner, 1970, 1984, 1989; Berner and Raiswell, 1984). Berner (1984) reviewed the relationship between organic carbon quality/quantity and pyrite sulfur concentration in sediments from several different depositional environments, namely normal marine, non-marine freshwater and Black Sea type euxinic sediments. Berner (1984, 1989) also defined as being normal marine in character those sediments that were deposited in bottom waters containing dissolved oxygen, and where bioturbation is brought about by oxygen-breathing bottom fauna. The term euxinic is applied to those environments where sediments are deposited in anoxic, H_2S-containing bottom waters. His investigates have demonstrated that depositional environments could be identified by quantitative relationships between sulfur and organic carbon.

In organic-rich sediments laid down in fresh water, much less diagenetic pyrite is formed than in analogous of dissolved sulfate found in most fresh waters as compared to seawater. As a result, modern organic-rich freshwater sediments exhibit a much higher organic carbon-to-pyrite sulfur ratio (C/S) than marine sediments with similar organic contents. On this basis, C/S ratios can be used to distinguish ancient marine from freshwater (or slightly brackish) sedimentary rocks. The C/S technique cannot distinguish brackish-water sediments deposited under salinities greater than half that of seawater from marine sediments, as demonstrated by analyses of modern Chesapeake Bay sediments. Also, the method is not applicable to nearly pure limestones or to rocks low in organic matter (less than about 1% organic carbon). Saline (high sulfate) phases of ancient lakes can be distinguished from nonsaline phases using the C/S method. Berner and Raiswell (1984) reported that the C/S ratio of marine sediments is low values (0.5-5), but the C/S ratio of freshwater sediment is high values (> 10).

The C/S ratio of the samples from Mae Moh, Chiang Muan, Mae Teep, Wang Nua, and Ngao are listed in Appendix F.

At Mae Moh coal field, the C/S ratio of J zone ranges from 0.32 to 3.10, with average 5.45. The C/S ratio of K zone ranges from 30.6 to 224, with average 87.4. The C/S ratio of Q zone ranges from 0.41 to 47.3, with average 26.7.

At Chiang Muan coal field, the C/S ratio of U1 zone ranges from 0.02 to 4.63, with average 2.31. The C/S ratio of U2 zone ranges from 0.02 to 30.4, with average 9.67.

At Mae Teep coal field, the C/S ratio is very wide and high values, which ranges from 15.1 to 224.

Berner and Raiswell (1983, 1984) and Berner (1984) use the plot of percent weight equivalence of carbon versus percent weight equivalence of sulfur the samples determine the sample assocoated to normal marine sediments. This method was used for plot of percent weight equivalence of carbon versus percent weight equivalence of sulfur for the samples from Mae Moh, Chiang Muan, Mae Teep, Wang Nua, and Ngao (Figure 4.41). The sample enclosed by dashed line show the association to

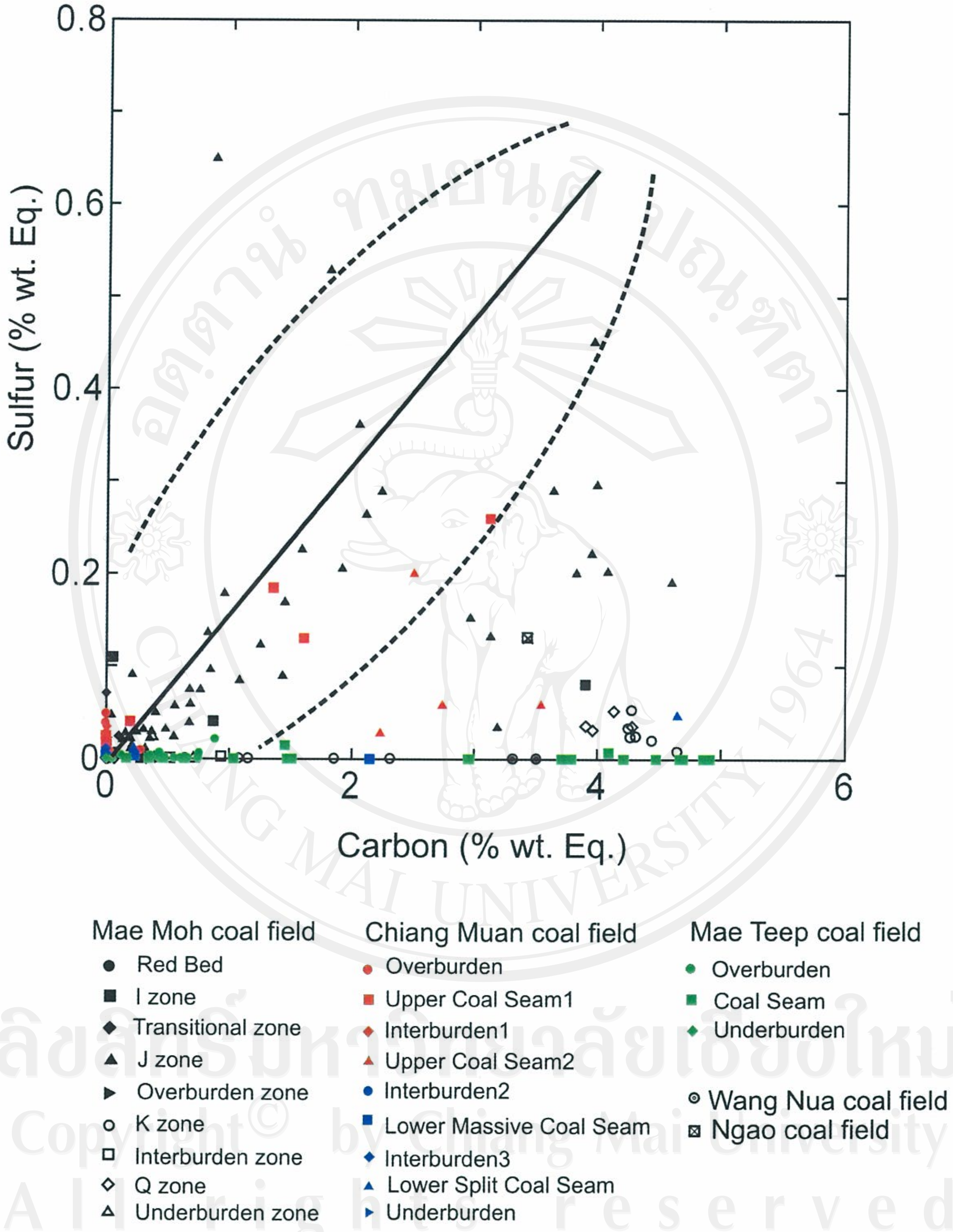


Figure 4.41 Plot of percent weight equivalence of carbon versus percent weight equivalence of sulfur from Mae Moh (101 samples), Chiang Muan (32 samples), Mae Teep (42 samples), Wang Nua (2 samples), and Ngao coal fields (1 sample). Regions enclosed by dashed line associate normal marine sediments (modified from Berner and Raiswell, 1983 and 1984; Berner, 1984).

normal marine sediments. The samples in dashed line consist of the samples from J zone of Mae Moh coal field and the samples from U1 and U2 of Chiang Muan coal field. The result of C/S ratio and plot between percent weight equivalence of carbon and sulfur can be concluded that that sediment from J zone of Mae Moh coal field and the samples from U1 and U2 of Chiang Muan coal field are associated with marine. It could be marine incursion during the deposition. The samples from the others layer of Mae Moh coal field and Chiang Muan coal field are deposited in freshwater environment. Additional, the sample from Mae Teep coal field, Wang Nua coal field, and Ngao coal field are also deposited in freshwater environment. However, the some samples from Mae Moh and Chiang Muan coal field that have the percent weight equivalence of sulfur more than 0.2 could be the brackish water.