CHAPTER 5

CONCLUSIONS

Seventy coal, sediment, gypsum and pyrite samples were collected from the northwest, northeast, C-1, and southwest pits of the Mae Moh coal field. These samples were studied using proximate and ultimate analyses, x-ray diffractometry, x-ray fluorescence spectrometry, induced couple plasma, coal petrography, and sulfur isotope analyses to determine the deposition processes, sediment sources, changes in depositional environments, and source of sulfur. The results of these geochemical analyses are summarized in Table 5.1.

Table 5.1 Conclusion table of geochemical analysis of Mae Moh coal field

Geochemical analysis	UB	Q zone	IB	K zone	OB	J zone	T	I zone	RB
Proximate analysis									
NW Pit									
- moisture (%)	-	10.03	-	9.54	-	-	-	-	-
- ash (%)	-	20.40	-	17.11	-	-	-	-	-
- volatile matter (%)	-	47.40	-	40.40	-	-	-	-	-
- fixed carbon (%)	-	22.12	-	32.90	-	-	-	-	-
NE Pit									
- moisture (%)	-	8.28	-	9.33	-	-	-	-	-
- ash (%)	-	38.90	-	43.11	-	-	-	-	-
- volatile matter (%)	-	27.58	-	36.76	-	-	-	-	-
- fixed carbon (%)	-	25.19	-	43.13	-	-	-	-	-
C-1 Pit									
- moisture (%)	-	-	-	-	-	12.66	-	-	-
- ash (%)	-	-	-	-	-	19.83	-	-	-
- volatile matter (%)	-	-	-	-	-	46.75	-	-	-
- fixed carbon (%)	-	-	-	-	-	20.76	-	-	-
SW Pit									
- moisture (%)	-	-	-	-	-	-	-	11.24	-
- ash (%)	-	-	-	-	-	-	-	5.65	-
- volatile matter (%)	-	-	-	-	-	-	-	48.99	-
- fixed carbon (%)	-	-	-	-	-	-	-	34.12	-
Ultimate analysis									
NW Pit									
- carbon (%)	-	34.95	-	43.13	-	-	-	-	-
- hydrogen (%)	-	3.55	-	4.79	-	-	-	-	-
- nitrogen (%)	-	3.01	-	3.62	-	-	-	-	-
- sulfur (%)	-	4.99	-	2.12	-	-	-	-	-
NE Pit									
- carbon (%)	-	32.11	-	57.13	-	-	-	-	-
- hydrogen (%)	-	2.94	-	5.31	-	-	-	-	-

Geochemical analysis	UB	Q zone	IB	K zone	OB	J zone	T	I zone	RB
- nitrogen (%)	-	1.59	-	3.07	-	-	-	-	-
- sulfur (%)	-	6.37	-	2.38	-	-	-	-	-
C-1 Pit									
- carbon (%)	-	-	-	-	-	37.09	-	-	-
- hydrogen (%)	-	-	-	-	-	3.36	-	-	-
- nitrogen (%)	-	-	-	-	-	2.05	-	-	-
- sulfur (%)	-	-	-	-	-	6.40	-	-	-
SW Pit									
- carbon (%)	-	-	-	-	-	-	-	46.29	-
- hydrogen (%)	-	-	-	-	-	-	-	4.42	-
- nitrogen (%)	-	-	-	-	-	-	-	3.48	-
- sulfur (%)	-	-	-	-	-	-	-	1.05	-
X-ray diffractometry									
NW Pit									
- calcite (%)	33.03	-	17.39	-	-	-	0.00	-	0.00
- quartz (%)	30.83	-	71.53	-	-	-	90.33	-	94.62
- gypsum (%)	0.00	-	0.00	-	-	-	0.00	-	0.00
- pyrite (%)	0.91	-	0.00	-	-	-	0.00	-	0.00
- illite (%)	1.10	-	4.72	-	-	-	1.55	-	0.69
- siderite (%)	27.52	-	0.00	-	-	-	0.00	-	1.86
- kaolinite (%)	6.61	-	6.36	-	-	-	8.12	-	2.83
- chlorite (%)	0.00	-	0.00	-	-	-	0.00	-	0.00
- dolomite (%)	0.00	-	0.00	-	-	-	0.00	-	0.00
NE Pit									
- calcite (%)	82.82	-	61.41	-	-	-	-	-	-
- quartz (%)	12.03	-	26.12	-	-	-	-	-	-
- gypsum (%)	0.00	-	0.00	-	-	-	-	-	-
- pyrite (%)	1.36	-	6.30	-	-	-	-	-	-
- illite (%)	0.00	-	1.24	-	-	-	-	-	-
- siderite (%)	2.16	-	1.26	-	-	-	-	-	-
- kaolinite (%)	1.63	-	3.67	-	-	-	-	-	-
- chlorite (%)	0.00	-	0.00	-	-	-	-	-	-
- dolomite (%)	0.00	-	0.00	-	-	-	-	-	-
C-1 Pit									
- calcite (%)	-	-	-	-	88.13	-	28.78	-	3.88
- quartz (%)	-	-	-	-	11.16	-	62.78	-	80.91
- gypsum (%)	-	-	-	-	0.00	-	0.66	-	6.33
- pyrite (%)	-	-	-	-	0.53	-	0.10	-	0.15
- illite (%)	-	-	-	-	0.00	-	1.49	-	1.10
- siderite (%)	-	-	-	-	0.18	-	0.00	-	0.00
- kaolinite (%)	-	-	-	-	0.00	-	5.79	-	7.63
- chlorite (%)	-	-	-	-	0.00	-	0.00	-	0.00
- dolomite (%)	-	-	-	-	0.00	-	0.40	-	0.00
SW Pit									
- calcite (%)	-	-	-	-	-	-	-	-	-
- quartz (%)	-	-	-	-	-	-	-	-	-
- gypsum (%)	-	-	-	-	-	-	-	-	-
- pyrite (%)	-	-	-	-	-	-	-	-	-
- illite (%)	-	-	-	-	-	-	-	-	-
- siderite (%)	-	-	-	-	-	-	-	-	-
- kaolinite (%)	-	-	-	-	-	-	-	-	-

Geochemical analysis	UB	Q zone	IB	K zone	OB	J zone	T	I zone	RB
- chlorite (%)	-	-	-	-	-	-	-	-	-
- dolomite (%)	-	-	-	-	-	-	-	-	-
X-ray fluorescence									
NW Pit									
- Na_2O (%)	0.42	0.26	0.00	0.21	-	-	-	-	-
- MgO (%)	0.21	2.56	2.04	3.26	-	-	-	-	-
- Al_2O_3 (%)	7.62	24.95	16.46	68.19	-	-	-	-	-
- SiO_2 (%)	23.88	47.90	41.41	39.44	-	-	-	-	-
- P_2O_5 (%)	0.32	0.15	0.07	0.84	-	-	-	-	-
- K_2O (%)	1.51	2.92	2.22	2.36	-	-	-	-	-
- CaO (%)	17.29	1.59	9.22	12.08	-	-	-	-	-
- TiO_2 (%)	0.30	0.54	0.42	0.35	-	-	-	-	-
- MnO (%)	0.40	0.02	0.01	0.05	-	-	-	-	-
- Fe_2O_3 (%)	21.09	8.75	2.50	10.80	-	-	-	-	-
- SO_3 (%)	0.71	1.83	0.03	8.87	-	-	-	-	-
NE Pit									
- Na_2O (%)	0.83	0.15	1.43	0.81	-	-	-	-	-
- MgO (%)	0.53	1.96	1.16	3.56	-	-	-	-	-
- Al_2O_3 (%)	11.12	23.51	10.18	17.7	-	-	-	-	-
- SiO_2 (%)	30.14	45.12	29.21	34.29	-	-	-	-	-
- P_2O_5 (%)	0.41	0.08	0.44	0.73	-	-	-	-	-
- K_2O (%)	1.99	2.98	2.14	2.25	-	-	-	-	-
- CaO (%)	22.78	1.34	31.03	9.60	-	-	-	-	-
- TiO_2 (%)	0.23	0.60	0.28	0.46	-	-	-	-	-
- MnO (%)	0.25	0.04	0.06	0.05	-	-	-	-	-
- Fe_2O_3 (%)	11.84	12.73	4.12	15.66	-	-	-	-	-
- SO_3 (%)	0.72	1.26	0.74	7.55	-	-	-	-	-
C-1 Pit									
- Na_2O (%)	-	-	-	-	0.70	0.00	-	-	-
- MgO (%)	-	-	-	-	2.28	4.34	-	-	-
- Al_2O_3 (%)	-	-	-	-	5.42	7.59	-	-	-
- SiO_2 (%)	-	-	-	-	16.89	16.81	-	-	-
- P_2O_5 (%)	-	-	-	-	0.60	1.58	-	-	-
- K_2O (%)	-	-	-	-	1.67	1.09	-	-	-
- CaO (%)	-	-	-	-	40.45	20.57	-	-	-
- TiO_2 (%)	-	-	-	-	0.10	0.34	-	-	-
- MnO (%)	-	-	-	-	0.09	0.05	-	-	-
- Fe_2O_3 (%)	-	-	-	-	2.58	21.89	-	-	-
- SO_3 (%)	-	-	-	-	0.96	16.87	-	-	-
SW Pit									
- Na_2O (%)	-	-	-	-	-	-	-	0.00	-
- MgO (%)	-	-	-	-	-	-	-	7.23	-
- Al_2O_3 (%)	-	-	-	-	-	-	-	11.18	-
- SiO_2 (%)	-	-	-	-	-	-	-	8.11	-
- P_2O_5 (%)	-	-	-	-	-	-	-	0.00	-
- K_2O (%)	-	-	-	-	-	-	-	0.71	-
- CaO (%)	-	-	-	-	-	-	-	26.75	-
- TiO_2 (%)	-	-	-	-	-	-	-	0.67	-
- MnO (%)	-	-	-	-	-	-	-	0.04	-
- Fe_2O_3 (%)	-	-	-	-	-	-	-	6.11	-
- SO_3 (%)	-	-	-	-	-	-	-	42.67	-

Geochemical analysis	UB	Q zone	IB	K zone	OB	J zone	T	I zone	RB
ICP analysis									
NW Pit									
- La (ppm)	9.70	31.20	28.1	20.13	-	-	-	-	-
- Ce (ppm)	18.20	59.05	51.1	34.55	-	-	-	-	-
- Ba (ppm)	268.4	639.80	399.9	789.00	-	-	-	-	-
- Cr (ppm)	30.80	100.30	49.80	946.20	-	-	-	-	-
- V (ppm)	36.90	241.80	82.10	120.50	-	-	-	-	-
- Cu (ppm)	14.90	71.95	26.90	60.90	-	-	-	-	-
- Zr (ppm)	69.50	188.70	113.7	88.73	-	-	-	-	-
- Zn (ppm)	40.20	178.35	76.60	94.70	-	-	-	-	-
- Co (ppm)	12.40	22.30	9.30	30.60	-	-	-	-	-
- Ni (ppm)	11.00	25.40	7.80	189.20	-	-	-	-	-
- Sr (ppm)	243.7	317.40	503.2	830.25	-	-	-	-	-
- Cd (ppm)	0.20	0.10	0.00	0.10	-	-	-	-	-
- Be (ppm)	1.50	4.60	1.50	2.20	-	-	-	-	-
- Y (ppm)	11.80	54.20	30.80	23.90	-	-	-	-	-
NE Pit									
- La (ppm)	9.70	37.70	13.80	24.50	-	-	-	-	-
- Ce (ppm)	7.30	70.95	32.60	49.70	-	-	-	-	-
- Ba (ppm)	323.4	601.0	389.4	1247.9	-	-	-	-	-
- Cr (ppm)	25.70	95.90	37.90	142.60	-	-	-	-	-
- V (ppm)	25.00	170.9	38.70	162.50	-	-	-	-	-
- Cu (ppm)	13.70	74.60	17.50	65.20	-	-	-	-	-
- Zr (ppm)	59.30	115.45	76.60	109.60	-	-	-	-	-
- Zn (ppm)	25.80	237.00	77.10	152.40	-	-	-	-	-
- Co (ppm)	8.20	23.10	7.10	25.55	-	-	-	-	-
- Ni (ppm)	7.30	24.70	10.10	43.50	-	-	-	-	-
- Sr (ppm)	431.6	256.70	435.1	812.10	-	-	-	-	-
- Cd (ppm)	0.10	0.50	0.00	0.20	-	-	-	-	-
- Be (ppm)	0.80	3.95	1.10	3.90	-	-	-	-	-
- Y (ppm)	11.60	38.90	14.10	33.18	-	-	-	-	-
C-1 Pit									
- La (ppm)	-	-	-	-	9.70	17.23	21.50	-	-
- Ce (ppm)	-	-	-	-	10.20	33.20	40.20	-	-
- Ba (ppm)	-	-	-	-	517.6	912.20	2740	-	-
- Cr (ppm)	-	-	-	-	56.60	265.30	70.40	-	-
- V (ppm)	-	-	-	-	18.80	217.10	78.80	-	-
- Cu (ppm)	-	-	-	-	12.90	57.60	25.70	-	-
- Zr (ppm)	-	-	-	-	59.30	110.00	53.10	-	-
- Zn (ppm)	-	-	-	-	63.60	93.90	51.20	-	-
- Co (ppm)	-	-	-	-	11.20	28.31	11.30	-	-
- Ni (ppm)	-	-	-	-	14.00	64.57	14.50	-	-
- Sr (ppm)	-	-	-	-	811.6	1119.0	306.1	-	-
- Cd (ppm)	-	-	-	-	0.00	0.10	0.20	-	-
- Be (ppm)	-	-	-	-	0.70	4.84	2.60	-	-
- Y (ppm)	-	-	-	-	9.30	14.66	15.60	-	-
SW Pit									
- La (ppm)	-	-	-	-	-	-	-	22.70	-
- Ce (ppm)	-	-	-	-	-	-	-	55.70	-
- Ba (ppm)	-	-	-	-	-	-	-	6094.0	-
- Cr (ppm)	-	-	-	-	-	-	-	153.30	-
- V (ppm)	-	-	-	-	-	-	-	232.20	-

Geochemical analysis	UB	Q zone	IB	K zone	OB	J zone	T	I zone	RB
- Cu (ppm)	-	-	-	-	-	-	-	39.3	-
- Zr (ppm)	-	-	-	-	-	-	-	56.3	-
- Zn (ppm)	-	-	-	-	-	-	-	58.9	-
- Co (ppm)	-	-	-	-	-	-	-	21.1	-
- Ni (ppm)	-	-	-	-	-	-	-	12.0	-
- Sr (ppm)	-	-	-	-	-	-	-	1631.4	-
- Cd (ppm)	-	-	-	-	-	-	-	0.1	-
- Be (ppm)	-	-	-	-	-	-	-	16.7	-
- Y (ppm)	-	-	-	-	-	-	-	370	-
Sulfur isotope									
NW Pit									
- gypsum (%)	-	-	-	+ 4.3‰, + 0.5‰	-	-	-	-	+20.0‰,+18.8‰, + 3.9‰, + 3.5‰, + 3.8‰, +16.4‰
- pyrite (%)	-	-	-	-	-	-	-	-	-
NE Pit									
- gypsum (%)	-	-	-	-	-	-	-	-	+16.4‰
- pyrite (%)	-	+19.7‰, +19.9‰	-	-	-	-	-	-	-
C-1 Pit									
- gypsum (%)	-	-	-	-	-	-	-	-	-
- pyrite (%)	-	-	-	-	-	-	-	-	-
SW Pit									
- gypsum (%)	-	-	-	-	-	-	-	-	-
- pyrite (%)	-	-	-	-	-	-	-	- 7.8‰, -13.6‰	-

Remarks UB = underburden IB = interburden OB = overburden
T = transition zone RB = red bed zone

The proximate and ultimate analyses showed that ash content averages 20.48 percent, moisture content 10.61 percent, volatile matter 41.67 percent, and fixed carbon 27.24 percent. The average carbon content is 40.3 percent, hydrogen 3.87 percent, nitrogen 2.56 percent, and sulfur 7.20 percent. The moisture content has a negative correlation with ash and a positive correlation with volatile matter. The correlation between hydrogen and carbon with ash is negative and positive with sulfur. There is no significant correlation between volatile matter/ash and fixed carbon/ash. Volatile matter has a positive correlation with hydrogen.

The underburden in the Mae Moh coal field was deposited in a silica-rich lacustrine environment, along with some calcareous claystone (quartz 82.82 percent, calcite 12.0 percent). The presence of siderite (27.52 percent) and pyrite (1.36 percent) indicate a strongly reducing environment. The high sulfur isotope values of pyrite in the Q zone,

+19.7 per mil and +19.9 per mil are dominated by reducing organic sulfur and indicate a normal accumulation of sediments in a freshwater environment at that time. Kaolinite (8.99 percent) and illite (0.74 percent) that occur in the Q zone could have been derived from rhyolite that flanked the Mae Moh basin. High quartz content indicates a large influx of silica during this period.

The presence of fusinite, which results from burning, indicates that the environment during Q zone deposition was shallow water and at times dry. The rare occurrence of alginite in the Q zone indicates that waterlogging was not common during peat accumulation. During K zone deposition, the environment slowly changed from a silica-rich lacustrine environment to a calcium, or alkaline, lacustrine environment. This is indicated by a silica dioxide to calcium oxide ratio of 35.31 to 1.58. Siderite and pyrite contents, 3.51 percent and 1.33 percent, respectively, indicate a reducing environment. The low positive sulfur isotope values from gypsum, +4.3 per mil and +0.5 per mil, in the K-1 seam and the presence of the macrofossils (Ratanasathien and others, 1997) suggest that there was catastrophism during this period (Sakai, 1957; Puchelt and others, 1971; Hoefs, 1973). In the K zone was inferred by the cutinite, sporinite rich coal whereas the tree trunk remains or textinite indicate that the area was a forest swamp. The water in this lacustrine environment was freshwater. This is indicated by the presence of thin-walled alginite and of sporinite.

During J zone deposition the environment changed abruptly to a highly calcium-rich lacustrine environment (calcium oxide 20.57 percent and calcite 82.27 percent) and the water was deep to very deep, such that peat could not form for a long period. The abundant pyrite in the J zone could be the result of a marine incursion. This is suggested by the negative values of sulfur isotope from marine pyrite, -7.8 per mil and -13.6 per mil (Thode and others, 1960; Vinogradov and others, 1962; Kaplan and others, 1963) and the high positive values of sulfur from gypsum, +20.0 per mil, +18.8 per mil, and +16.4 per mil (Deevey and others, 1963; Nakai and Jensen, 1964). The negative sulfur isotope value of pyrite in the thin layer of the I zone coal seam and the abundance of framboidal pyrite indicate that the J zone marine incursion continued into the I zone. This continued marine incursion is suggested by the decrease of the strontium/calcium ratio from the lower sequence to the upper sequence, from 208.4×10^{-4} to 28.34×10^{-4}. This marine incursion terminated coal accumulation in the Mae Moh basin.

The abrupt change from the calcium-rich lacustrine environment of the J zone to a high silica content in transition and red bed zone could indicate a major change of depositional environment or an unconformity between these sequences. The high values of some trace elements, such as barium, 544.27 parts per million, cobalt, 17.92 parts per million, chromium, 216.8 parts per million, and vanadium, 113.7 parts per million, indicate that the source of these elements was not only from the erosion of igneous rocks that flank the Mae Moh basin but also from volcanic activity. This volcanic activity is indicated by the volcanic debris in the J-4 and J-5 seams and by the siliceous diatom-rich beds in the K zone, which may have resulted from volcanic ash (Ratanasathien and others, 1997). The high values of these elements are in line with the known very high average content of cobalt, chromium, vanadium, strontium, and barium reported by Krauskopf (1967) from Tertiary volcanic rocks.