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Preliminary report of the trace element geochemistry of an Indonesian peat deposit

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PRELIMINARY REPORT OF THE TRACE ELEMENT GEOCHEMISTRY OF AN INDONESIAN PEAT DEPOSIT

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ABSTRACT

Thirty-one samples from a peat deposit in Sumatra, Indonesia, were analyzed for thirty elements by instrumental neutron activation analysis. The average concentrations of most trace elements were remarkably similar to average concentrations of coals from the Appalachian basin; over half of the average concentrations for the two areas agreed within ±20 %. The geochemical results suggest a correlation between trace-element content and the location of the sample within the deposit. Three general groups can be recognized. The first consists of 9 samples distinguished by generally low concentrations of most elements except As, Au, and Zn. These samples are generally from the interior of the peat deposit. The second consists of 19 samples from cores at the edges or from the top or bottom of the deposit. These generally have higher concentrations of most trace elements than the first group except for As, Au and Zn. A third group contains 1 sample each from the bottom of three cores near the middle of the deposit. These samples fall off the correlation lines for several element pairs indicating a different geochemical environment. The geochemical relationships indicate that Sumatra peat deposits are good geochemical analogs for the formation of Carboniferous coal deposits of the Appalachian basin.

INTRODUCTION

Many studies discuss the trace element relationships in coal (e.g. Zubovic 1966; Gluskoter and others; 1977 Finkelman, 1980; Bouska 1981). However, little is known of the trace element content of peat with the exception of a few elements, such as uranium, and some studies of the mineral matter in peat (e.g. Raymond and Andrejko, 1983). A few studies have been made to include relationships between peat geochemistry and depositional environment (e.g. Raymond and others, 1987). In addition, an overview of research on peat utilization and environmental considerations has been made by Boron and others, (1987).

Coal is generally considered to be derived from humic peat deposits. In most high rank coals most trace elements are believed to be associated with minerals. Elements in coal (except organically bound C, H, N, O, and S) have been defined by Gluskoter (1975) as "mineral matter." Mineral matter in coal has been classified by Mackowsky (1968) as either being syngenetic (formed during coalification) or epigenetic (formed after coalification). Cecil and others (1981) classified mineral matter as authigenetic (formed from the original plants) and detrital (brought in from outside the coal bed), and suggested that most mineral matter in coal is derived authigenically from plant matter. However, Finkelman (1981) suggested that the most important source of mineral matter in many bituminous coals is water-borne detritus. Finkelman (1982) also suggested that minerals often considered to be authigenic may be altered detrital particles. Andrejko and others (1983) proposed a three-part classification system based on the genesis of mineral matter in coal as authigenic, detrital, and diagenetic. Diagenetic minerals would include minerals formed from alterations of other mineral species such as desilication of original clay material (De Kimpe and others, 1964; Staub and Cohen, 1978), alteration of iron sulfide to iron sulfates (Raymond and others, 1983) and alteration of biogenic carbonate due to heavy etching (Cohen and Guber, 1968). Similar classifications have been suggested for describing peat (Andrejko and others, 1983).

The trace element occurrence in peat and low rank coals (lignite and subbituminous coals)is more complex than in bituminous coals due to a greater organic association of many trace elements. The exact nature of these associations is not completely understood, but peat and low rank coals have a greater number of reactive organic sites (Miller and Given, 1978) to which ions can be attached than do higher rank coals. Trace elements are therefore associated with a variety of organic, as well as mineral, components in peat.

Trace elements in peat may be associated with organic (decaying plant matter) or mineral matter. This paper discusses relationships of trace elements in peat, to location and geologic setting in a swamp in Sumatra, Indonesia (Figure 1). The Peat samples were collected during a June to August,1986 visit to Sumatra by Cameron working in full collaboration with Supardi of the Directorate of Mineral Resources in the Directorate General of Geology and Mineral Resources, Republic of Indonesia.

Geologic Setting and Physiographic Setting

The Batang Hari River, which crosses the study area, rises in the Barisan Mountains, generally flows eastward through the piedmont and into the plains scarcely more than 35 m above sea level, and finally enters the swamp-forest covered delta just beyond Jambi (Figure 1).

The Barisan Mountains are the southern extension of a complex mountain system forming the backbone of Sumatra. The watershed is generally not more than 56 km from the Indian Ocean. These mountains, together with the plateaus they enclose, are tilted at a low angle from west to east. Longitudinal rift valleys are common, as well as volcanic outpourings of material ranging from andesite to volcanic ash. Pumice, tufa, and ash spread eastward, partly as volcaniclastic deposits or debris, and partly as redistributed waterborne alluvium. The east coast swamps are largely redistributed debris from Quarternary eruptions. Apart from the piedmont where oil and coal occur in Tertiary sediments, the recent alluvium from the volcanic highlands blankets eastern Sumatra (Dobby, 1950).

Easterly and northeasterly flowing rivers that headed in the backbone of western Sumatra reaches the coastal plains over decreasing stream gradients caused by rising sea level and heavy loads of mud and decaying vegetation. A delta-like landform advances from Jambi toward the South China Sea to the northeast. The power for vertical down cutting is minimal except locally where tides are high and swift. The streams aggrade laterally forming constantly changing courses and leaving numerous abandoned channels. Sungai Kumpeh River, partly circling the Batang Hari, appears to be a semi-abandoned channel of the Batang Hari. Distributaries form and natural levees are built throughout the delta. The outcrop of Tertiary bedrock (Figure 1) suggests an originally broad embayment into which the ancestral Batang Hari River debouched.

Peat accumulation began at least 8,000 B.P. after broad estuarine embayments along the coast of Sumatra began to fill in with fine-grained sediment (Chambers and Sobur, 1977). Small deposits of peat that were buried about 7580 ±340 B.P. are exposed in the river bank of the Batang Hari near the Town of Jambi (Cameron and others, 1987). Post-glacial sea level rise and stabilization and high sediment-load runoff from the western Barisan Mountain Range slowed down-cutting and induced infilling of coastal embayments. Decreased coastal gradients resulted in channel avulsion and abandonment along the coastlines creating numerous depressions for peat accumulation. Initially, mangroves rapidly colonized emerging mud flats and mud bars, consolidating sediments and thereby accelerating the process of land extension (Bird, 1982). As the coastline continued to extend seaward, freshwater peat forest vegetation succeeded and freshwater peat began to accumulate. The peat deposit ranges from 1 to 7 m in thickness along a 20 km tranverse, A-A', within a meander of the Batang Hari (Figures 2 and 3). The Batang Hari has eroded the thick southeastern portion of the deposit and is actively depositing levee sediments up to 2-m thick, and up to 250 m from the river bank. The thin northwestern edge of the peat deposit overlies dark gray clays and silts interpreted as estuarine fill and alluvium (Cameron and others, 1987).

The peat may have accumulated originally in an abandoned floodplain depression but, for the most part, it accumulated by paludification contemporaneously with coastal progradation. Because of the low ash (generally less than 2 percent) contents of samples from near the base of the center of the deposit, ombrotrophy (supply of nutrient from precipitation) may have occurred very early in the deposit's development which began at the site of the cross section A-A' about 4300 B.P. (Cameron and others, 1987). Ash contents are highest along the base and along the thin eroded margins of the deposit. As seen in the cross-section A-A' (Figures 1 and 3), the majority of the peat is well to moderately decomposed woody hemic, exept in the upper central portions of the deposit. Across the peat surface the vegetation is fairly uniform and is still in an early peat forest phase which, based on the relative homogeneity of the internal peat stratigraphy, has possibly existed since the beginnings of ombrotrophic conditions. Only in the Core E near the middle of the section where pandan trees occur, is there a major difference in surface vegetation and peat type. The peat here is very fibrous and much harder to collect due to very high water/slurry content.

EXPERIMENTAL

An Eikelman auger was used to core along Traverse A-A' and to collect undisturbed samples for analysis. Figure 3 shows the position of core sites along the traverse. Cores are designated by letters and samples are designated in the form of C-TD-BD where C is the letter designator for the core; TD is the depth below the surface in cm to the top of the sample and BD is the depth in cm to the bottom of the sample (see Tables 1,2 and 3).

Thirty-one wet peat samples, up to 150 g each (as received), were dried at 110°C for 16 hours and moisture loss was determined. After grinding, about 0.5 g of dried peat from each sample was irradiated in the U.S. Geological Survey reactor for 8 hours at a flux of $2\text{x}10^{12}\text{n/cm}^2\text{sec}$ and analyzed for 30 elements by instrumental neutron activation analysis (INAA). Procedures used were similar to those used to analyze coals in this laboratory (Palmer and Baedecker, 1988). After the analysis of the peat samples further experiments showed that some moisture had been picked up during the grinding and subsequent storage of the samples, but in no case had more than 9% moisture by weight been added. The data were normalized to account for the added moisture.

RESULTS AND DISCUSSION

Peat quality is assessed by criteria such as peat type, pH, moisture content and ash content. Peat classification systems based on field assessments of humification and decomposition (Von Post and Granlund, 1926), fiber content and botanical composition (Farnham, 1968), or combinations of both (Farnham and Finney, 1965; McKinzie, 1974) are used. The USDA system which classifies peat as fibric, hemic, and sapric is used widely and generally applicable especially in tropical lowland forest peats except when the peat is very woody (Lopulina and others, 1987; Esterle and others 1987). These three peat types often have major differences in ash contents within a deposit. Because the ash content of commercial peat should not exceed 25% dry weight, two additional sample types, clayey peat (ash content 25 to 50 percent), and peaty clay (ash content greater than 50 percent) were added to the USDA classification system as used in our study. The moisture loss, ash content of dried peat, pH, and peat type data for the 31 peat samples in this study are given in Table 1. On an as recieved basis, 27 samples had more than 79 percent moisture; only one had less than 50 percent. On an ash-free basis all samples have more than 79 percent moisture (Table 1). The ash content on a dry basis was generally low (18 peat samples were <8%), but some samples taken from the top or bottom of the peat depoist or in core A' (Figure 3) were much higher, up to 78.5 percent on a dry basis. Peats analyzed in this study are classified as follows: 19 samples, hemic; 4, sapric; 3, clayey peat; 5, peaty clay.

The results of the INAA analysis of trace elements in the dried samples are shown in Table 2. Because some peat is a precursor of coal, it is worthwhile to compare the concentration of trace elements in this peat to that in bituminous coal. Zubovic and others (1980) analyzed 644 bituminous coal samples from the eastern United States. Although these coals are clearly different in time of deposition, plant type, location, and degree of maturation from the peats in this study, the trace element concentrations are similar. One reason for this is the similarity of average ash contents, 11.9% reported by Zubovic and others (1980) and 14.2% for this study. Another reason for this is that bituminous coals are usually low in water (<3%) and so compare closely in moisture content with dried peat. In all cases the ranges of concentrations overlapped. This was not too surprising since the ranges were often two orders of magnitude or more. However, the mean differed by less than a factor of 2.5 for all elements except Fe, Co, and As; for Na, K, Sc, Cr, Zn, Br, Rb, La, Ce, Sm, Eu, Lu, and U the difference was less than 20%. For Ba, Nd, Yb, W, and Hg differences in means greater than 20% may have been due in part to ignoring many values that were below the detection limit. New averages for elements where greater than 20% of the samples were below the detection limit were calculated based on correlations with other elements for which concentrations were determined in all 31 samples. All correlation coefficients (r values) values used to determine these new averages were greater than 0.92 except W vs. Sc where r=0.84. New averages were not determined for Sr which had all upper limits, Nd which had all upper limits except two samples and Au because there was not enough information in the National Coal Resource Data System (NCRDS) to warrant comparison. The estimate for Rb, whose average value decreased by a factor of approximately 2 using the correlation estimates above (0.26 to 0.12) is probably not comparable to the average estimate because roughly 50% of the values in NCRDS also were upper limits. Because the average (eliminating upper limits) is based on about the same percentage as the average computed from the NCRDS data it is probably more reasonable to compare this average with the NCRDS data than the average estimated using correlation lines and, in fact, the two average values for Rb agree within ±10 % of each other (Table 2).

Some samples were unusually high in As with values as high as 2,220 ppm. Ten samples had As concentrations greater than 130 ppm and six of these samples were greater than 170 ppm which was the highest As value reported by Zubovic and others (1980) for Appalachian basin coals. The average As concentration was ten times the average for these bituminous coals, but more than half of the samples were below the average U.S. bituminous coal of 18 ppm. Differences in As concentration could possibly be due to unusual geochemical conditions such as the presence of sulfide or differences in pH. However, sulfur concentrations are so low in other samples taken from the same cores (Table 3; Cameron and others, 1987) that there is not enough sulfur to account for the high As concentrations and there is no correlation of pH (Table 1) with As. However, there is a good correlation of As with Au, at least for samples with high As, suggesting that whatever mechanism is concentrating As is also concentrating Au. This correlation will be discussed in more detail later in this paper. The concentration of Au is as high as 111 ppb in sample D-430-480 (Table 2). The ash content for this sample (Table 1) is 2.86% so the gold content in the ash of this sample is nearly 4 ppm gold in the ash which is ore grade. Four other samples have over 0.5 ppm Au in the ash.

Cobalt and iron were unusually low in the Indonesian peat samples compared with Appalachian coals. This may be related to low sulfur or just due to difference in source rock material. All Co values and all except one Fe value were below those of the average eastern U.S. bituminous coal. Six different samples had concentration values of Co which were lower than the lowest samples reported by Zubovic and others (1980). The concentration of Sm in 11 peat samples was lower than the minimum concentration for Sm in coal but the average for Sm in peat was only 19% lower than the average in coal.

The peats were further classified based on graphic and statistical treatments of trace element data. Correlation matrices and rmode factor analysis were calculated on the trace element data and the log transformed data and log normal and linear scatter diagrams for correlations of several elements and total ash were plotted. Three types of scatter plots were found: (1) plots where a single correlation was found indicating that a single dominant geochemical process is controlling all samples; (2) plots where two separate straight line relationships exist which indicates at least 2 different chemical relationships for different sample groups; and (3) plots where no correlation was found which indicates that these elements were probably not in the same chemical form or were partitioned among many forms.

Several observations result from these studies. All elements except Zn, As, Se, and Au are significantly correlated directly with ash content at the 95% confidence level (Figure 4) but the correlation coefficient (r value) for the correlation was never above 0.9 for N (the number of samples) $\leq$ 31. Br has an inverse correlation with ash content indicating that it is organically associated. Most elements that correlated directly with ash content were correlated with each other and were not correlated with elements not correlated with ash. Br was inversely correlated with most elements. The r values for the correlation of the alkali metals and alkaline earth elements Na, K, Rb, Cs, and Ba were all $\geq$0.9 for N$\leq$ 31 for all possible pairs. Sc was strongly correlated ($r \geq 0.9$) with Na, K, Cs, La, Ce, Sm, Eu, Tb, and Th; Cr was strongly correlated with Hf, Ta, Th and U. In addition, Th was strongly correlated with both La and U; U was strongly correlated with both Ta, and W. All rare earth element (La, Ce, Sm, Eu, Tb, Yb, and Lu) pairs are strongly correlated except for Sm-Yb, Eu-Yb, Sm-Lu and Eu-Lu, which were significantly correlated at the greater than 99% level but had r values of $\leq$0.9. Examples of scatter diagrams showing these correlations are given in Figures 5 and 6. Many other element pairs of ash-correlated elements were also significantly correlated at the >99% confidence level, which had r values of less than 0.9. Results for log transformed data were similar except that Rb and W did not correlate with ash at the 95% confidence level; the r values for Na-Sc, K-Sc, were slightly below 0.9; and the r value for Sm-Yb was greater than 0.9.

Most elements that correlated (directly or inversely) with ash did not correlate with Zn, As, Se, or Au at the 95% confidence level. Some element pairs did not show a positive correlation because there are two distinctly different sample populations that have different correlations. Examples of this are Fe vs. As, Fe vs. Au, and As vs. Au. Figure 7 shows these scatter diagrams. The same two populations can be used for Co vs. Zn and for Zn vs. As (Figure 8) although the distinction is not as clear. Rmode factor analysis also confirms the two distinctly different chemical groups (based on scatter diagrams in Figures 7 and 8). One group, characterized by high Fe and low As, consists of those samples taken from the top and from the bottom of the peat deposit in cores B, C, D, and E and all samples from cores A and I (Figure 3). The other group, characterized by high As (up to 2200 ppm) and relatively low Fe, is made up of samples from the center of cores B-E. The only exception to this is sample E-500-525 (132 ppm As and 0.19% Fe) which lies stratigraphically below E-400-450 (1.48 ppm As and 0.231% Fe). This exception may be due to interfingering of the groups or may be due to changes in the peat as evidenced by a major change in vegetation near core E and change in peat type to a more fibrous peat which was a high water/slurry content. Figure 3 shows a possible arrangement of these chemical groups in the peat dome.

Correlations were calculated for each chemical group, and results for element pairs, which did not correlate for all samples as one group are shown in Figure 4. Zn generally correlated directly with most elements in the high Fe-low As group. Gold only correlated directly with Fe and As in the low Fe-high As group.

Three samples often did not plot on the regression lines. They were samples B-725-740, C-700-710 and D-549-555. Each of these samples is from the bottom of the peat deposit. These samples are in the low Fe-high As group and they generally reduce the correlation coefficients for that group as well as for all samples. Figure 9 shows some correlations showing this effect.

SUMMARY

The association of most elements with each other is probably controlled by ground water both as a nutrient for the plants and an environment for their degradation. Correlation coefficients are, in general, not extremely high because several geochemical processes occur influencing the correlation coefficients.

The similarities in concentrations between the average peat concentrations and the Appalachian bituminous coal indicate that this peat may represent a good modern analog for trace element distribution in Appalachian coal, which is known to have been formed from tropical peat. If this is true, the trace element concentrations remain similar throughout diagenesis. This also suggests that the trace element contribution from plants, groundwater and detrital influence in this analog is similar to that of coal or, alternatively, all change which takes place in trace element concentration occurs during early degradation processes. The similarity between the average concentrations may be ash related (the average ash for the Appalachian coal is 11.9% compared to 14.2% for this peat) or may be purely coincidental. More detailed comparisons to specific coal beds in the Appalachian basin which were known to have similar influences need to be assessed in order to judge the significance of these observations.

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Table 1. Peat quality data--Peat classification, moisture pH and ash.

Core-Top Depth -Bottom Depth (cm)	Percent Moisture* (PM)	Percent Ash (Dry)* (PA)	Percent Moisture Ash Free (PMAF)	Acidity pH*	Peat Classification
A-21-36	63.63	60.86	81.71	4.71	Peaty Clay
A-36-50	79.50	32.14	85.21	4.65	Clayey Peat
A-100-150	86.78	19.40	89.56	5.74	Sapric Peat
A-150-180	81.13	65.44	92.55	4.90	Peaty Clay
A-180-200	85.55	34.92	90.09	4.62	Clayey Peat
A-220-250	88.38	13.14	89.75	4.13	Sapric Peat
A-250-300	93.54	32.93	95.52	4.30	Clayey Peat
A-300-350	89.60	9.81	90.52	4.24	Hemic Peat
A-400-450	91.13	3.94	91.44	4.62	Hemic Peat
A-450-500	90.10	4.52	90.45	4.64	Hemic Peat
A-500-550	91.14	5.17	91.55	4.94	Hemic Peat
A-600-650	91.14	24.15	93.56	5.24	Hemic Peat
B-200-255	88.55	20.33	90.66	4.20	Hemic Peat
B-400-450	85.90	6.03	86.63	4.40	Hemic Peat
B-600-650	92.75	4.12	93.03	4.16	Hemic Peat
B-700-725	91.02	6.86	91.58	4.52	Hemic Peat
B-725-740	48.41	78.50	80.35	4.20	Peaty Clay
C-100-150	93.73	1.53	93.82	3.28	Sapric Peat
C-200-250	89.00	0.75	89.01	2.88	Hemic Peat
C-400-450	90.64	0.72	90.65	3.38	Hemic Peat
C-500-550	89.20	0.49	89.21	3.78	Hemic Peat
C-700-710	67.77	63.77	85.30	3.97	Peaty Clay
D-130-155	93.29	2.18	93.42	3.24	Hemic Peat
D-155-180	90.63	5.85	91.12	3.77	Hemic Peat
D-430-480	94.64	2.86	94.78	3.28	Hemic Peat
D-540-549	90.66	7.91	91.33	4.41	Hemic Peat
D-549-555	57.03	65.20	79.23	4.73	Peaty Clay
E-200-250	92.60	2.35	92.76	3.60	Hemic Peat
E-400-450	91.47	1.79	91.60	3.36	Hemic Peat
E-500-525	88.64	13.24	90.03	3.81	Hemic Peat
I-100-150	93.97	5.97	94.30	3.14	Hemic Peat

*Data taken from Cameron and others (1987).
**PMAF = (PM/(100-(100-PM)(PA/100)))100

Table 2. Instrumental neutron activation analysis of some Indonesian peat samples.

Core-Top Depth -Bottom Depth	Na (%)	K (%)	Sc (ppm)	Cr (ppm)	Fe (%)	Co (ppm)	Zn (ppm)	As (ppm)	Se (ppm)	Br (ppm)
A-21-36	0.142	0.830	17.3	46.5	1.15	4.47	49.7	3.62	1.77	3.14
A-36-50	0.0593	0.351	12.0	27.2	0.793	3.15	36.7	4.46	0.974	5.74
A-100-150	0.0497	0.281	8.27	20.4	0.619	3.95	23.8	8.19	0.817	10.9
A-150-180	0.0925	0.808	15.5	41.5	1.23	5.55	42.9	8.24	< 1.14	8.53
A-180-200	0.0499	0.362	12.4	30.4	0.790	4.21	30.9	9.11	1.54	12.9
A-220-250	0.0558	0.454	11.1	27.1	0.752	4.67	31.4	11.3	1.44	14.9
A-250-300	0.0513	0.382	10.2	24.1	0.703	4.58	29.2	42.7	1.29	14.5
A-300-350	0.0343	0.177	7.59	20.4	0.571	3.22	22.1	15.2	1.61	10.3
A-400-450	0.0233	0.0965	2.98	7.78	0.877	5.01	15.1	146.	1.52	16.3
A-450-500	0.0167	< 0.0760	2.08	5.42	0.874	4.46	11.9	62.8	1.64	17.1
A-500-550	0.0179	0.0609	1.85	4.93	0.466	2.41	11.2	18.2	0.783	11.8
A-600-650	0.0290	0.0988	4.71	22.6	1.54	3.01	22.8	97.5	1.84	25.9
B-200-255	0.0374	0.316	9.96	23.8	0.503	2.99	33.5	9.02	1.08	15.8
B-400-450	0.0120	0.0360	2.59	5.75	0.248	2.50	28.7	253.	1.01	10.3
B-600-650	0.0117	0.0676	2.56	6.69	0.296	2.00	49.8	674.	1.16	12.7
B-700-725	0.0124	0.0349	4.57	11.8	0.969	2.77	17.9	44.9	2.46	23.1
B-725-740	0.0508	0.354	9.89	57.7	1.21	2.74	25.9	4.12	< 0.505	0.754
C-100-150	0.0120	0.0402	0.275	0.742	0.163	0.226	11.6	449.	1.16	28.9
C-200-250	0.00565	< 0.0318	0.570	2.08	0.0941	0.542	5.76	132.	2.03	22.5
C-400-450	0.00612	< 0.0435	0.800	4.00	0.236	1.14	30.3	433.	1.55	21.1
C-500-550	0.0101	0.0244	0.939	2.25	0.172	1.21	9.89	7.09	0.998	13.6
C-700-710	0.0370	0.276	7.26	56.2	0.544	1.48	20.2	5.92	< 1.02	2.53
D-130-155	0.0314	< 0.0969	0.288	1.61	0.0693	0.314	8.88	4.09	2.00	33.9
D-155-180	0.0107	0.0480	1.33	8.03	0.217	0.735	20.4	806.	1.36	23.1
D-430-480	0.0123	< 0.0654	0.484	4.08	0.418	2.83	135.	2220.	2.17	31.4
D-540-549	0.00781	0.0223	1.14	10.4	0.311	1.31	12.3	2.60	1.54	16.0
D-549-555	0.0314	0.212	4.90	66.5	0.341	1.20	11.5	12.0	1.01	4.32
E-200-250	0.00549	< 0.0324	0.228	1.45	0.120	0.750	18.6	179.	2.06	31.9
E-400-450	0.00635	< 0.0435	0.706	11.1	0.231	1.37	9.11	1.48	1.73	18.5
E-500-525	0.00696	0.0265	0.327	5.14	0.193	1.00	54.0	132.	1.55	19.5
I-100-150	0.0176	0.0577	1.21	4.31	0.126	0.442	6.76	1.88	1.56	49.6
Average Peat*	0.0306	0.226(0.22)	5.03	18.1	0.543	2.46	27.0	187	1.49	17.1
Average Coal**	0.0350***	0.231***	4.0	17	1.46***	7.9	25	18	3.8	19.8***
Range Peat	0.00549-0.142	0.0324-0.830	0.2-17	1.5-66	0.069-1.23	0.23-5	6.7-135	1.5-2220	<0.5-2.2	0.075-49
Range Coal	0.0006-0.4465	0.0016-2.00	0.6-27	2.3-84	0.0073-10.1	0.8-90	1.3-1600	<1-170	<0.6-20	0.05-164
Geo. Mean Peat	0.0209	0.128	2.51	10.1	0.403	1.85	21.0	29.9	1.43	13.3
Geo. Mean Coal	---	----	3.3	14	----	6.2	14	8.4	2.8	--

* For elements with more than 20% upper limits alternate averages (shown in parentheses) were calculated from correlation equation for lines with the element with the highest r value which had no upper limits: K vs Na, r=0.96;

** Data from Zubovic and others (1980) for 644 eastern U.S. bituminous coals unless otherwise noted.

*** Data from NCRDS for approximately 3000 coals from Appalachian basin with values greater than zero and ash less than 50 %. (Oman, 1987)

Table 2. Instrumental neutron activation analysis of some Indonesian peat samples.

Core-Top Depth -Bottom Depth	Tb (ppm)	Yb (ppm)	Lu (ppm)	Hf (ppm)	Ta (ppm)	W (ppm)	Au (ppb)	Hg (ppm)	Th (ppm)	U (ppm)
A-21-36	0.561	2.65	0.312	4.02	1.09	3.02	----	< 0.920	11.1	2.75
A-36-50	0.556	2.21	0.266	1.78	0.416	1.40	----	1.20	6.70	1.61
A-100-150	0.287	1.22	0.164	1.47	0.344	1.09	----	< 0.429	5.54	1.26
A-150-180	0.433	1.98	0.229	3.46	0.880	2.82	3.35	0.815	10.1	2.65
A-180-200	0.427	1.74	0.211	2.16	0.475	1.47	----	< 0.529	7.87	1.78
A-220-250	0.331	1.54	0.173	2.07	0.505	1.61	----	< 0.639	7.10	1.87
A-250-300	0.333	1.34	0.183	1.79	0.426	0.784	< 4.27	< 0.747	6.58	1.55
A-300-350	0.216	1.07	0.156	1.59	0.329	1.10	2.75	< 0.428	5.88	1.47
A-400-450	0.167	0.605	0.0692	0.465	0.0731	< 0.978	----	0.413	2.01	0.609
A-450-500	0.145	0.621	0.0711	0.296	0.107	< 0.868	3.16	0.433	1.55	< 0.651
A-500-550	0.101	0.352	0.0600	0.301	0.0824	< 0.755	----	0.271	1.35	0.350
A-600-650	0.144	0.874	0.0930	2.10	0.325	1.03	3.78	0.425	4.53	1.15
B-200-255	0.320	1.41	0.190	1.87	0.411	1.14	----	0.705	6.33	1.71
B-400-450	0.141	0.663	0.0629	0.353	0.0714	< 0.643	14.0	< 0.289	1.70	< 0.857
B-600-650	0.117	< 1.29	< 0.182	0.374	0.105	< 0.966	27.2	0.494	1.83	< 1.39
B-700-725	0.123	0.649	0.0460	0.554	0.102	< 0.645	----	< 0.430	4.29	0.674
B-725-740	0.399	2.62	0.322	9.75	1.32	2.72	----	< 0.706	8.60	2.89
C-100-150	< 0.0309	< 1.07	< 0.149	0.0900	< 0.0747	< 0.853	12.6	0.255	0.173	< 1.17
C-200-250	< 0.0241	< 0.658	< 0.0987	0.235	0.0596	0.859	3.89	0.279	0.641	< 0.768
C-400-450	0.0477	< 1.09	< 0.0978	0.199	0.0493	< 0.870	16.8	< 0.435	0.757	< 1.20
C-500-550	0.0767	0.297	0.0350	0.152	0.0369	< 0.441	----	< 0.342	0.872	0.227
C-700-710	0.377	2.37	0.289	8.80	1.16	2.39	----	< 0.410	10.7	2.64
D-130-155	< 0.0431	< 0.538	< 0.0861	0.0545	0.0428	< 0.969	----	0.645	0.167	< 0.646
D-155-180	0.0495	< 1.60	< 0.245	0.908	0.153	< 0.958	32.1	0.358	1.52	< 1.70
D-430-480	< 0.0327	< 2.72	< 0.436	0.293	0.0467	< 1.85	111.	0.373	0.419	< 2.83
D-540-549	0.0664	0.434	0.0462	1.27	0.150	0.415	----	< 0.271	1.51	0.514
D-549-555	0.422	2.48	0.337	12.1	1.12	2.19	----	< 0.405	8.07	2.31
E-200-250	< 0.0324	< 0.756	< 0.108	0.0819	< 0.0648	< 0.648	9.13	0.423	0.111	< 0.864
E-400-450	0.0495	0.361	< 0.0653	0.620	0.0810	< 0.653	----	< 0.435	0.898	< 0.544
E-500-525	< 0.0295	< 0.738	< 0.105	0.572	0.0688	< 0.738	5.12	0.334	0.316	< 0.843
I-100-150	0.0527	< 0.542	0.0404	0.414	0.151	< 0.976	----	0.473	0.930	< 0.651
Average Peat*	0.238	1.31(0.91)	0.160(0.11)	1.94	0.351	1.60(0.91)	18.8	0.493	3.88	1.56(1.2)
Average Coal**	0.32	0.98	0.17	0.8	0.24***	0.92***	----	0.23	3.01***	1.8
Range Peat	<0.024-5	<0.3-2.7	<0.5	0.05-12	<0.06-1.12	<0.44-2.8	<4-111	<0.3-0.81	0.11-11	0.72-63.8
Range Coal	<0.01-2	<0.2-4.8	<0.1-0.8	<0.1-4	---	---	---	0.1-1.8	0.19-48	1.7-45.9
Geo. Mean Peat	0.178	1.05	0.125	0.795	0.194	1.40	9.58	0.450	2.03	6.66
Geo. Mean Coal	0.26	0.84	0.15	0.61	----	---	----	0.12	2.31	9.76

* For elements with more than 20% upper limits alternate averages (shown in parentheses) were calculated from correlation equation for lines with the element with the highest r value which had no upper limits: Yb vs La, r=0.93; Lu vs La, r=0.92; W vs Cr, r=0.84; U vs Cr, r=0.92.

** Data from Zubovic and others (1980) for 644 eastern U.S. bituminous coals unless otherwise noted.

*** Data from NCRDS for approximately 3000 coals from Appalachian basin with values greater than zero and ash less than 50 %. (Oman, 1987)

Table 2. Instrumental neutron activation analysis of some Indonesian peat samples.

Core-Top Depth -Bottom Depth	Rb (ppm)	Sr (ppm)	Sb (ppm)	Cs (ppm)	Ba (ppm)	La (ppm)	Ce (ppm)	Nd (ppm)	Sm (ppm)	Eu (ppm)
A-21-36	55.3	< 112.	1.39	7.96	302.	26.8	43.8	< 30.7	4.24	0.839
A-36-50	23.8	< 138.	1.43	3.41	155.	22.5	44.9	20.2	4.50	1.03
A-100-150	16.7	< 107.	1.05	2.77	< 193.	13.9	24.7	< 16.1	2.61	0.537
A-150-180	55.0	< 146.	1.07	7.05	270.	20.0	35.6	< 31.2	3.48	0.689
A-180-200	27.4	< 127.	0.997	4.11	118.	18.0	34.0	< 29.6	3.54	0.739
A-220-250	32.8	< 117.	1.05	5.20	< 202.	15.9	27.4	< 20.2	2.85	0.578
A-250-300	28.8	< 117.	0.961	4.31	110.	14.9	26.0	< 30.9	2.73	0.546
A-300-350	17.0	< 107.	1.16	4.33	103.	10.7	17.6	< 25.7	1.88	0.381
A-400-450	< 11.4	< 76.1	0.554	0.646	< 196.	6.49	12.1	< 29.3	1.44	0.304
A-450-500	< 11.1	< 65.1	0.528	0.336	< 174.	5.15	10.3	< 26.0	1.20	0.238
A-500-550	< 9.48	< 64.7	0.274	0.555	< 140.	3.45	6.56	< 20.5	0.708	0.155
A-600-650	10.5	< 85.3	0.402	1.64	< 192.	8.35	15.8	< 28.8	1.34	0.251
B-200-255	25.3	< 118.	1.07	4.82	< 215.	15.4	26.0	< 31.1	2.77	0.562
B-400-450	< 9.21	< 75.0	0.410	0.680	< 246.	6.36	11.6	< 32.1	1.28	0.268
B-600-650	6.16	< 75.1	0.490	0.724	< 429.	5.20	8.78	< 53.6	0.959	0.211
B-700-725	< 10.3	< 86.0	0.290	0.711	< 194.	8.23	15.9	< 29.0	1.32	0.236
B-725-740	27.2	< 90.8	0.833	4.52	104.	17.6	30.5	12.5	2.57	0.457
C-100-150	< 4.97	< 28.8	0.185	0.0868	< 331.	0.540	< 0.747	< 42.7	0.0718	0.0136
C-200-250	< 5.29	< 43.9	0.191	< 0.0768	< 230.	0.866	0.905	< 32.9	0.114	0.0307
C-400-450	< 7.35	< 54.3	0.350	0.0564	< 337.	1.93	3.78	< 43.5	0.341	0.0723
C-500-550	< 7.43	< 44.1	0.173	< 0.0882	< 143.	3.16	5.62	< 20.9	0.685	0.154
C-700-710	22.0	< 82.0	0.962	2.81	< 143.	15.0	26.1	< 20.5	2.24	0.381
D-130-155	< 5.38	< 43.1	0.0950	< 0.0754	< 237	0.365	< 1.61	< 32.3	0.0373	0.0146
D-155-180	< 9.39	< 63.8	0.330	0.498	< 532.	1.77	2.80	< 74.5	0.267	0.0585
D-430-480	< 9.09	< 54.5	0.880	0.175	< 871.	1.20	2.23	< 120.	0.239	< 0.0327
D-540-549	< 8.03	< 65.0	0.200	0.193	< 173.	3.00	4.73	< 27.1	0.467	0.0654
D-549-555	16.2	< 70.9	0.937	1.97	89.1	20.3	38.0	< 23.3	3.17	0.502
E-200-250	< 5.24	< 32.4	< 0.200	< 0.0648	< 248.	0.381	< 1.19	< 32.4	0.0553	< 0.0292
E-400-450	< 7.94	< 54.4	0.118	0.0918	< 174.	2.43	4.09	< 27.2	0.292	0.0478
E-500-525	< 7.06	< 42.2	0.138	0.0708	< 232.	1.07	1.44	< 31.6	0.152	0.0318
I-100-150	< 7.02	< 54.2	0.148	0.443	< 195.	2.44	3.61	< 28.2	0.322	0.0630
Average Peat*	26.0 (12)	-----	0.623	2.23	156 (81)	8.82	17.3	16.4(-)	1.54	0.326
Average Coal**	28.2***	90	1.0	1.1	68	11	20	9.8	1.9	0.39
Range Peat	<7-55	<150	0.15-1.43	<0.06-8	<900	0.4-20	<0.8-45	<120	0.037-4.5	<0.3-1
Range Coal	2-141	3.9-920	<0.1-7.4	<0.1-8	4.3-570	<1-58	0.44-110	<1-60	0.4-14	<0.8-3.1
Geo. Mean Peat	22.5	---	0.466	0.968	141	4.91	11	15.9	0.818	0.190
Geo. Mean Coal	24.1	65	0.73	0.66	48	8.8	16	3.7	1.6	0.33

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* For elements with more than 20% upper limits alternate averages (shown in parentheses) were calculated from correlation equation for lines with the element with the highest r value which had no upper limits: Rb vs Sc, r=0.93; Ba vs Na, r=0.95; Sr all values upper limits and Nd only 2 values no correlations calculated.

** Data from Zubovic and others (1980) for 644 eastern U.S. bituminous coals unless otherwise noted.

*** Data from NCRDS for approximately 3000 coals from Appalachian basin with values greater than zero and ash less than 50 %. (Oman, 1987)

Table 3. Heating value, acidity, proximate and ultimate analysis of samples in Cores A, B, C, D, E, I. Data taken from Cameron and others (1987).

Core-Top Depth-Bottom Depth	Heating Value BTU/lb Moisture Free	Acidity (pH)	Moisture Free							
			Proximate analysis			Ultimate analysis				
			Ash %	Volatile Matter %	Fixed Carbon %	Hydrogen %	Carbon %	Nitrogen %	Sulfur %	Oxygen %
A-50-100	7,665	5.01	25.11	45.71	29.18	3.99	43.86	0.79	0.56	25.67
A-350-400	10,353	4.75	9.45	58.49	32.06	5.01	56.21	1.02	0.45	27.84
A-550-600	9,932	5.44	8.46	59.32	32.22	5.02	56.00	0.97	0.37	36.39
B-100-150	9,425	3.63	8.66	55.72	35.62	4.58	55.41	1.05	0.26	30.01
B-300-350	9,543	4.01	11.31	54.75	33.94	4.81	53.65	0.91	0.49	28.80
B-500-550	10,088	4.58	6.24	58.44	35.32	5.06	57.19	1.04	0.46	29.99
C-300-350	10,983	3.50	1.27	63.68	35.05	5.06	61.02	1.05	0.21	31.36
C-600-650	10,538	3.84	2.47	61.04	26.49	5.13	60.07	0.96	0.28	31.07
D-230-280	10,212	3.14	1.90	62.63	35.47	5.00	59.07	1.17	0.09	---
E-100-150	11,108	3.54	1.78	63.38	34.84	5.44	61.89	1.07	0.08	29.71
E-300-350	10,705	3.23	2.44	60.43	37.13	5.02	60.00	1.05	0.10	30.38
I-150-200	10,735	3.12	1.91	59.36	38.73	4.98	60.26	0.9	0.73	31.19

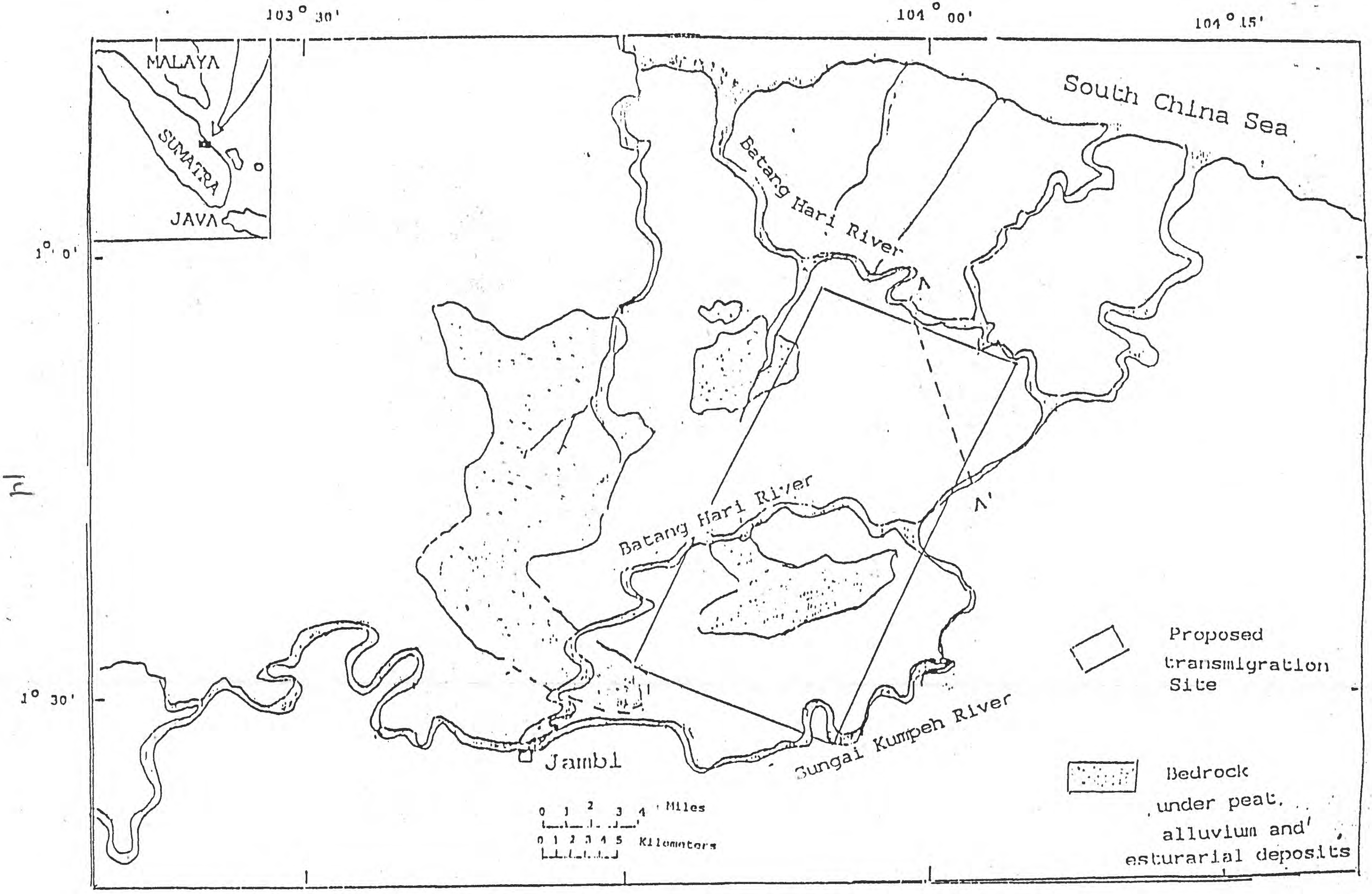

Figure 1. Location of Study Area showing position of cross section along Traverse A-A' (Adapted from Cameron and others, 1987)

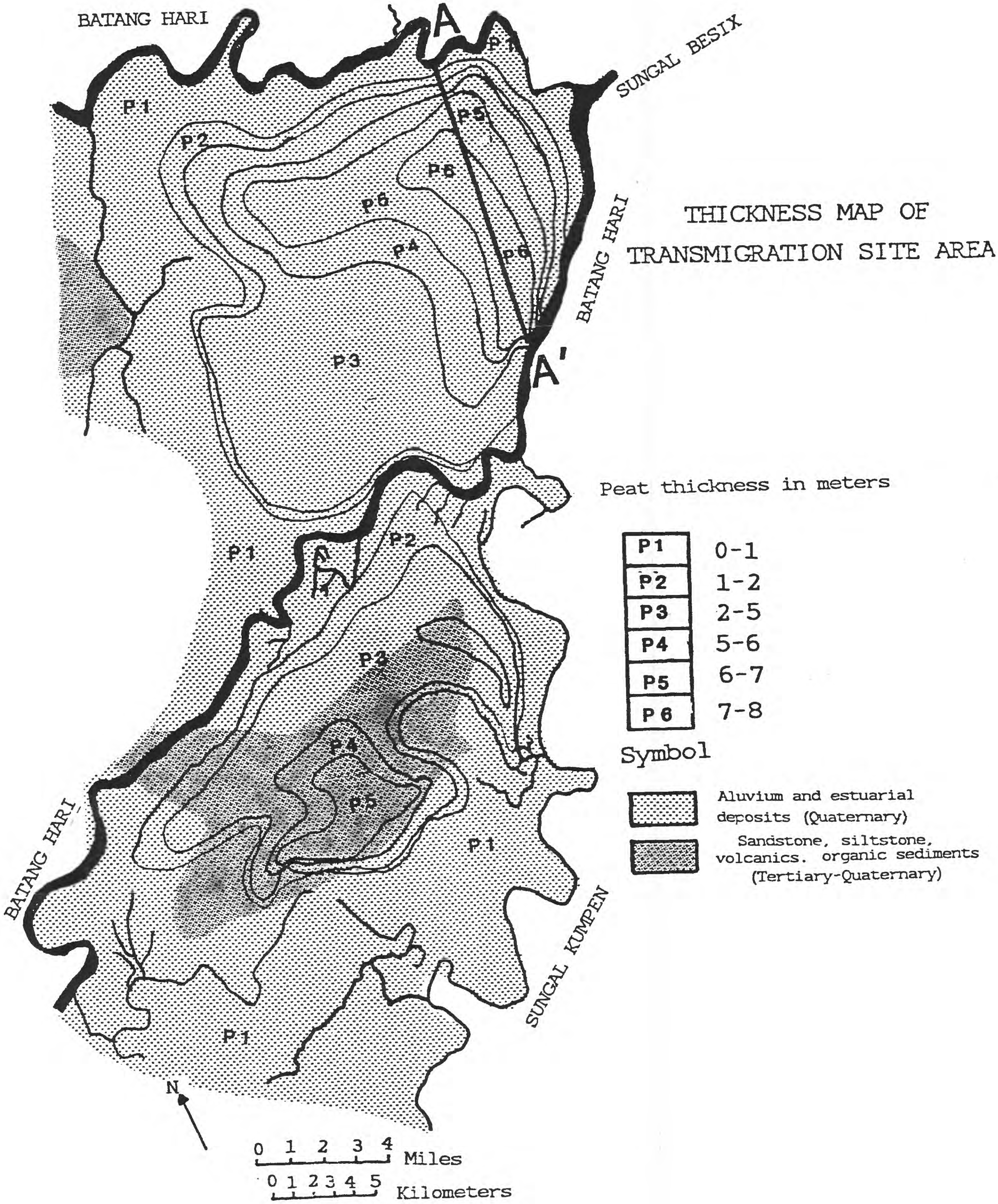

Figure 2. Geology and Peat Thickness map. (Adapted from Cameron and others, 1987)

JAMBI CROSS SECTION A-A'
SUMATRA

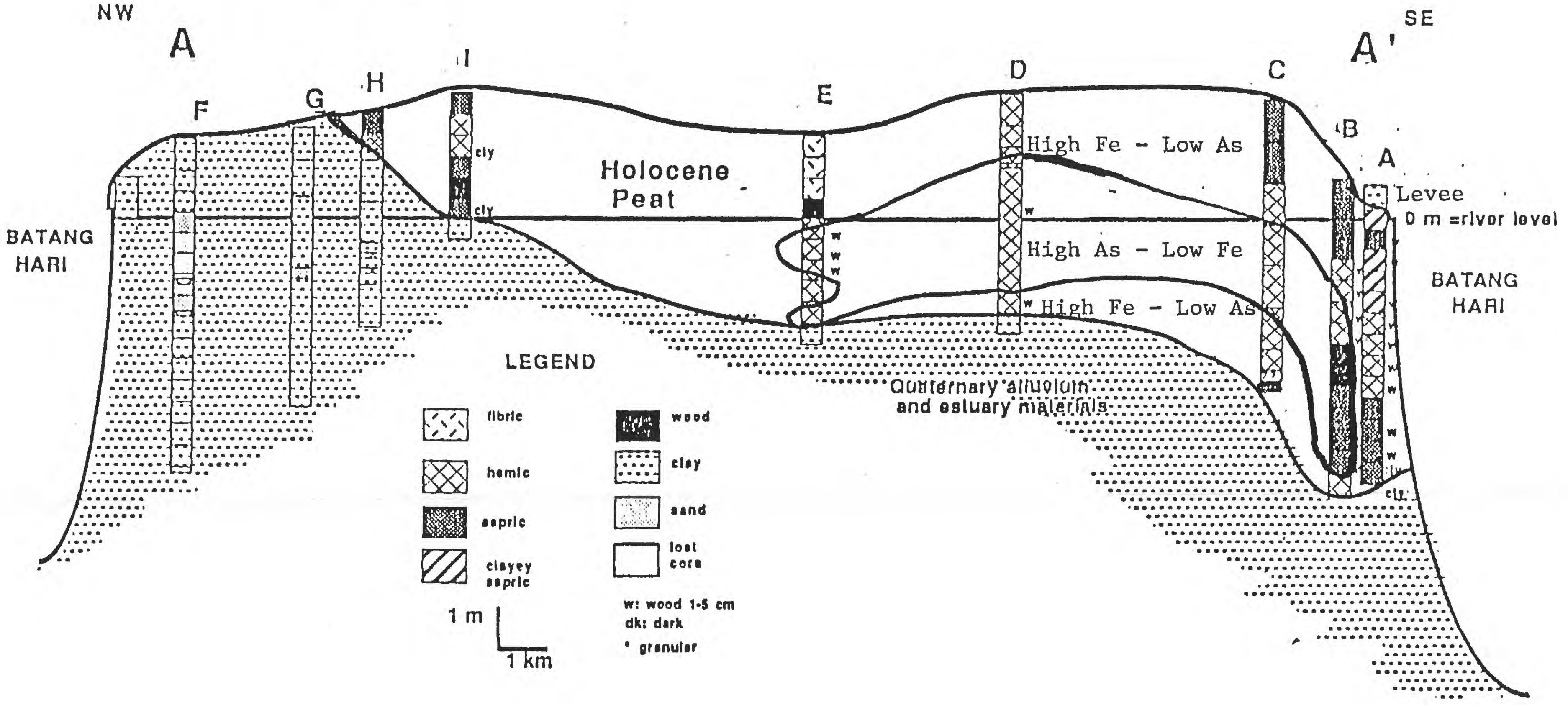

Figure 3.Cross section along A-A' (Adapted from Cameron and others, 1987)

	Na	K	Sc	Cr	Fe	Co	Zn	As	Se	Br	Rb	Sb	Cs	Ba	La	Hf	Ta	W	Au	Hg	Th	U
K	■																					
Sc	■	■																				
Cr	▥	▥	▥																			
Fe	▥	▥	▥	▥																		
Co	▥	▥	▥	□	▥																	
Zn	⊙	□	⬢	◇	⊙	⊙▽																
As					△◇		△▥															
Se			−▽																			
Br	−▥	−□	−▥	−▥	−□	−□	−◇	−▽	−□													
Rb	■	■	□			□	⊙															
Sb	▥	▥	▥	▥	▥	▥	□			−▥	□											
Cs	■	■	■	▥	▥	▥	⬢			−▥	■	▥										
Ba	■	■	▥				⊙				■		■									
La	▥	▥	■	▥	▥	▥	⊙	−□		−▥	▥	▥	▥	▥								
Hf	□		□	▥						−▥		□	□		▥							
Ta	▥	▥	▥	■	□		◇			−▥		▥	▥		▥	■						
W	▥	▥	□	▥						−▥	□		◇		▥	□	■					
Au					△◇	▽	▥	▲■					△									
Hg	▥	□	▥	▥			◇					▥	▥		▥	□	□					
Th	▥	▥	■	■	▥	▥	⊙	−□		−▥	▥	▥	▥	□	■	▥	▥	▥		▥		
U	▥	▥	▥	■			⊙			−▥	□	▥	▥		▥	▥	■	■			■	
Ash	▥	▥	▥	▥	▥	▥	⊙			−□	□	▥	▥	▥	▥	□	▥	□		▥	▥	□
	Na	K	Sc	Cr	Fe	Co	Zn	As	Se	Br	Rb	Sb	Cs	Ba	La	Hf	Ta	W	Au	Hg	Th	U

KEY	
■	r>0.9; All Samples
▥	LC>99.5; r<0.9; All Samples
□	LC>95<99.5; All Samples
▲	r>0.9; High As-Low Fe Group
△	LC>99.5; r<0.9; High As-Low Fe
▽	LC>95<99.5; High As-Low Fe
⬢	r>0.9; High Fe-Low As Group
⊙	LC>99.5; r<0.9; High Fe-Low As
◇	LC>95<99.5; High Fe-Low As
−	Negative Correlation e.g. r<0

Figure 4. Correlation diagram for elements and Ash for 31 Indonesian peat samples of this study. LC is the level of confidence of the correlation; r is the correlation coefficient. When only an upper limit or no value was calculated for either element of an element pair the values were ignored in the correlation which reduced the number of samples for the correlation. If an element pair did not correlate for all samples above the detection limit at the 95 percent confidence level, correlations were attempted on high-As low-Fe (9 samples) and the high-Fe low-As (22 samples) subgroups. Element pairs for which all or nearly all samples of a subgroup were absent due to one or both elements being below the detection limit show the symbol for the correlation of the whole group and the subgroup. All others show correlations of either the whole group or one or both subgroups.

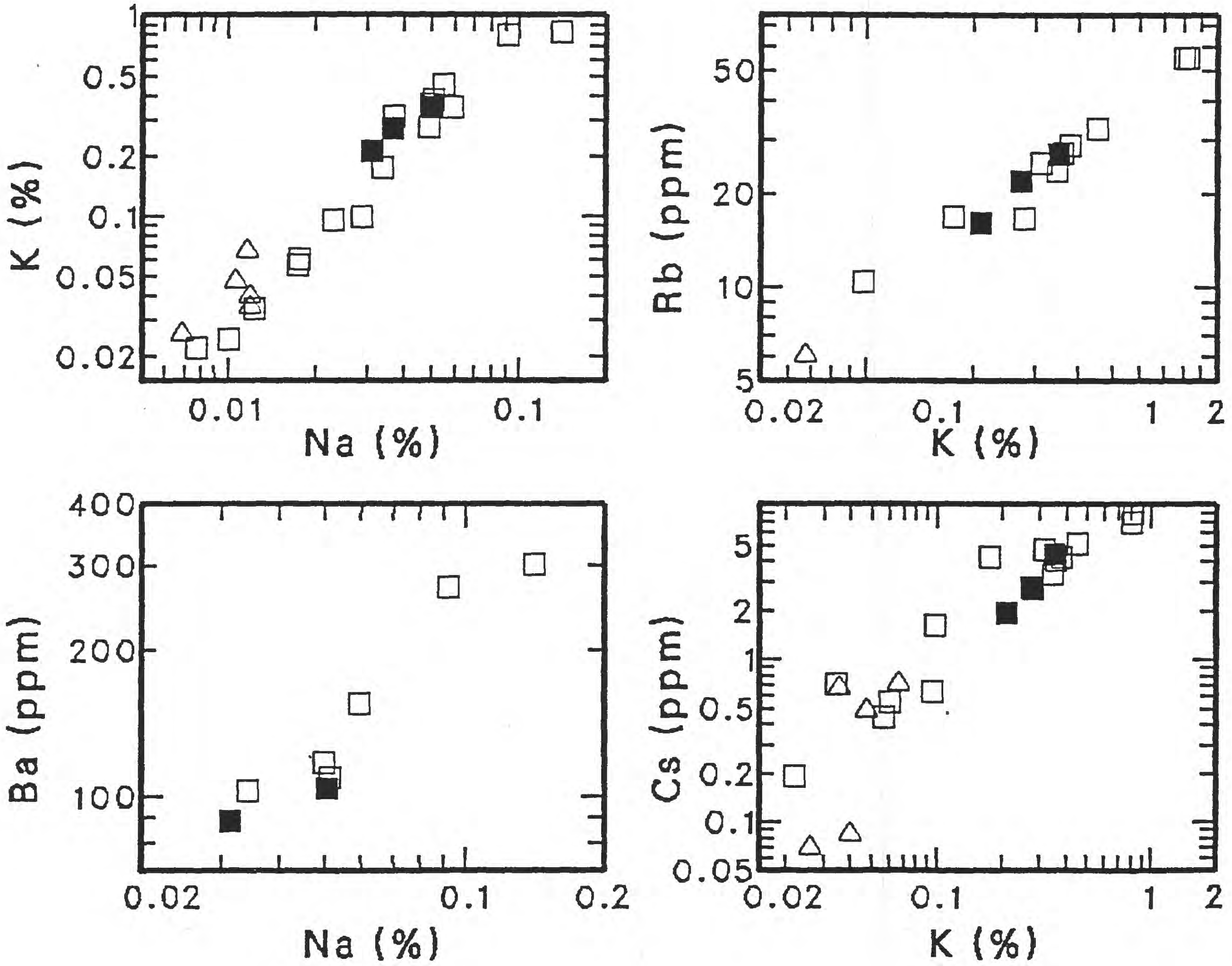

Figure 5. Selected scatter diagrams of alkali and alkaline earth elements.

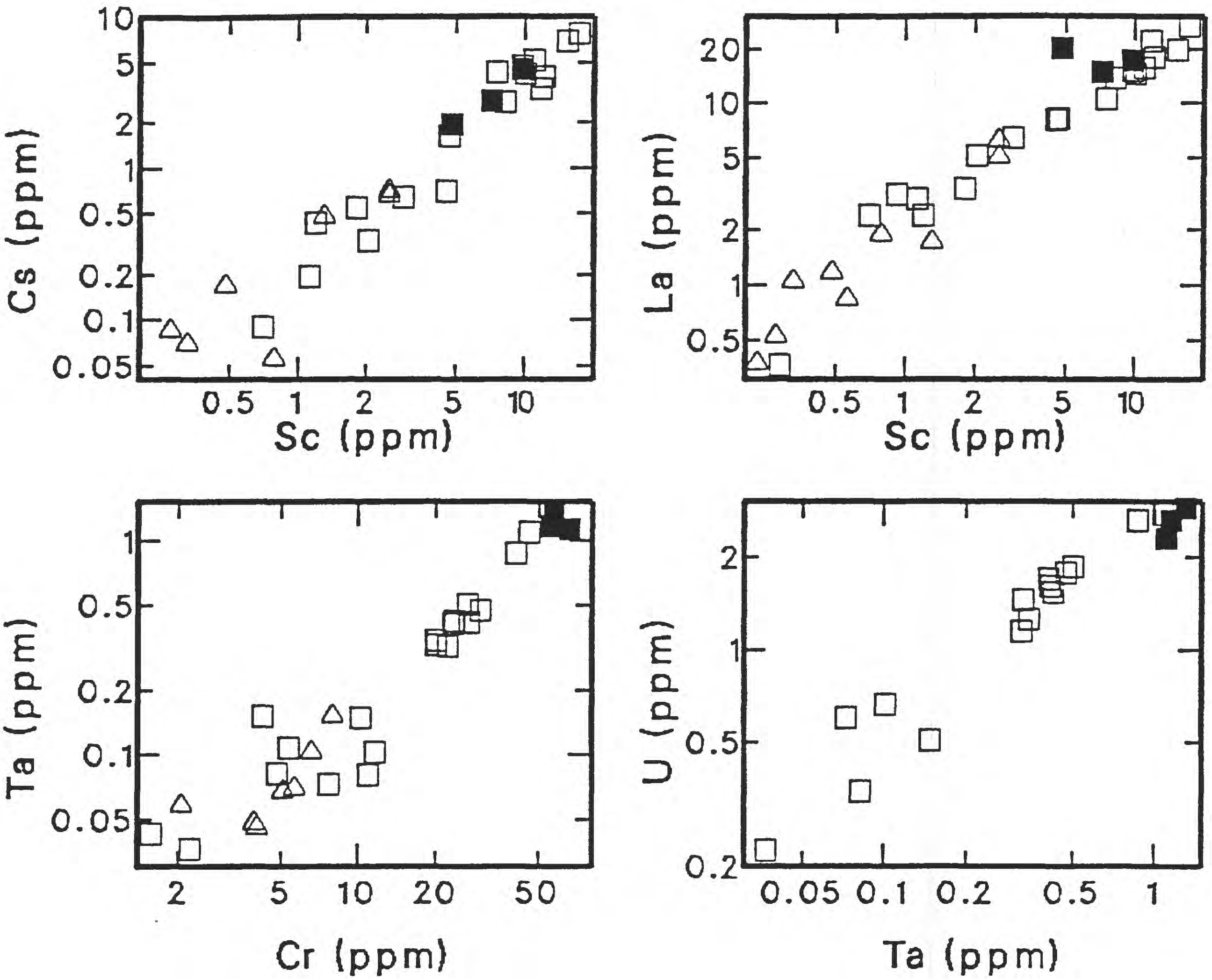

Figure 6. Selected scatter diagrams with correlation coefficients greater than 0.9 for both original and log transformed data.

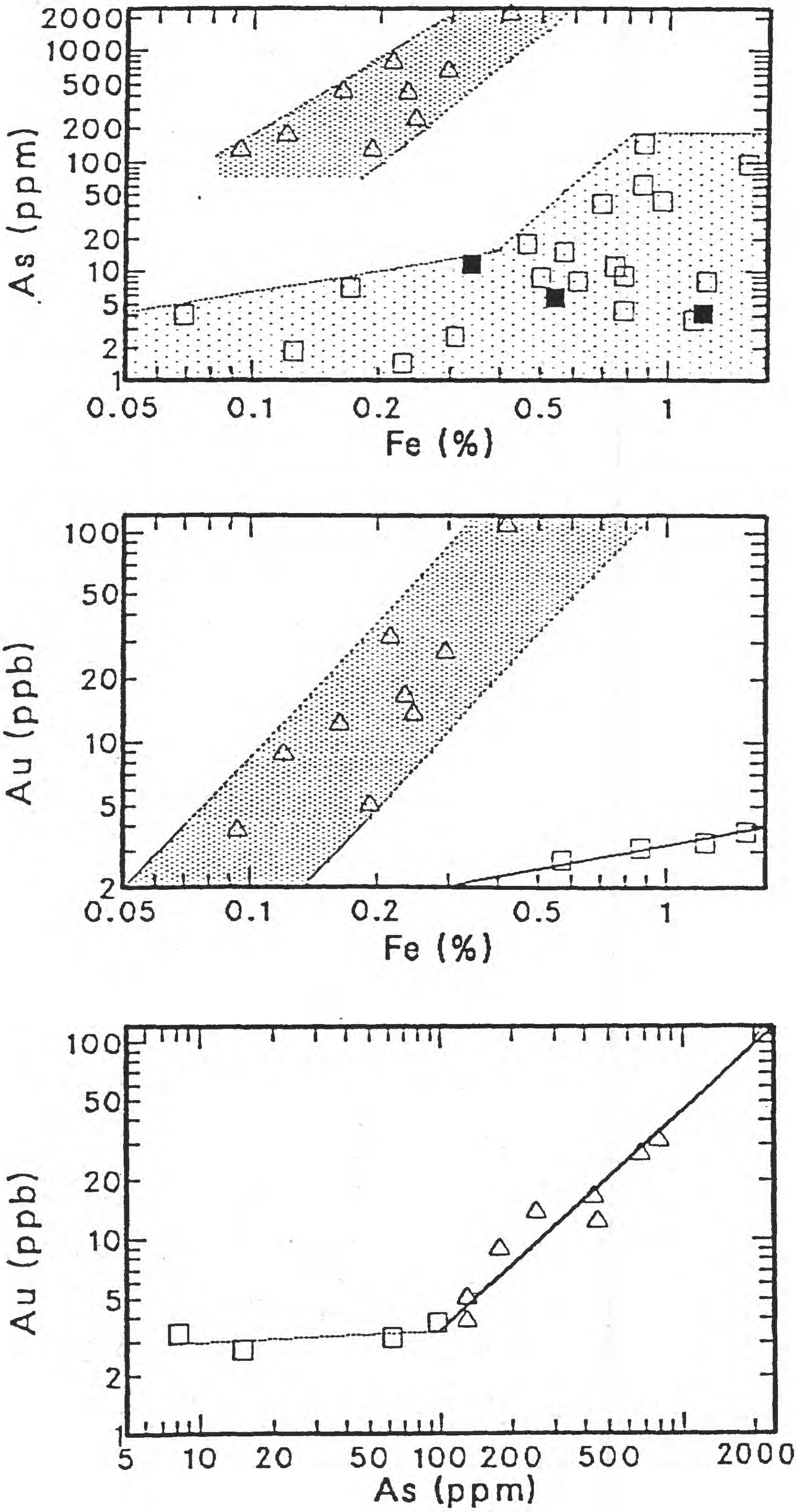

Figure 7. Correlations of Fe, As and Au showing 2 separate areas or regression lines for the two sample subgroups (high As-low Fe; triangles and high Fe-low As; all other samples)

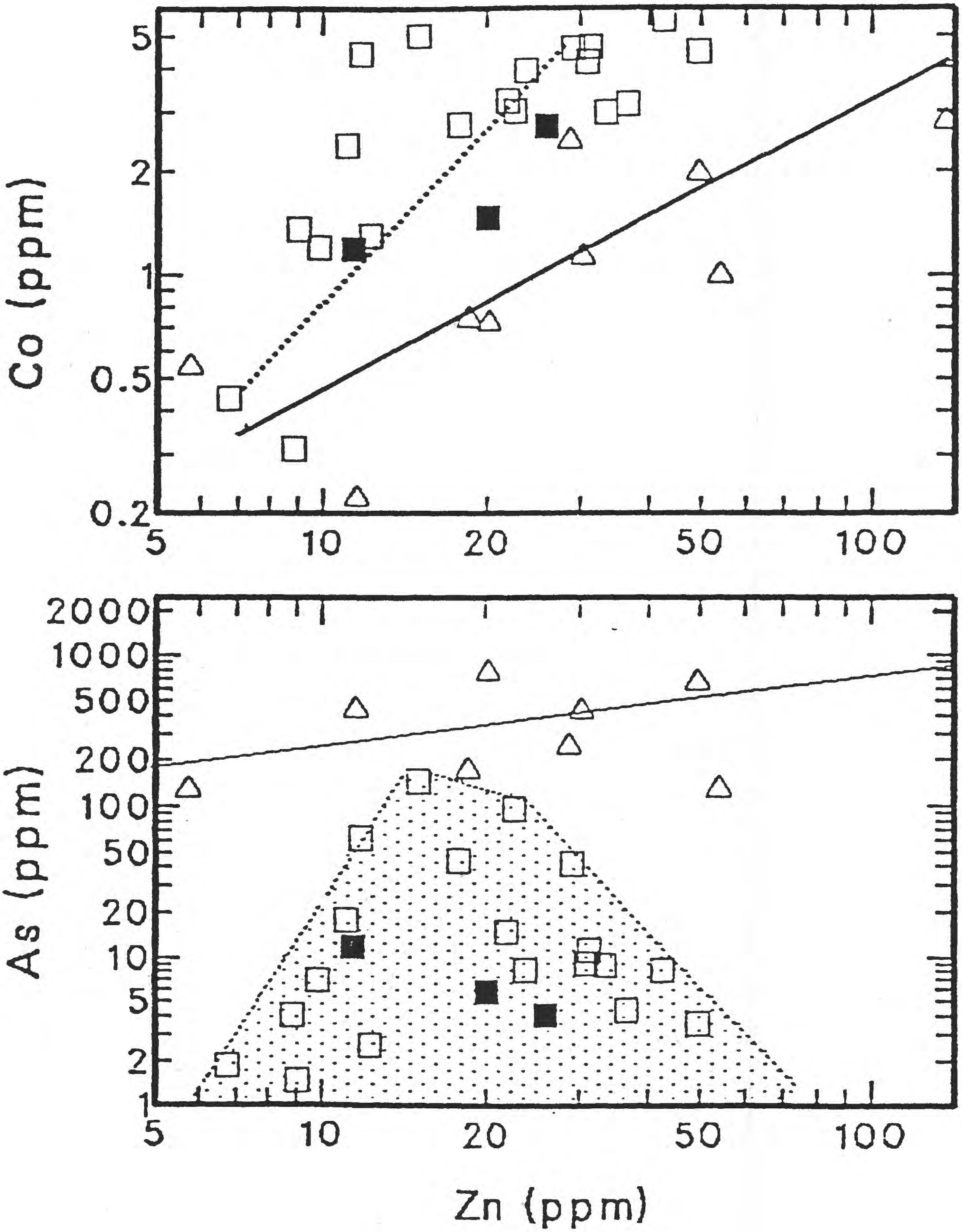

Figure 8. Co vs. Zn and As vs. Zn showing two possible correlations lines for the two sample subgroups (high As-low Fe; triangles and high Fe-low As; all other samples)

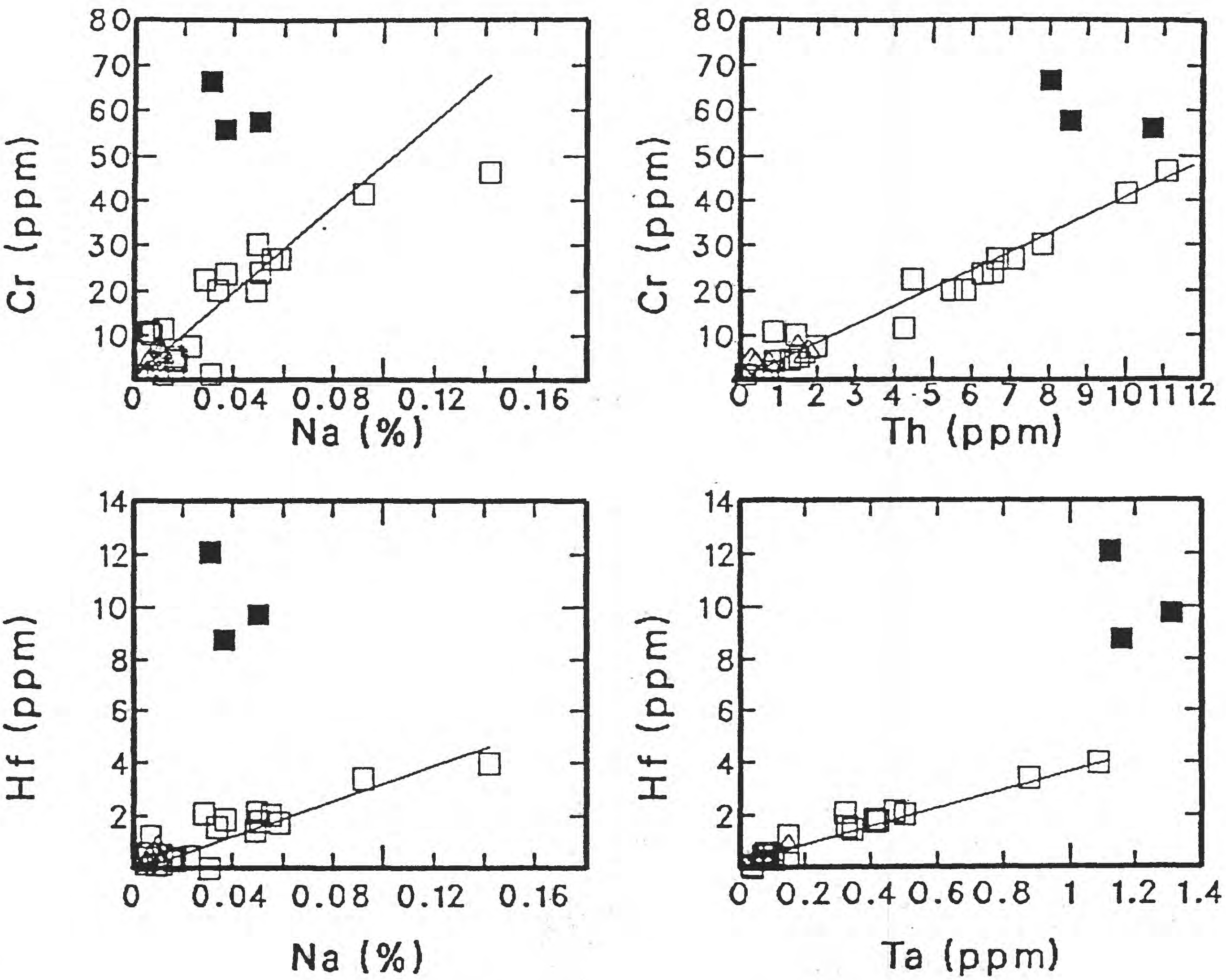

Figure 9. Selected correlations showing the bottom samples of cores B, C, and D (solid squares) fall off the regression line (calculated for all samples except these three samples) for several element pairs.