PRELIMINARY ANALYSES OF COAL REFUSE MATERIAL FROM VANCOUVER ISLAND

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ABSTRACT

The first period of coal mining on Vancouver Island lasted from 1847 to 1967, and during that period, waste material from the coal cleaning accumulated in a number of areas along the east coast of Vancouver Island. Three of these areas were sampled and analysed for coal related properties, major oxides, and trace metals. Results indicate that the material is generally similar in composition to average shale.

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Key Words: Waste coal, trace metals, coal refuse, Vancouver Island.

THE EARLY VANCOUVER ISLAND COAL INDUSTRY

Coal mining on Vancouver Island started in 1847 near Port Hardy on the northeast coast. Subsequently mining moved south to the Nanaimo and Cumberland areas, where activity continued until 1967. This early period of coal mining activity has left a legacy of coal mine waste. There are a number of coal refuse piles on Vancouver Island, especially in the Nanaimo area, and the total accumulation may be as high as 2.5 million tonnes (Gardner 1997).

The early mines removed rock from raw coal using simple wash plants and hand picking tables to remove large rock fragments. This produced a waste product composed of large fragments of rock and high-ash coal and referred to as coarse rejects. In some areas where clean coal was being loaded onto barges, some fell off conveyors or trains to accumulate as finer, cleaner coaly material.

Coal waste in the Ladysmith area originates from the Extension Mine, which opened in the 1890s as an extension of the Wellington Mine. Workers were moved to the new town of Oyster Harbour, later to be called Ladysmith. A wash plant was built in the area, and waste from the plant now forms Slag Point. Coal from the wash plant was shipped out from the harbour.

THE ENVIRONMENTAL HAZARDS OF COAL REFUSE

Coal in situ contains varying amounts of rock and water in addition to the organic carbon and associated volatile material. It is very difficult to totally separate the included rock and report a weight percent, so the organic material is burnt off and the remaining weight reported as percent ash, which is a bit less than the original weight of included rock. Thermal coals are shipped, after removal of rock, at ash concentrations up to about 15%. Coking coals (metallurgical coals), which are made into coke (the fuel in blast furnaces), are washed to ash contents generally less than 10%. The definition of coal varies, but generally anything over about 50% ash is not considered coal. This means that most coal mines, whether they are mining thermal or coking coal, have to process the coal to remove included rock. These wash plants usually produce two streams of waste material—coarse reject (greater than 0.6 mm) and tailings (less than 0.6 mm). Generally, modern wash plants have a yield of 65% to 85%, which means that 35% to15% of the weight of raw material entering the wash plant becomes waste material dumped somewhere close to the mining activity. It is usually buried or re-contoured and vegetated, but it does represent a concentration of material from a specific geological environment.

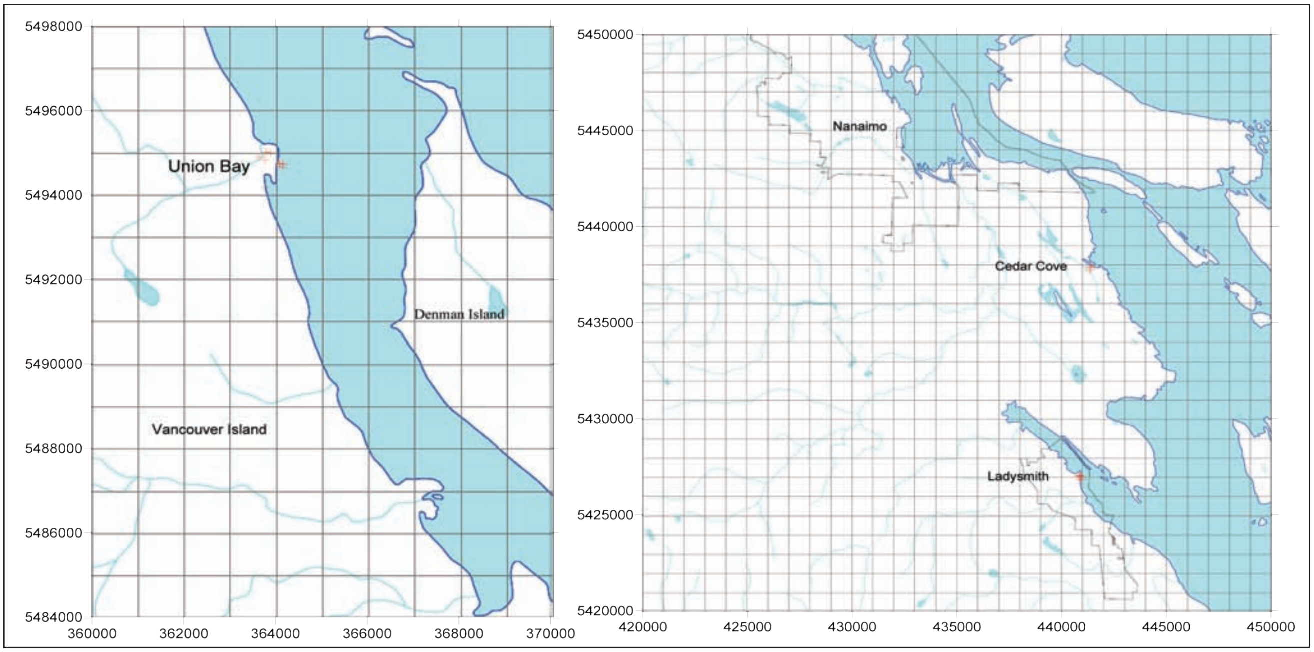


Figure 1: Sample locations north (Union Bay) and south (Cedar Cove and Ladysmith) of Nanaimo. UTM grid scale is 1 km.

Most of the concern about coal waste involves the possibility that the coal waste is leaching harmful trace metals into the environment. Coal itself is composed of environmentally benign organic carbon; unfortunately, coal and the rock closely associated with coal seams often contain appreciable amounts of sulphides and some trace elements. Sulphide minerals, predominantly pyrite (FeS_2), often contain trace amounts of elements other than iron and will oxidize to produce acidic water that releases and mobilizes these elements. There may also be increased concentrations of certain trace elements in rock material associated with coal, which was deposited in conjunction with vegetation in an oxygen-deficient, slightly acid, swamp environment; some trace elements are bound in insoluble forms and concentrated in this type of environment.

It is important to clarify the terms trace metals and trace elements as they are used in literature. The term trace metal may refer either to a metal (element) that is indeed rare or to the amount that occurs in a particular environment. The term is often applied to metallic elements such as iron, magnesium, zinc, copper, chromium, nickel, cobalt, vanadium, arsenic, molybdenum, and selenium. Possibly only selenium and vanadium are actually rare in overall terms. In contrast, the term trace element is broader and generally is used to refer to any element that occurs in very small concentrations in a particular environment.

In 2007, BC coal mines were expected to produce over 25 million tonnes of clean coal and over 5 million tonnes of coarse and fine refuse. This material will be permanently sequestered within mine lease areas in such a way as to not cause environmental problems. The record for safe disposal of this material is good based on the fact that there has been large-scale surface coal mining in BC for the last 40 years without major environmental problems related to coal waste handling.

STUDY AREAS

Samples were collected in 3 areas along the east coast of Vancouver Island, including Union Bay, Cedar Cove (Canary Cove and Clam Bay), and Ladysmith Slag Point areas (Figure 1). Union Bay was the site of the major wash plant and load-out for coal mined in the Cumberland area. Mining started in the area in 1869 when Baynes Sound Coal Company started operations in the Tsable River area; however, most of the activity soon moved to the Cumberland area, where mining continued until 1953. The Tsable River Mine continued operation, finally by removing coal from mine pillars, until 1967, when it closed as the last operating coal mine on the island.

SAMPLING AND ANALYSIS

Samples were collected from beaches, exposed banks of waste material, and from the top surface of piles of waste material. Fragment size varied from pebble to fine sand, and the mass of each sample collected varied based on fragment size and ranged from less than 1 kg to about 5 kg. Wherever possible, shallow holes up to 1 m deep were dug so that one or two samples could be collected to represent a simple stratigraphic section. On beaches, this required digging a hole up to 1 m deep (Figure 2). In some banks it was possible to sample a section up to 2 m thick (Figure

Figure 2: Photo; Union Bay intertidal zone, location 646.

Figure 3: Photo; Union Bay; bank into waste coal pile, l ocation 662.

3). In some places (Union Bay intertidal zone), there was a heavy iron staining (Figure 4). A total of 43 samples were collected (Table 1). Larger samples were split, with one split screened into 2 sizes to provide coarse-sized and fine-sized samples.

Inspection of samples provided some information on amount of coal in samples, and those that were noticeably coaly were sent for coal-specific analyses as well as x-ray fluorescence (XRF) major oxide and ICP-MS analyses (Table 2). Other samples not visibly coal-rich were sent for ash, XRF (Table 3), and ICP-MS (using a hot aqua-regia digestion; Table 4) analyses.

The XRF analysis provides a good estimate of the amount of organic matter in samples because samples are fused prior to analysis and the loss of weight is a measure of organic carbon and the remaining weight correlates closely to American Society for Testing and Materials (ASTM) ash measurements (Figure 5). It appears that ash concentration determined by XRF is about 0.5% lower, but the correlation between the 2 methods is generally very good.

Figure 4: Photo; Union Bay intertidal zone, location 646; heavy iron staining on surface.

TABLE 1: SAMPLE LOCATIONS AND DESCRIPTIONS.

Sample No	lat	long	Zone 10		Notes
Union Bay			easting	northing	
641	49-35.209	124-53.083	363773	5494180	Vertical bluff Sample top 40 cm coaly
642					Vertical bluff Sample middle 1 m down from top coaly
643					Vertical bluff Sample bottom 2 m down from top coaly
Intertidal zone Sampling					
644	49-35.475	124-52.773	364159	5494663	top 3cm mdst+coaly
645					middle 8-12 cm mdst+coaly
646					bottom 15-20 cm mdst+coaly
647	49-35.512	124-52.763	364173	5494732	low inter tidal zone top 4 cm mdst+coaly
648					low inter tidal zone 10-15 cm middle sample mdst+coaly
649					low inter tidal zone aprox depth 40 cm mdst+coaly
Intertidal					
650	49-35.524	124-52.784	364148	5494754	1 of 3 top heavy iron stain 0-4 cm
651					middle 10-15 cm black layer
652					deeper layer 20-30 cm grey/black
653	49-35.514	124-52.842	364078	5494738	upper inter tidal zone iron cemented surface layer hard pan
654	49-35.516	124-52.836	364085	5494741	top of coal pile15-20cm mdst
655					surface top 4 cm coaly mdst
Estuary					
660	49-35.661	124-53.078	363800	5495017	by creek black sand layer surface sample top 10-20 cm coaly
661					15-20 cm deep iron stained coaly
662	49-35.597	124-53.215	363632	5494903	waste coal/rock pile 30 cm down from top mdst
663					waste coal/rock pile 1.5 m down from top mdst
Top of waste Pile					
664	49-35.564	124-53.000	363894	5495002	top of coal hills 30 cm deepmdst
665	49-35.564	124-53.1	363769	5494838	Surface sample top 4 cm mdst
Cedar Cove/Canary Cove					
666	49-05.566	123-48.152	441408	5437859	coal waste pile adjacent to beach surface top 4 cm coaly
667					depth 30-35 cm taken coal waste pile adjacent to beach coaly
668	49-05.577	123-48.192	441360	5437880	surface top 4 cm coaly
669					65 cm deep coaly
Intertidal Zone					
670	49-05.614	123-48.188	441365	5437949	surface sample top 4 cm
671					depth to sample 20 cm coaly
Clam Bay					
672	49-05.498	123-48.184	441368	5437734	surface top 4 cm coaly
673					deep sample 30-40 cm hole 80 cm deep coaly
674	49-05.497	123-48.188	441363	5437732	surface top 4 cm mdst
675					sample 20 cm deep mdst
Ladysmith Slag Point					
676	48-59.706	123-48.537	440824	5427007	beach surface sample top 5 cm coaly
677					beach asmple 20-30 cm deep coaly
678	48-59.740	123-48.494	440877	5427070	surface top 5 cm coaly
679					30 cm deep sample coaly
Intertidal SE side of pile beach on ocean side					
680	48-59.669	123-48.418	440968	5426937	surface sample top 5 cm coaly
681					sample 20 cm deep coaly
Coaly Bluff					
682	48-59.612	123-48.457	440920	5426832	surfce to 30 cm mdst
683					1.5 m down from top mdst
Beach Above tide					
684	48-59.698	123-48.522	440842	5426992	surface top 5 cm sandy
685					50 cm deep Lots of iron/cable debris
Top of Waste pile					
686	48-59.728	123-48.496	440874	5427047	surface top 5 cm coaly
687					sample 40 cm deep coaly

TABLE 2: COAL-SPECIFIC ANALYSES OF SOME SAMPLES.

									Forms Of Sulfur		
sample	Moist adb	Ash adb	Moist res	VM adb	FC adb	CV db	CV	S%	Pyritic S%	sulphate S%	Organic S%
Union Bay											
641	2.14	48.15	1.33	21.18	29.34			0.54			
642	2.12	28.34	1.26	26.27	44.13			0.66	0.235	0.001	0.420
643	1.86	53.13	1.08	20.34	25.45			0.50			
644	1.29	87.49	0.79	9.69	2.03	3506	3478	0.31			
645	1.77	66.37	0.81	16.55	16.27	4431	4395	0.50			
646	1.08	85.80	0.69	8.95	4.56	3401	3378	0.54			
647	1.94	76.27	1.16	13.08	9.49						
648	1.38	67.37	1.07	16.15	15.41						
649	1.17	91.88	0.63	7.72	-0.23						
660	3.40	39.46	1.67	23.95	34.92	4477	4402	0.87			
661	1.50	74.81	1.05	13.67	10.47	979	969	1.22			
Cedar Cove											
666	2.75	24.57	1.82	32.10	41.51	5463	5364	0.55			
667	2.51	27.66	1.64	31.06	39.64	5440	5351	0.59			
668	31.17	61.31	1.11	20.16	17.42	2509	2481	0.47			
669	2.42	37.98	1.30	26.44	34.28	4657	4596	0.55			
670	1.92	55.53	1.12	21.07	22.28						
671	1.27	60.00	0.86	21.04	18.10						
672	1.57	69.75	1.03	16.59	12.63						
673	1.60	67.93	0.93	18.19	12.95						
Ladysmith Slag Point											
676	2.06	60.36	1.07	19.57	19.00						
677	2.02	49.50	1.04	23.82	25.64						
678	1.46	83.89	0.92	11.49	3.70	600	594	0.14			
679	1.67	75.36	1.00	14.48	9.16	981	971	0.31			
680	1.54	75.65	0.94	15.74	7.67						
681	1.52	71.33	1.10	16.61	10.96						
684	1.75	77.94	0.83	12.89	8.34	786	779	0.23			
685	2.14	60.23	1.24	18.93	19.60	2349	2320	0.28			
686	1.61	82.82	0.90	11.87	4.41						
687	1.74	76.44	1.04	14.59	7.93						

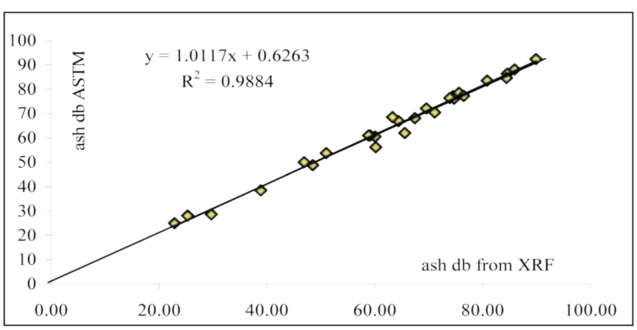


Figure 5: Correlation of ash determined by ASTM standard method and by XRF.

ECONOMIC CONSIDERATIONS

There are a number of coal refuse piles on Vancouver Island, especially in the Nanaimo area, and the total tonnage may be as high as 2.5 million tonnes (Gardner 1997). Portable wash plants exist that can upgrade the material by removing some of the ash until the remaining product has a useable heat value. Generally this means reducing the ash content to less than 15%. A number of companies have investigated the possibility of upgrading material to a marketable thermal coal product, but at present there are no active proposals. Coking coal properties such as fluidity (a measure of coal rheology) or free-swelling index (FSI) are lost as the coal weathers or ages at surface, so that there is no possibility of processing refuse piles to produce a coking coal product.

Most of the samples collected for this study have high ash contents (Table 3) with the exception of samples collected at Cedar Cove. It should be remembered that when

TABLE 3: XRF MAJOR OXIDE ANALYSES.

sample	Ash	SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	P205	Ba(F)
641	48.5	57.34	1.26	30.63	5.39	0.04	0.49	1.27	0.38	1.43	0.19	0.03
642	29.7	51.54	1.35	29.47	4.57	0.04	0.39	6.16	0.38	1.27	0.26	0.04
643	51.0	57.53	1.30	30.59	4.28	0.02	0.59	1.91	0.34	1.47	0.10	0.03
644	85.9	57.00	0.99	19.71	10.65	0.05	1.81	4.46	2.11	1.08	0.13	0.03
645	64.4	55.80	1.20	24.96	7.02	0.05	1.39	3.74	1.55	1.25	0.12	0.03
646	84.6	57.50	1.03	16.97	8.85	0.07	2.64	6.63	2.62	0.90	0.13	0.03
647	74.5	56.16	1.03	23.26	7.97	0.03	1.32	3.88	1.81	1.33	0.18	0.03
648	67.4	52.38	1.21	23.65	7.59	0.05	1.93	6.40	1.79	1.13	0.16	0.03
649	89.9	53.03	1.06	13.55	8.17	0.10	3.52	12.56	3.08	0.63	0.13	0.02
650	71.5	39.05	0.84	13.89	34.56	0.04	1.80	4.06	2.45	0.67	0.22	0.02
651	74.3	54.30	1.42	23.32	7.19	0.10	2.15	6.17	1.62	0.91	0.15	0.02
652	93.5	51.27	1.19	14.15	9.61	0.13	4.84	12.04	3.16	0.53	0.14	0.01
654	78.0	55.52	1.07	23.61	11.40	0.03	1.57	2.51	1.28	1.35	0.16	0.03
655	85.3	45.75	1.11	17.43	22.68	0.08	2.80	5.15	1.72	0.78	0.21	0.02
662	58.7	56.77	1.18	28.12	3.05	0.01	0.43	2.84	0.56	1.67	0.07	0.06
663	69.0	52.75	1.14	23.92	2.74	0.01	0.34	6.65	0.55	1.57	0.05	0.05
664	54.8	52.28	2.22	26.25	9.84	0.05	2.10	3.42	1.12	0.93	0.13	0.05
665	49.1	57.47	1.67	29.40	6.73	0.01	0.40	0.19	0.52	1.50	0.12	0.05
666	22.9	55.25	1.26	24.55	6.68	0.06	2.60	2.49	0.78	1.72	0.99	0.20
667	25.3	51.71	1.16	22.67	5.51	0.04	2.76	6.61	0.73	1.56	0.82	0.17
668 S	65.6	56.60	0.91	21.70	7.23	0.07	3.66	3.66	1.12	1.76	0.18	0.05
668 T	59.7	55.59	0.92	21.12	6.97	0.06	3.50	4.81	1.17	1.71	0.21	0.05
669 T	38.9	57.67	1.27	23.49	5.88	0.05	2.86	2.27	1.54	1.65	0.31	0.08
669 S	31.5	55.06	1.15	23.71	6.54	0.07	3.52	2.10	1.91	1.76	0.53	0.09
670	60.2	58.89	0.79	18.70	5.27	0.05	2.72	5.02	2.28	1.70	0.24	0.06
671	60.1	54.27	0.81	17.45	5.20	0.06	2.89	9.40	2.24	1.46	0.31	0.08
672 T	71.1	59.98	0.76	17.41	8.12	0.13	2.85	3.94	1.40	1.36	0.22	0.04
672 S	63.3	57.66	0.88	19.84	7.64	0.10	3.45	3.29	1.76	1.65	0.26	0.05
673 T	70.0	57.88	0.83	18.04	8.31	0.14	3.07	3.98	1.69	1.46	0.21	0.04
673 S	58.5	56.14	0.94	21.10	7.72	0.09	3.63	3.25	1.91	1.71	0.29	0.06
674	67.1	56.12	0.82	18.34	7.50	0.08	3.06	5.99	1.55	1.44	0.29	0.05
675	68.1	53.44	0.79	17.61	9.47	0.07	2.92	6.19	1.45	1.38	0.25	0.05
676 T	56.6	59.51	1.14	24.04	4.11	0.03	2.05	2.45	1.93	1.85	0.13	0.06
676 S	59.2	60.07	1.14	23.66	4.31	0.03	2.10	1.67	1.90	1.85	0.12	0.06
677 T	46.9	59.12	1.19	25.10	4.06	0.03	2.00	1.26	1.88	1.88	0.13	0.07
677 S	49.6	59.25	1.19	24.71	4.06	0.02	2.02	1.69	1.85	1.88	0.13	0.07
678 t	84.4	58.46	1.08	21.86	6.38	0.06	2.58	3.58	1.42	1.72	0.16	0.05
678 S	81.3	58.60	1.09	23.40	5.57	0.05	2.17	3.11	1.09	1.87	0.09	0.05
679 T	74.7	58.56	1.10	23.29	5.05	0.05	2.05	3.26	1.69	1.87	0.08	0.05
679 S	74.0	58.55	1.10	24.06	5.03	0.05	2.10	2.72	1.32	1.90	0.10	0.06
680 T	73.9	56.49	1.08	24.81	4.30	0.05	1.94	4.24	1.08	1.86	0.08	0.05
680 S	74.1	56.49	1.06	24.40	3.89	0.04	1.90	4.97	1.19	1.87	0.09	0.05
681 T	69.6	57.47	1.11	25.31	4.08	0.02	1.92	3.54	1.09	1.92	0.08	0.06
681 S	68.6	57.45	1.12	25.09	3.94	0.03	1.90	4.00	1.05	1.93	0.09	0.05
682	77.4	58.90	1.13	25.26	4.11	0.04	1.77	3.50	0.57	1.80	0.12	0.07
683	73.6	57.49	1.10	24.40	4.69	0.05	1.95	4.25	0.53	1.82	0.07	0.06
684 T	74.2	61.32	1.03	22.24	5.05	0.04	2.10	2.63	1.72	1.72	0.10	0.05
684 S	76.6	62.19	0.99	21.80	4.81	0.04	2.11	2.17	1.92	1.74	0.09	0.05
685 T	58.9	60.13	1.24	25.85	4.53	0.03	1.99	0.81	1.27	1.90	0.18	0.06
685 S	58.2	60.04	1.22	25.80	4.59	0.04	2.03	0.88	1.27	1.91	0.12	0.07
686 t	80.8	58.23	1.07	22.67	5.77	0.05	2.50	3.66	1.44	1.78	0.09	0.05
686 S	80.4	58.84	1.08	24.03	5.05	0.04	2.25	2.99	1.10	1.92	0.08	0.05
678 T	76.5	58.25	1.07	23.65	4.89	0.04	2.18	3.67	1.11	1.89	0.11	0.06
678 S	76.3	58.37	1.10	24.47	4.90	0.03	2.17	2.88	1.09	1.92	0.10	0.06

TABLE 4: ICP-MS MAJOR AND MINOR ELEMENT ANALYSES.

	Ca	Fe	Mg	Na	K	P	S	Ba	As	Bi	Cd	Co	Cr	Cu	Ga	La	Mn	Mo	Ni	Pb	Sb	Sc	Sr	Th	Tl	U	V	Zn
sample	%	%	%	%	%	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Union Bay																												
641	0.81	3.21	0.22	0.05	0.46	514	0.12	118	13	0.3	0.3	11	59	74	16.7	20	395	1.8	217	10.7	0.4	21.1	147	3.8	0.6	1.0	136	70
642	4.08	2.45	0.15	0.04	0.41	1294	1.01	202	17	0.2	0.2	17	69	89	16.4	20	372	2.4	167	12.8	0.4	25.1	332	3.4	0.6	1.2	238	70
643	1.21	2.37	0.25	0.04	0.50	418	0.32	137	9	0.2	0.2	16	60	72	15.9	21	255	2.1	32	12.7	0.3	22.9	150	3.5	0.4	1.2	187	85
644	1.80	6.78	0.62	0.24	0.40	579	0.53	70	15	0.1	0.1	9	59	43	11.1	10	261	2.8	25	6.1	0.1	11.8	116	1.9	0.2	0.9	90	46
645	2.05	4.32	0.57	0.37	0.56	550	0.67	154	10	0.2	0.4	17	88	76	16.5	16	363	1.7	38	10.9	0.2	19.1	164	2.9	0.4	0.9	125	62
646	2.66	5.09	0.77	0.34	0.34	606	0.51	76	12	0.1	0.1	15	100	44	10.6	5	355	1.4	32	5.8	0.1	11	160	1.5	0.2	0.6	112	49
647	2.18	5.15	0.58	0.42	0.59	885	0.60	108	23	0.2	0.1	6	90	49	14.7	15	276	1.8	27	9.8	0.2	16.3	185	2.6	0.3	1.1	117	52
648	3.50	4.83	0.65	0.39	0.56	809	0.84	127	24	0.1	0.1	10	101	66	16.5	10	301	1.7	37	9.1	0.2	17.5	298	2.6	0.4	1.3	133	60
649	6.19	3.97	1.06	0.37	0.20	527	0.17	38	11	<.1	<.1	11	91	47	9.2	<2	458	0.8	29	3.1	<.1	9.8	394	0.7	<.1	0.3	120	49
650	1.48	19.70	0.55	0.64	0.31	1015	0.57	87	22	0.1	0.1	3	78	55	9.7	8	256	13.2	21	6.9	0.3	9.5	162	1.3	0.1	3.1	90	22
651	2.70	3.45	0.52	0.17	0.34	687	0.44	59	11	0.1	0.1	14	89	58	13.8	10	566	0.9	31	6.6	0.1	15	105	1.9	0.2	0.6	118	48
652	4.80	3.99	1.24	0.26	0.15	584	0.14	29	13	<.1	<.1	16	83	54	9.7	<2	538	0.6	33	2.0	<.1	9	284	0.6	<.1	0.2	115	47
654	0.64	6.55	0.50	0.22	0.44	597	0.20	83	20	0.1	<.1	7	56	48	11.1	13	207	5.4	373	7.6	0.3	11.8	72	2.3	0.1	2.0	96	48
655	1.34	13.39	0.69	0.32	0.31	698	0.46	59	20	0.1	0.1	7	46	65	9.9	10	291	12.7	447	5.8	0.4	9.7	85	1.5	0.2	3.5	93	37
662	2.09	1.90	0.21	0.13	0.63	270	1.50	89	27	0.2	<.1	<1	49	18	12.6	19	28	2.6	10	11.3	0.2	15	243	3.0	0.5	1.5	104	23
663	4.89	1.70	0.15	0.07	0.58	185	3.60	45	25	0.2	<.1	<1	45	15	11.0	14	28	2.3	10	6.0	0.9	11.8	224	2.3	0.6	1.1	77	18
664	1.12	5.37	0.42	0.27	0.39	535	0.10	389	149	0.1	<.1	6	127	55	18.6	16	101	1.8	34	9.7	1.1	15.7	200	2.8	0.7	0.8	204	27
665	0.13	5.00	0.20	0.07	0.69	542	0.08	325	79	0.2	<.1	3	131	38	20.3	17	39	2.6	28	12.5	0.7	21.5	222	3.7	0.6	1.9	196	31

Hg all values less than 20 ppb   Se only 1 value greater than 1 ppm

	Ca	Fe	Mg	Na	K	P	S	Ba	As	Bi	Cd	Co	Cr	Cu	Ga	La	Mn	Mo	Ni	Pb	Sb	Sc	Sr	Th	Tl	U	V	Zn
sample	%	%	%	%	%	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Cedar Cove																												
666	1.70	4.08	1.24	0.19	0.80	4914	0.58	394	14	0.3	0.3	13	219	111	17.6	15	487	2.1	140	32.6	0.2	27.7	2317	3.1	0.4	1.3	195	85
667	4.75	3.71	1.55	0.16	0.71	4067	1.23	150	24	0.2	0.2	16	208	113	18.5	7	432	2.4	147	12.5	0.1	28.7	2409	2.9	0.4	1.3	187	75
668 S	2.74	4.79	1.96	0.35	0.88	961	0.58	254	11	0.1	0.1	11	180	56	16.1	12	614	0.8	144	15.8	0.1	21.3	376	2.1	0.2	0.8	145	104
668 T	3.33	3.89	1.65	0.33	0.75	946	0.57	270	9	0.1	0.1	9	146	55	15.2	10	503	1.0	116	11.1	0.1	20.8	479	2.1	0.2	0.9	135	79
669 T	1.25	3.25	1.35	0.62	0.90	1499	0.51	421	10	0.2	0.1	11	182	99	18.0	14	402	1.7	109	18.4	0.2	24.3	673	2.9	0.2	1.7	175	77
669 S	1.59	4.35	1.89	0.93	1.04	2413	0.88	274	14	0.1	0.1	15	254	118	19.3	12	615	2.2	166	11.9	0.2	26.5	1013	2.4	0.2	1.8	217	77
670	2.72	2.77	1.20	0.56	0.63	1000	0.53	245	5	0.1	0.1	6	148	44	13.3	9	319	0.7	87	12.0	<.1	17.3	461	1.9	0.2	0.8	107	59
671	6.22	3.15	1.42	0.67	0.67	1522	0.83	303	10	0.1	0.1	8	169	61	12.9	2	397	1.3	95	13.9	0.1	17.9	1073	1.8	0.2	1.1	127	61
672 T	2.69	5.26	1.58	0.36	0.72	1008	0.71	206	12	0.1	0.1	12	125	45	12.5	15	1018	1.3	112	10.1	0.1	17.5	301	1.9	0.2	0.8	112	92
672 S	2.44	5.88	2.11	0.61	0.99	1390	0.64	309	15	0.1	0.1	16	192	99	16.4	14	878	1.2	158	14.1	0.1	22.3	458	2.4	0.3	1.0	152	131
673 T	2.99	6.27	1.85	0.41	0.91	1100	0.89	210	26	0.1	0.1	18	170	57	13.7	17	1248	1.3	153	9.2	0.1	20.5	284	2.1	0.4	1.2	134	120
673 S	2.24	4.80	1.91	0.58	0.90	1348	0.63	328	21	0.2	0.1	13	167	79	16.9	14	731	1.7	142	12.5	0.1	23.6	567	2.2	0.3	1.0	152	94
674	4.35	5.39	1.68	0.54	0.83	1569	1.10	235	23	0.1	0.1	13	155	55	14.1	10	720	1.2	127	11.2	0.1	19.3	692	1.9	0.2	0.9	131	95
675	5.00	8.29	1.83	0.54	0.90	1531	1.93	157	44	0.1	0.1	15	167	59	13.7	10	722	1.2	145	13.2	0.1	18.3	640	1.8	0.8	0.7	135	114

Hg all values less than 20 ppb   Se only 1 value greater than 1 ppm

	Ca	Fe	Mg	Na	K	P	S	Ba	As	Bi	Cd	Co	Cr	Cu	Ga	La	Mn	Mo	Ni	Pb	Sb	Sc	Sr	Th	Tl	U	V	Zn
sample	%	%	%	%	%	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Ladysmith																												
676 T	1.33	2.16	0.97	0.74	0.95	542	0.38	339	11	0.2	0.2	6	116	87	16.2	19	226	1.4	55	27.3	0.2	20	205	3.0	0.3	1.2	139	114
676 S	0.79	2.69	1.12	0.74	1.12	658	0.35	366	7	0.2	0.2	8	170	94	17.3	21	276	1.5	67	29.7	0.2	20.9	178	3.1	0.3	1.2	158	134
677 T	0.72	2.57	1.10	0.86	1.17	707	0.41	470	7	0.3	0.3	10	207	102	19.3	21	240	5.0	76	24.7	0.2	24.8	284	3.7	0.4	1.5	182	141
677 S	0.92	2.48	1.08	0.75	1.08	652	0.41	451	4	0.3	0.3	9	168	94	18.1	20	243	5.6	70	25.7	0.3	23.1	247	3.5	0.4	1.3	164	122
678 t	2.11	4.26	1.30	0.33	1.04	511	0.20	274	10	0.2	<.1	10	114	55	16.2	21	500	1.5	73	17.4	0.1	19	142	2.7	0.3	0.6	122	166
678 S	2.03	3.63	1.10	0.33	1.06	431	0.19	275	10	0.2	0.1	7	102	56	15.9	22	444	0.6	67	20.5	0.1	18.6	118	2.6	0.3	0.7	113	178
679 T	2.25	3.31	1.08	0.47	1.08	410	0.33	313	8	0.2	0.1	8	115	70	16.8	22	441	0.6	64	20.1	0.2	20.9	150	2.9	0.3	0.8	128	130
679 S	1.90	3.37	1.14	0.50	1.09	484	0.27	311	10	0.2	0.1	8	117	72	17.2	22	449	0.6	67	18.8	0.1	21.7	143	3.1	0.3	0.7	131	147
680 T	3.30	3.10	1.11	0.48	1.11	423	0.51	300	12	0.2	0.1	8	111	66	17.6	20	391	0.3	74	15.9	0.1	21.6	172	3.1	0.5	0.7	127	119
680 S	3.59	2.32	1.02	0.51	1.05	371	0.31	259	11	0.2	0.1	5	93	63	16.5	21	367	0.3	55	15.8	0.1	20.2	163	3.1	0.4	0.7	118	96
681 T	2.73	2.73	1.11	0.50	1.09	373	0.42	308	13	0.2	0.1	6	115	82	17.2	24	322	0.4	66	16.3	0.1	22.1	166	3.1	0.3	0.8	134	114
681 S	3.14	2.66	1.12	0.47	1.10	438	0.35	314	7	0.2	0.1	7	120	84	16.7	22	339	0.5	68	17.5	0.1	22.1	191	3.2	0.4	0.9	138	129
682	2.97	3.00	1.11	0.12	1.05	302	0.13	467	11	0.3	0.3	8	109	74	19.5	25	439	0.4	65	15.4	0.2	23.4	151	3.2	0.4	0.6	137	139
683	3.34	3.26	1.16	0.10	1.03	366	0.18	371	10	0.2	0.3	10	123	80	17.8	24	487	0.4	84	14.7	0.1	23.8	183	3.2	0.4	0.7	141	150
684 T	1.17	3.07	0.94	0.38	0.87	509	0.19	255	10	0.2	0.1	6	132	74	14.0	18	329	0.6	59	22.3	0.1	17.2	129	2.4	0.3	0.7	122	137
684 S	0.68	2.81	0.91	0.43	0.85	462	0.17	202	12	0.2	<.1	6	121	70	12.9	16	316	0.6	53	25.4	0.1	15.6	94	2.4	0.2	0.7	112	165
685 T	0.40	3.02	0.98	0.44	0.98	641	0.13	371	11	0.2	<.1	9	136	107	15.6	20	397	1.0	70	55.3	0.2	20.8	163	3.0	0.3	1.7	154	124
685 S	0.37	2.47	0.95	0.42	0.97	583	0.11	337	10	0.3	0.1	9	127	104	16.8	20	350	1.1	61	73.0	0.3	22.2	154	3.3	0.3	1.9	136	108
686 t	1.81	3.09	1.02	0.27	0.88	427	0.16	223	10	0.2	<.1	7	87	49	15.2	21	354	0.5	57	31.5	0.2	17.5	125	2.8	0.3	0.6	95	134
686 S	1.72	2.78	1.01	0.26	0.95	337	0.15	221	11	0.2	<.1	6	87	55	14.9	23	328	0.4	57	20.0	0.2	18.5	112	2.6	0.3	0.6	94	141

Hg all values less than 20 ppb   Se only 1 value greater than 1 ppm

	Ca	Fe	Mg	Na	K	P	S	Ba	As	Bi	Cd	Co	Cr	Cu	Ga	La	Mn	Mo	Ni	Pb	Sb	Sc	Sr	Th	Tl	U	V	Zn
sample	%	%	%	%	%	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Ladysmith																												
676 T	1.33	2.16	0.97	0.74	0.95	542	0.38	339	11	0.2	0.2	6	116	87	16.2	19	226	1.4	55	27.3	0.2	20	205	3.0	0.3	1.2	139	114
676 S	0.79	2.69	1.12	0.74	1.12	658	0.35	366	7	0.2	0.2	8	170	94	17.3	21	276	1.5	67	29.7	0.2	20.9	178	3.1	0.3	1.2	158	134
677 T	0.72	2.57	1.10	0.86	1.17	707	0.41	470	7	0.3	0.3	10	207	102	19.3	21	240	5.0	76	24.7	0.2	24.8	284	3.7	0.4	1.5	182	141
677 S	0.92	2.48	1.08	0.75	1.08	652	0.41	451	4	0.3	0.3	9	168	94	18.1	20	243	5.6	70	25.7	0.3	23.1	247	3.5	0.4	1.3	164	122
678 t	2.11	4.26	1.30	0.33	1.04	511	0.20	274	10	0.2	<.1	10	114	55	16.2	21	500	1.5	73	17.4	0.1	19	142	2.7	0.3	0.6	122	166
678 S	2.03	3.63	1.10	0.33	1.06	431	0.19	275	10	0.2	0.1	7	102	56	15.9	22	444	0.6	67	20.5	0.1	18.6	118	2.6	0.3	0.7	113	178
679 T	2.25	3.31	1.08	0.47	1.08	410	0.33	313	8	0.2	0.1	8	115	70	16.8	22	441	0.6	64	20.1	0.2	20.9	150	2.9	0.3	0.8	128	130
679 S	1.90	3.37	1.14	0.50	1.09	484	0.27	311	10	0.2	0.1	8	117	72	17.2	22	449	0.6	67	18.8	0.1	21.7	143	3.1	0.3	0.7	131	147
680 T	3.30	3.10	1.11	0.48	1.11	423	0.51	300	12	0.2	0.1	8	111	66	17.6	20	391	0.3	74	15.9	0.1	21.6	172	3.1	0.5	0.7	127	119
680 S	3.59	2.32	1.02	0.51	1.05	371	0.31	259	11	0.2	0.1	5	93	63	16.5	21	367	0.3	55	15.8	0.1	20.2	163	3.1	0.4	0.7	118	96
681 T	2.73	2.73	1.11	0.50	1.09	373	0.42	308	13	0.2	0.1	6	115	82	17.2	24	322	0.4	66	16.3	0.1	22.1	166	3.1	0.3	0.8	134	114
681 S	3.14	2.66	1.12	0.47	1.10	438	0.35	314	7	0.2	0.1	7	120	84	16.7	22	339	0.5	68	17.5	0.1	22.1	191	3.2	0.4	0.9	138	129
682	2.97	3.00	1.11	0.12	1.05	302	0.13	467	11	0.3	0.3	8	109	74	19.5	25	439	0.4	65	15.4	0.2	23.4	151	3.2	0.4	0.6	137	139
683	3.34	3.26	1.16	0.10	1.03	366	0.18	371	10	0.2	0.3	10	123	80	17.8	24	487	0.4	84	14.7	0.1	23.8	183	3.2	0.4	0.7	141	150
684 T	1.17	3.07	0.94	0.38	0.87	509	0.19	255	10	0.2	0.1	6	132	74	14.0	18	329	0.6	59	22.3	0.1	17.2	129	2.4	0.3	0.7	122	137
684 S	0.68	2.81	0.91	0.43	0.85	462	0.17	202	12	0.2	<.1	6	121	70	12.9	16	316	0.6	53	25.4	0.1	15.6	94	2.4	0.2	0.7	112	165
685 T	0.40	3.02	0.98	0.44	0.98	641	0.13	371	11	0.2	<.1	9	136	107	15.6	20	397	1.0	70	55.3	0.2	20.8	163	3.0	0.3	1.7	154	124
685 S	0.37	2.47	0.95	0.42	0.97	583	0.11	337	10	0.3	0.1	9	127	104	16.8	20	350	1.1	61	73.0	0.3	22.2	154	3.3	0.3	1.9	136	108
686 t	1.81	3.09	1.02	0.27	0.88	427	0.16	223	10	0.2	<.1	7	87	49	15.2	21	354	0.5	57	31.5	0.2	17.5	125	2.8	0.3	0.6	95	134
686 S	1.72	2.78	1.01	0.26	0.95	337	0.15	221	11	0.2	<.1	6	87	55	14.9	23	328	0.4	57	20.0	0.2	18.5	112	2.6	0.3	0.6	94	141

Hg all values less than 20 ppb   Se only 1 value greater than 1 ppm

a sample is ashed, there is a loss of weight from the mineral matter, so that a concentration of approximately 85% ash corresponds to a mineral matter concentration of 100% (i.e., no organic carbon content).

RESULTS AND DISCUSSION

Major Elements in Coal Waste

Sulphur occurs in coal as sulphides, as sulphates, or as organic sulphur. Trace metals may be associated with sulphur if the sulphur is present as sulphides. These sulphides may be dispersed in coal or associated with ash. Sulphur has a negative correlation with ash and no correlation with Fe (Figure 6), indicating that a lot of the sulphur is occurring as organic or sulphate sulphur associated with the coal. This is probably because sulphides originally present in the coal waste have oxidized and released SO_3. Trace metals would also be released and mobilized by the acidic water.

One of the advantages of pairing XRF and ICP-MS analyses is that it provides information on what proportion of major elements may be in a soluble form. XRF measures the total amount present, whereas ICP-MS measures the amount that is soluble in a hot acid leach. The amount of Fe detected by ICP-MS is similar to that detected by XRF, indicating that most of the iron is probably soluble and probably occurs in sulphides, carbonates, or hydroxides. A similar comparison for Ca, K, and Na indicates that lower percentages of these elements are potentially soluble and mobile (Figure 7).

Trace Elements in Coal Waste

As a starting point, it is important to understand how trace elements are distributed in coal. Coal is not 100% organic carbon—even when washed it contains an amount of included mineral matter analysed as ash. Consequently concentrations of trace elements in coal can have either an ash or an organic carbon affinity. To complicate the picture further, a lot of trace elements are associated with sulphide minerals in coal, and these sulphide minerals (mainly pyrite) may be associated with ash in the seam or with coal in the seam. In coals with varying ash contents, one should try to assign an affinity of the trace elements to either the organic material, the ash, or the sulphides (if present in reasonable amounts). Average trace element concentrations in shales and continental crust are shown in Figure 8. There are some data for coals from Vancouver Island (Van De Flier-Keller and Dumais 1988) and for coals from northeastern and southeastern British Columbia (Grieve 1991) (Figure 9). It is obvious from Figures 8 and 9 that the distribution of trace elements in crustal rocks,

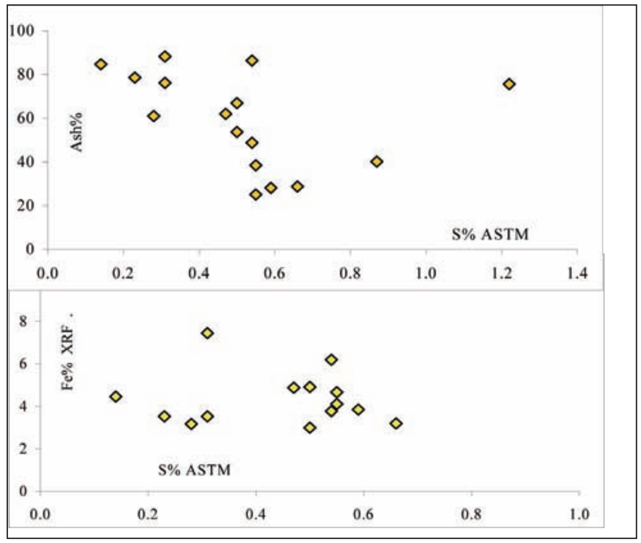


Figure 6: Association of sulphur with ash and iron; data from Union Bay, Cedar Cove, and Slag Point.

shales, and coals is similar. It appears that average element concentrations for coal waste are generally similar to world coal values (Figure 9) and a bit higher than Vancouver Island fresh coal values. The waste coal material has much higher ash concentrations than these suites of coal samples and probably should be compared to the average shale data (Figure 8).

There is no evidence of major enrichment or depletion of elements in the waste coal material, except for possibly enrichment in copper and chromium, which are both higher than the average values for Vancouver Island and world coals (Figure 9).

Trace Element Associations

The association of trace elements for the various areas is demonstrated using linear correlation matrixes. This works well in most cases but can be misleading when the data contain a few very high or low values that overly influence linear correlations. Correlation matrixes are constructed for the 3 study areas—Union Bay, Cedar Cove, and Ladysmith (Tables 5, 6, and 7). These tables help identify elements that have an ash association or a sulphur (possibly pyrite) association. Most of the elements have a negative association with ash, indicating a coal or sulphide association. Plots for copper (Figure 10) indicate that copper has a weak negative correlation with ash and a correlation with sulphur that is possibly positive at low concentrations but negative at high concentrations (secondary sulphate sulphur). Copper also has no correlation with iron (Figure 10), which does not support a sulphide association. The association of copper in samples is therefore not clear, but it may have been released from sulphides and since bound to the organic material. The association of chromium is not

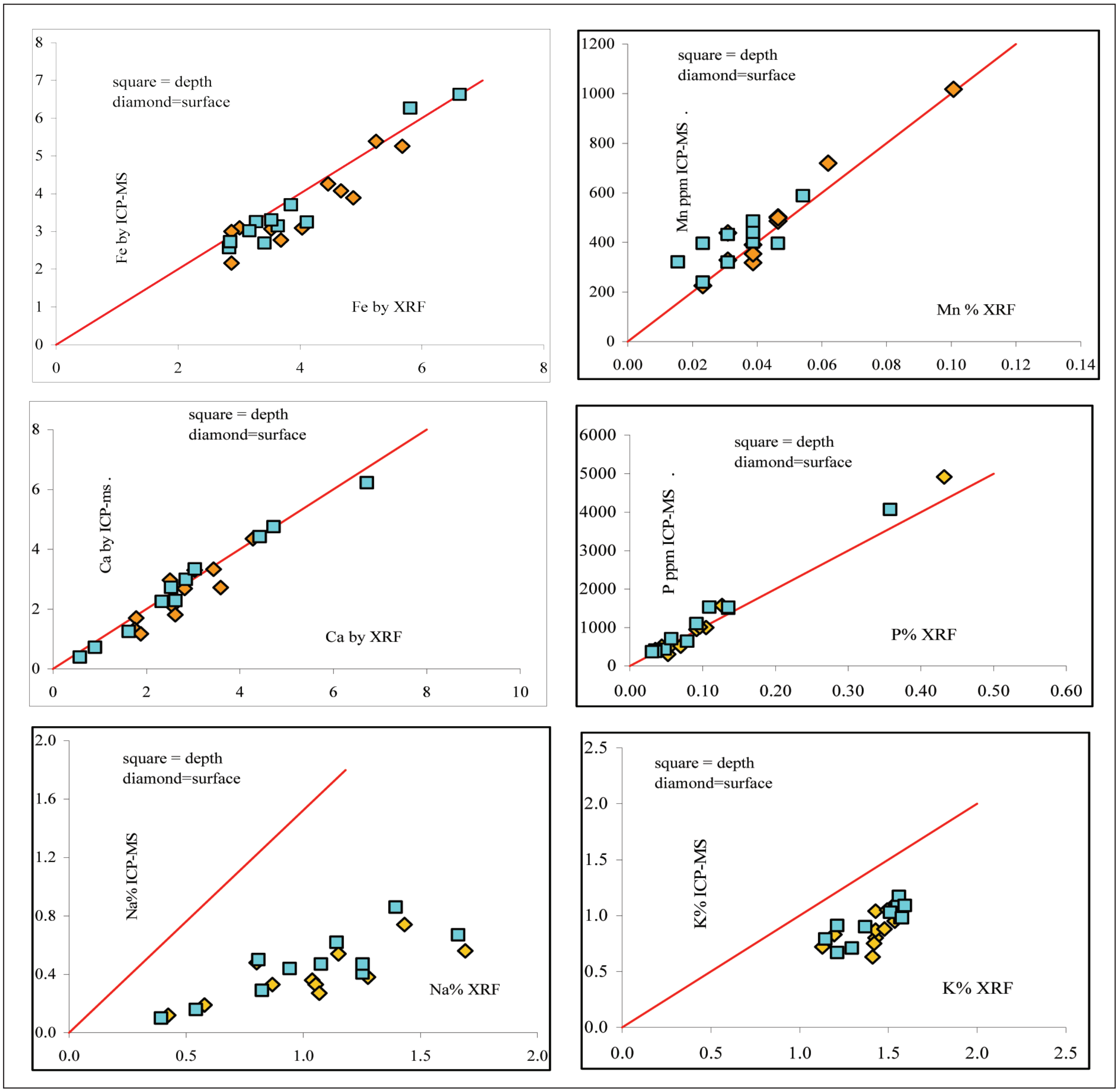


Figure 7: Comparison of Fe, Ca, Na, and K analyses by XRF and ICP-MS.

clear; it has a negative correlation with ash and no correlation with sulphur (Tables 5 and 6), though it does correlate with other trace metals. Copper may have been bound to the organic material after being released from sulphides.

Mercury is a trace element of general concern; however, in this study only 2 analyses were above the detection limit of 10 ppb, and they were both less than 20 ppb.

Arsenic is often associated with pyrite, and in this study there is no correlation with ash and, except for the 2 high values for samples 664 and 665 (Table 4), only a weak correlation with sulphur (Figure 11). There is no explanation for the 2 high arsenic values.

Only 2 elements (chromium and copper) are above both world averages (Clarke and Sloss 1992) and values from the Nanaimo and Comox Basins (Van Der Flier-Keller and Dumais 1988) (Figure 9). These elements do not correlate with sulphur or ash but appear to correlate with other trace metals (Tables 5, 6, and 7). It appears that they are not present in sulphides but may be bound to the organic material.

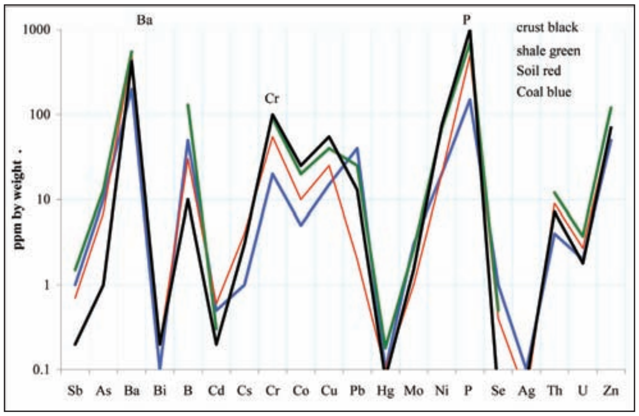


Figure 8: Average trace element data from Clark and Sloss (1992).

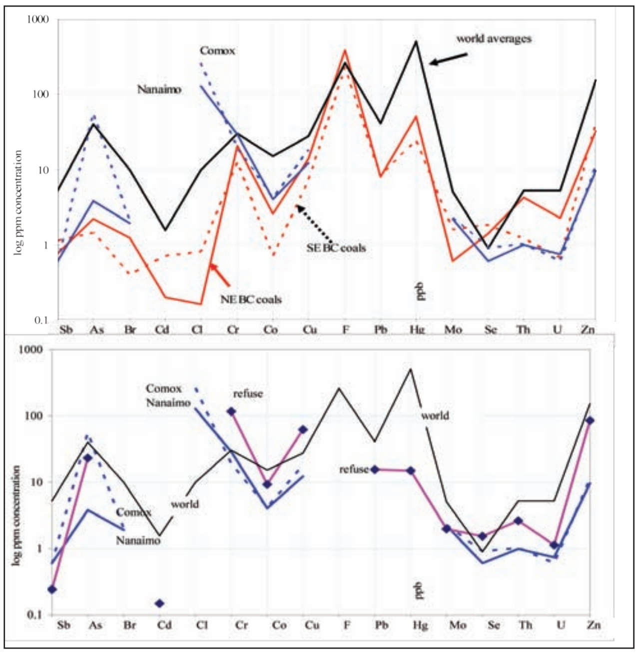


Figure 9: Trace elements concentrations in coals and waste material (BC and world data).

Depth Profile Data

A number of small trench samples were collected at Union Bay, Cedar Cove, and Ladysmith. At each location a sample was collected at surface, a second at about 20 cm, and sometimes a third at about 50 cm depth. Data available for the sets of samples include total ash, major oxide, and trace metal concentrations. The data from Union Bay are displayed in a number of plots (Figure 12 a, b, c, d, and e). Major elements are plotted for some of the profiles—these are concentrations determined by ICP-MS and therefore represent the soluble component of the total concentration. Comparing the total concentration of iron and calcium (by XRF) to the ICP-MS concentration does not indicate a change in concentrations with depth or a change in the proportions extracted by acid leach and ICP-MS analysis

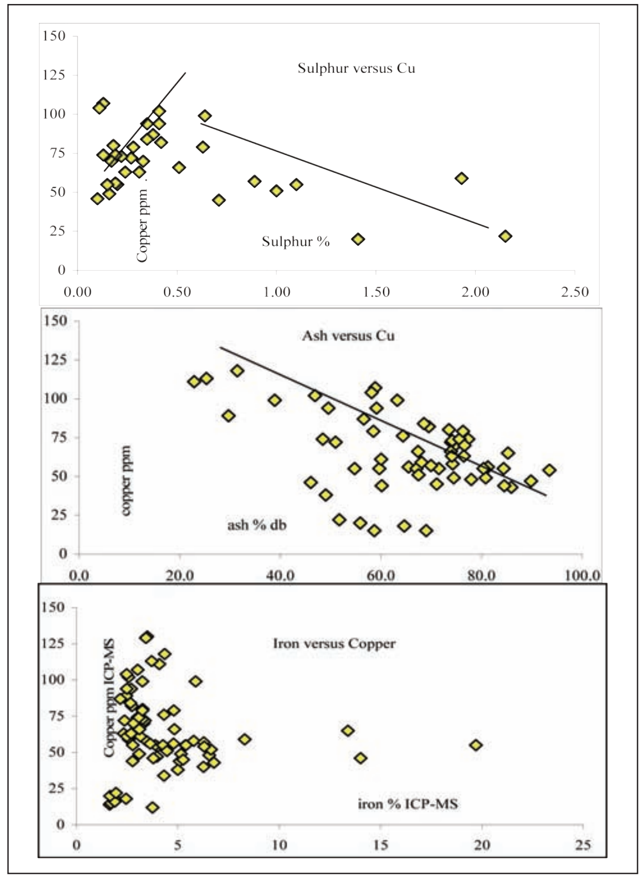


Figure 10: Copper versus sulphur, ash, and iron.

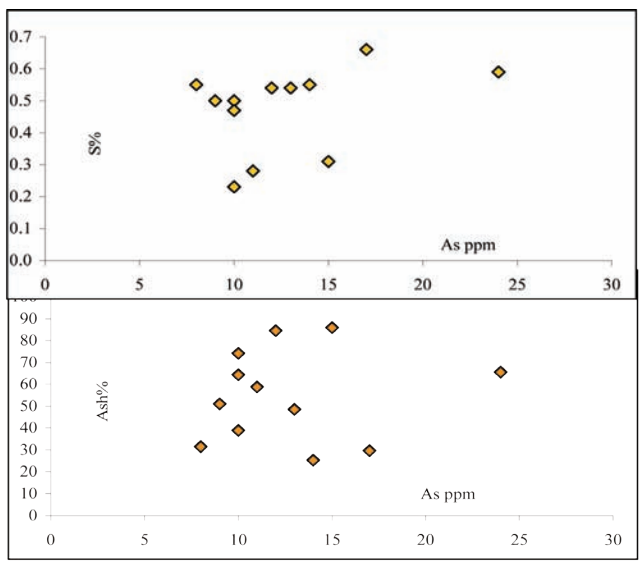


Figure 11: Relationship of arsenic with ash and sulphur.

(Figure 7). For both elements, most of the iron and calcium is acid-leacheable. Trace element concentrations do not vary much with depth, indicating a lack of mobility or that any mobile component has already moved on. Ash contents of all samples are high, with little variation with depth.

TABLE 5: CORRELATION MATRIX FOR TRACE ELEMENTS, UNION BAY AREA.

x	ash	As	Ba	Bi	Cd	Co	Cr	Cu	Ga	Mo	Ni	P	Pb	Sb	Sc	Sr	Th	U	S	Zn
ash	1.00																			
As	-0.65	1.00																		
Ba	**-0.79**	**0.92**	1.00																	
Bi	-0.42	-0.20	-0.07	1.00																
Cd	0.11	-0.50	-0.24	0.29	1.00															
Co	0.48	-0.35	-0.20	-0.41	0.68	1.00														
Cr	-0.33	0.61	**0.73**	-0.27	-0.12	0.28	1.00													
Cu	0.06	0.05	0.23	-0.34	0.56	**0.78**	0.56	1.00												
Ga	**-0.80**	0.66	**0.87**	0.09	0.03	-0.08	**0.72**	0.44	1.00											
Mo	-0.39	0.19	0.24	0.18	-0.27	-0.51	-0.21	-0.35	0.29	1.00										
Ni	0.07	0.17	0.33	-0.47	0.37	**0.78**	**0.75**	**0.95**	0.47	-0.37	1.00									
P	0.22	-0.04	0.08	-0.35	0.11	0.49	0.54	**0.72**	0.33	-0.22	**0.74**	1.00								
Pb	**-0.86**	0.43	**0.70**	0.46	0.22	-0.20	0.40	0.23	**0.87**	0.41	0.18	0.18	1.00							
Sb	-0.61	**0.80**	0.64	0.09	-0.48	-0.52	0.30	-0.23	0.43	0.20	-0.15	-0.40	0.17	1.00						
Sc	**-0.75**	0.36	0.66	0.35	0.30	-0.03	0.56	0.44	**0.93**	0.32	0.41	0.34	**0.92**	0.16	1.00					
Sr	0.12	-0.06	-0.15	0.10	-0.28	-0.07	0.13	0.00	-0.15	-0.61	0.03	-0.02	-0.34	0.27	-0.16	1.00				
Th	**-0.91**	0.47	0.69	0.54	0.06	-0.38	0.29	0.05	**0.84**	0.59	0.01	0.01	**0.96**	0.41	**0.88**	-0.37	1.00			
U	**-0.73**	0.23	0.43	0.48	-0.21	-0.54	0.16	-0.19	0.64	0.69	-0.18	**0.00**	**0.77**	0.19	**0.74**	-0.18	**0.86**	1.00		
S	-0.05	-0.28	-0.43	0.39	-0.09	-0.49	-0.72	-0.61	-0.37	0.25	-0.72	-0.64	-0.20	0.23	-0.29	-0.03	0.01	0.12	1.00	
Zn	0.46	-0.46	-0.27	-0.28	0.62	**0.85**	0.26	**0.83**	0.04	-0.41	**0.77**	**0.78**	-0.05	-0.66	0.17	0.04	-0.24	-0.28	-0.49	1.00

TABLE 6: CORRELATION MATRIX FOR TRACE ELEMENTS, CEDAR COVE AREA.

x	ash	As	Ba	Bi	Cd	Co	Cr	Cu	Ga	Mo	Ni	P	Pb	Sb	Sc	Sr	Th	U	S	Zn
ash	1.00																			
As	0.16	1.00																		
Ba	-0.36	-0.53	1.00																	
Bi	**-0.74**	-0.02	0.53	1.00																
Cd	-0.72	0.01	0.22	**0.82**	1.00															
Co	-0.13	0.66	-0.28	0.11	0.17	1.00														
Cr	**-0.78**	0.04	0.25	0.40	0.46	0.44	1.00													
Cu	**-0.86**	0.00	0.39	0.62	0.54	0.45	**0.88**	1.00												
Ga	**-0.82**	-0.09	0.40	0.57	0.41	0.34	**0.82**	**0.90**	1.00											
Mo	**-0.84**	0.16	0.17	0.67	0.59	0.49	0.73	**0.86**	**0.74**	1.00										
Ni	-0.21	0.51	-0.17	0.10	0.18	**0.88**	0.64	0.53	0.54	0.44	1.00									
P	**-0.85**	0.12	0.15	**0.77**	**0.93**	0.31	0.67	**0.73**	0.58	**0.80**	0.32	1.00								
Pb	-0.59	-0.16	0.64	**0.79**	**0.81**	-0.06	0.43	0.48	0.40	0.35	0.05	0.68	1.00							
Sb	**-0.74**	-0.31	0.65	0.54	0.41	-0.02	0.66	0.68	0.64	0.59	0.09	0.50	0.63	1.00						
Sc	**-0.89**	0.00	0.32	**0.72**	0.64	0.44	**0.82**	**0.92**	**0.94**	**0.86**	0.56	**0.78**	0.49	0.60	1.00					
Sr	**-0.84**	0.08	0.08	**0.72**	**0.88**	0.18	0.60	0.67	0.52	**0.77**	0.18	**0.97**	0.59	0.38	**0.73**	1.00				
Th	**-0.87**	-0.14	0.49	**0.82**	**0.72**	0.30	0.66	**0.86**	**0.82**	**0.74**	0.31	**0.76**	0.67	0.68	**0.90**	**0.70**	1.00			
U	**-0.76**	-0.19	0.47	0.41	0.25	0.27	**0.75**	**0.79**	**0.73**	**0.75**	0.26	0.45	0.27	**0.82**	**0.71**	0.41	0.69	1.00		
S	**0.11**	**0.90**	-0.67	-0.19	-0.03	0.45	0.05	-0.04	-0.17	0.13	0.31	0.13	-0.24	-0.29	-0.11	0.16	-0.25	-0.19	1.00	
Zn	0.45	0.54	-0.19	-0.20	-0.16	0.70	-0.03	-0.05	-0.08	-0.20	0.66	-0.21	-0.10	-0.37	-0.08	-0.36	-0.11	-0.28	0.26	1.00

TABLE 7: CORRELATION MATRIX FOR TRACE ELEMENTS, LADYSMITH AREA.

x	ash	As	Ba	Bi	Cd	Co	Cr	Cu	Ga	Mo	Ni	P	Pb	Sb	Sc	Sr	Th	U	S	Zn
ash	1.00																			
As	0.05	1.00																		
Ba	-0.11	-0.04	1.00																	
Bi	0.17	0.19	**0.82**	1.00																
Cd	0.20	0.00	**0.88**	0.62	1.00															
Co	0.41	-0.29	0.35	0.04	0.64	1.00														
Cr	-0.32	-0.43	0.37	-0.15	0.32	0.66	1.00													
Cu	**-0.86**	-0.13	0.49	0.12	0.31	-0.06	0.59	1.00												
Ga	-0.19	0.35	**0.84**	**0.81**	0.68	0.13	0.10	0.44	1.00											
Mo	**0.70**	-0.17	-0.30	-0.14	-0.28	0.48	0.09	-0.52	-0.38	1.00										
Ni	0.06	-0.16	0.28	-0.18	0.52	**0.82**	**0.75**	0.20	0.07	0.12	1.00									
P	0.32	-0.14	-0.68	-0.54	**-0.72**	0.17	0.02	-0.42	-0.53	0.69	0.00	1.00								
Pb	0.27	-0.14	-0.46	-0.20	-0.58	-0.21	-0.30	-0.36	-0.33	0.34	-0.43	0.62	1.00							
Sb	0.10	-0.14	0.57	0.67	0.31	0.06	-0.06	0.08	0.54	-0.07	-0.30	-0.38	0.20	1.00						
Sc	-0.63	0.06	**0.76**	0.42	0.71	0.18	0.52	**0.85**	**0.78**	-0.56	0.35	-0.58	-0.54	0.24	1.00					
Sr	-0.67	-0.27	0.26	-0.15	0.27	0.12	0.56	0.66	0.11	-0.43	0.43	-0.42	-0.76	-0.23	0.60	1.00				
Th	-0.68	0.25	0.37	0.31	0.24	-0.24	0.06	0.69	0.69	-0.52	-0.11	-0.28	-0.25	0.13	0.77	0.37	1.00			
U	-0.68	-0.24	-0.32	-0.38	-0.57	-0.47	0.10	0.52	-0.19	-0.27	-0.26	0.19	0.41	-0.05	0.11	0.18	0.38	1.00		
S	-0.57	0.28	-0.46	-0.44	-0.69	-0.43	-0.04	0.19	-0.12	-0.32	-0.18	0.19	0.07	-0.23	**0.01**	0.26	0.29	0.57	1.00	
Zn	0.69	-0.18	0.03	0.05	0.22	0.56	0.14	-0.40	-0.14	0.60	0.37	0.45	0.46	-0.02	-0.32	-0.58	-0.49	-0.28	-0.60	1.00

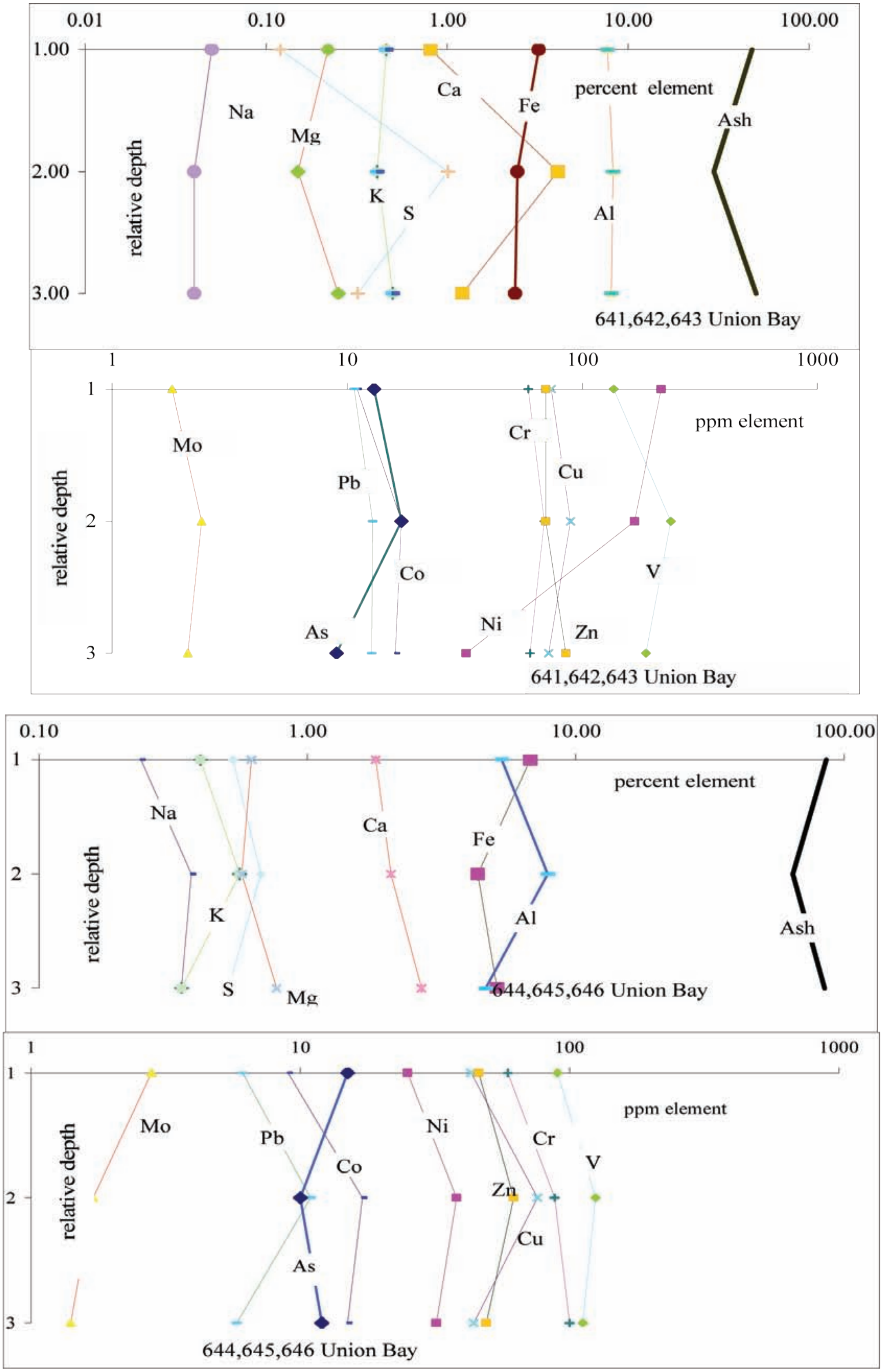


Figure 12a: Depth profile data for major and trace elements for locations Union Bay. Relative depths are surface and approximately 20 cm and 50 cm.

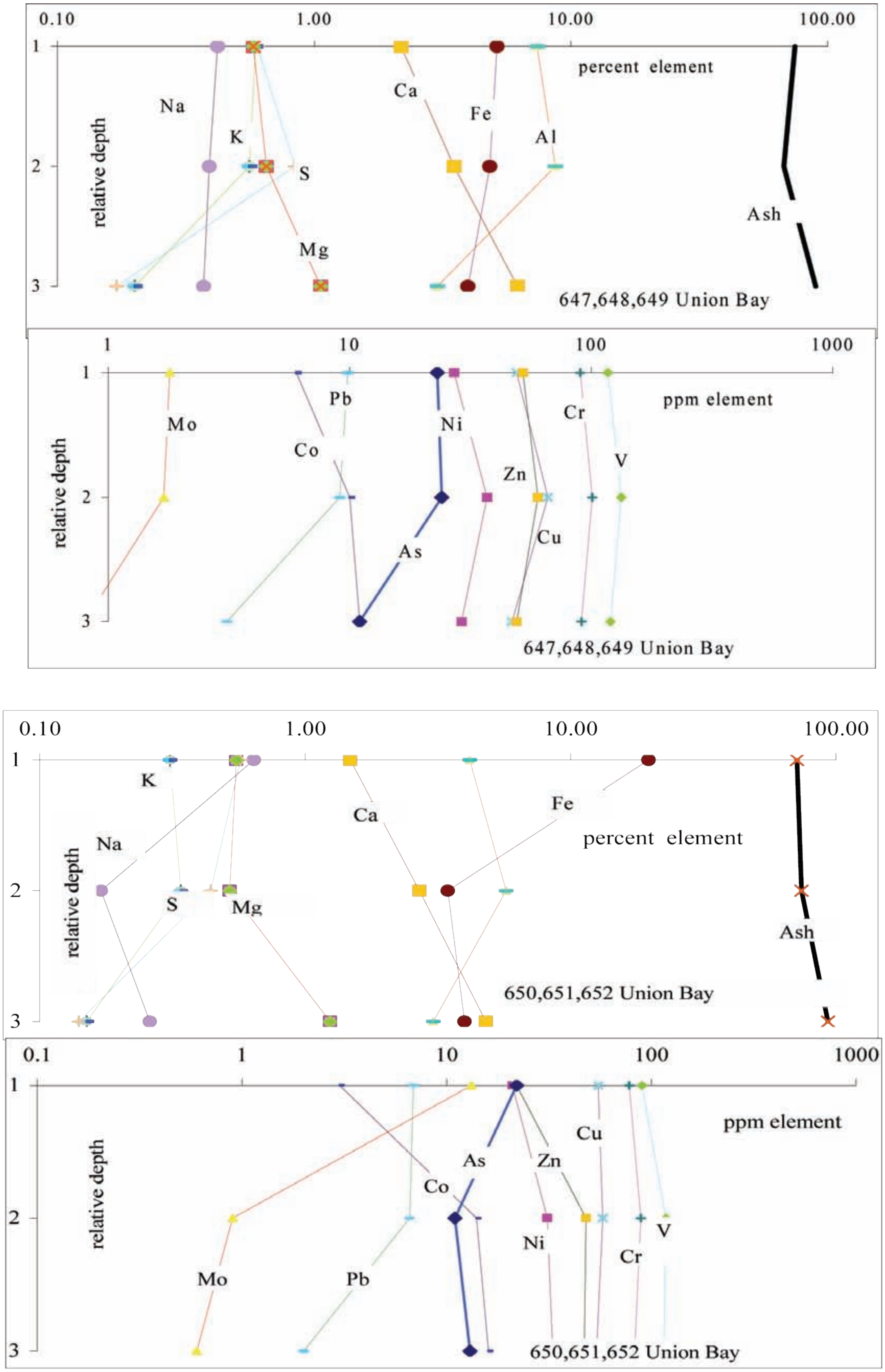


Figure 12b: Depth profile data for major and trace elements for locations Union Bay. Relative depths are surface and approximately 20 cm and 50 cm.

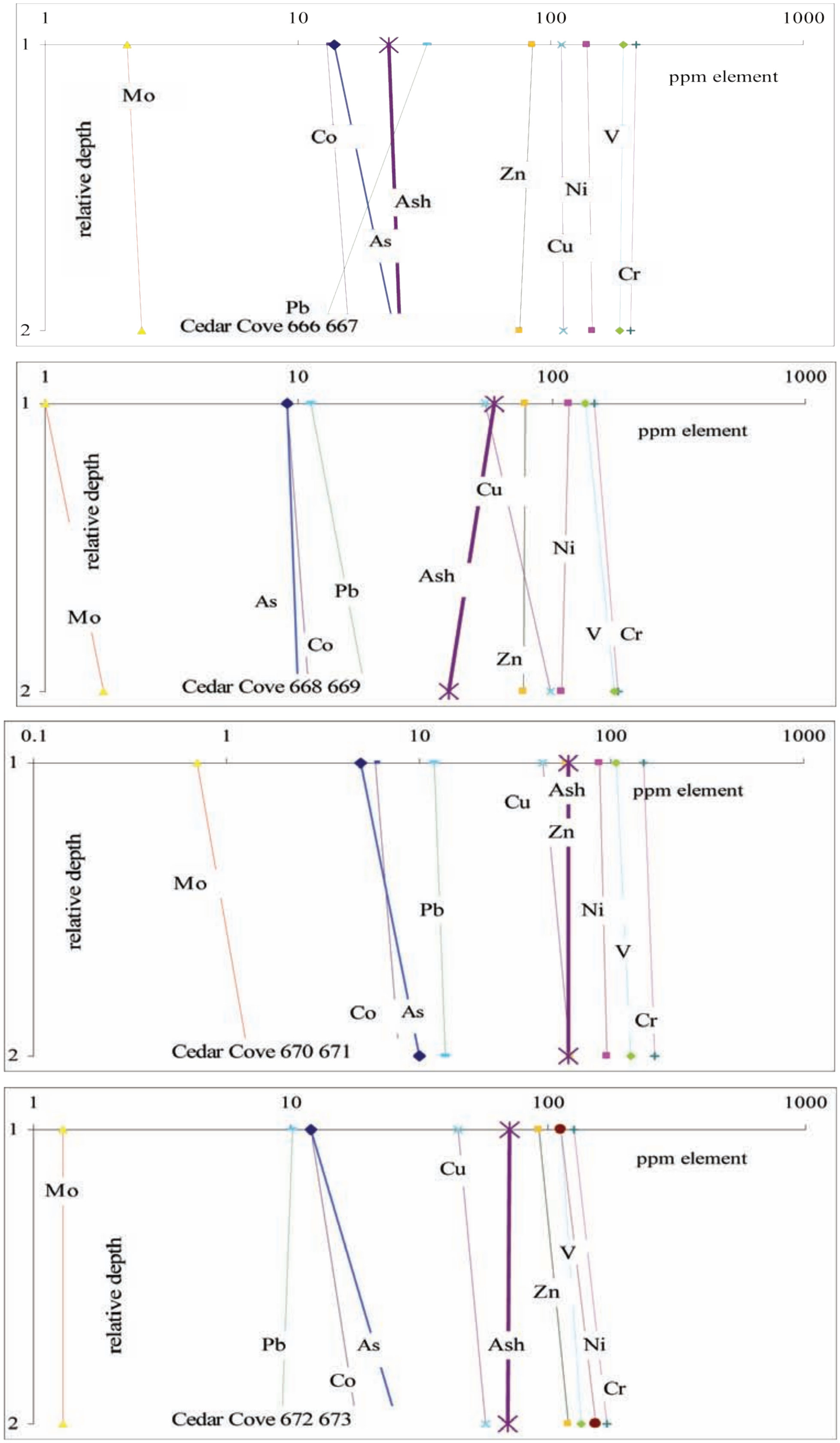


Figure 12c: Depth profile data for major and trace elements for locations Cedar Cove. Relative depths are surface and approximately 20 cm and 50 cm.

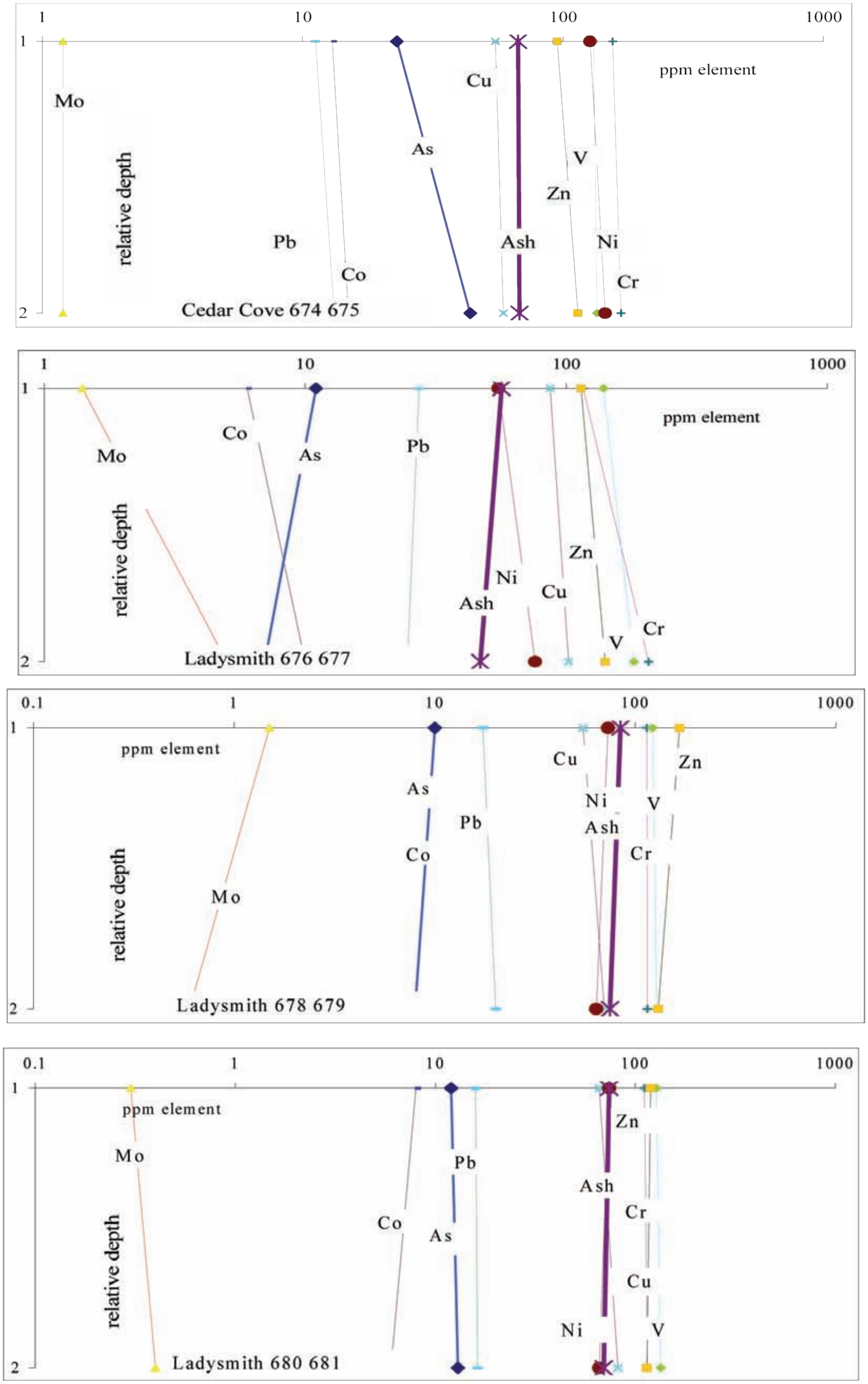
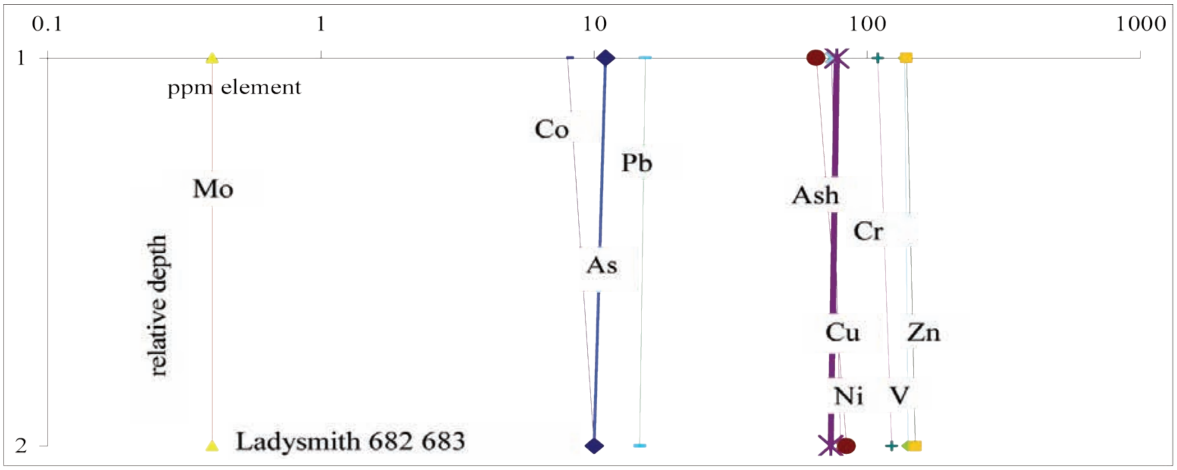
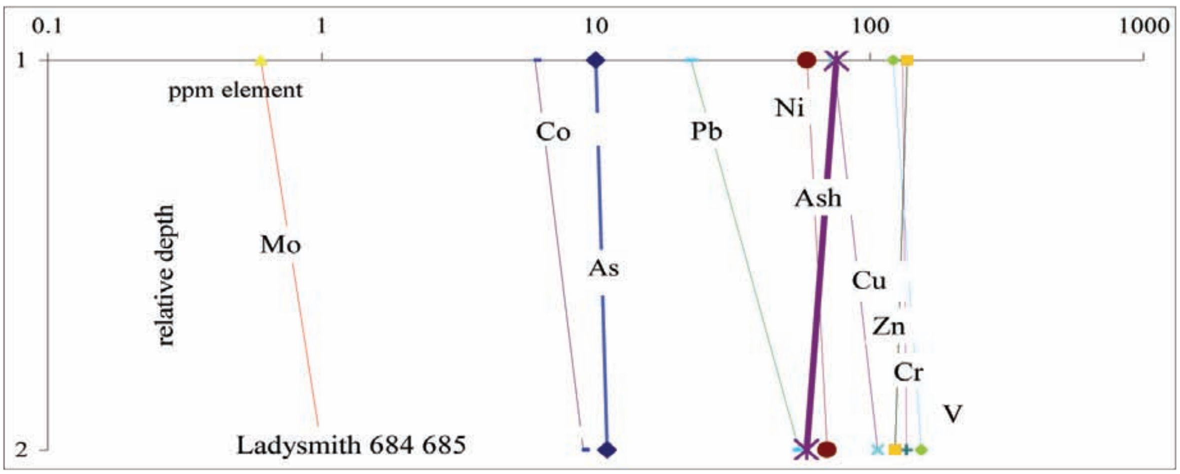


Figure 12d: Depth profile data for major and trace elements for locations Ladysmith. Relative depths are surface and approximately 20 cm and 50 cm.





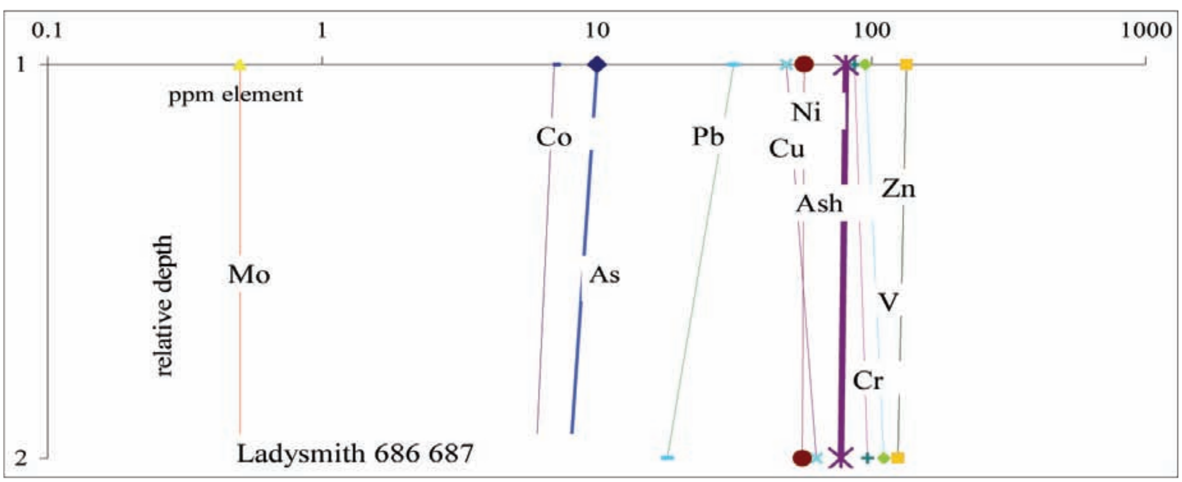


Figure 12e: Depth profile data for major and trace elements for locations Ladysmith. Relative depths are surface and approximately 20 cm and 50 cm.

Union Bay beach is characterized by heavy iron staining and samples (644, 645, 646) (647, 648, 649), and (650, 651, 652) were collected at different depths in 3 test holes dug on this beach. There are no major changes in trace or major element chemistry with depth down to about 0.7 m at the bottom of the holes. Samples of the heavily rust-stained section at the surface have higher concentrations of iron and molybdenum, and in all 3 profiles sulphur decreases with depth. The material is weathered refuse from which most of the pyrite probably has been oxidized to yield sulphates and iron oxides. Samples generally have high ash contents, and this influences major oxide and trace metal concentrations in terms of comparisons to coal with less ash. Swaine (1990) provides a table of average trace element concentration in coal, soils, and shale, and Van Der Flier-Keller and Goodarzi (1992) provide average trace element and major oxide contents for coals from the Comox and Nanaimo coalfields. Data from these sources are plotted with average data from Union Bay (Figure 13). It is apparent that the Union Bay data plot in between average coal and average shale and have higher contents of most elements than do the Nanaimo and Comox coals. This is probably because the Union Bay samples have higher ash contents, which range from 30% to 94% and are generally higher than the coal samples analysed by Van Der Flier-Keller and Goodarzi (1992).

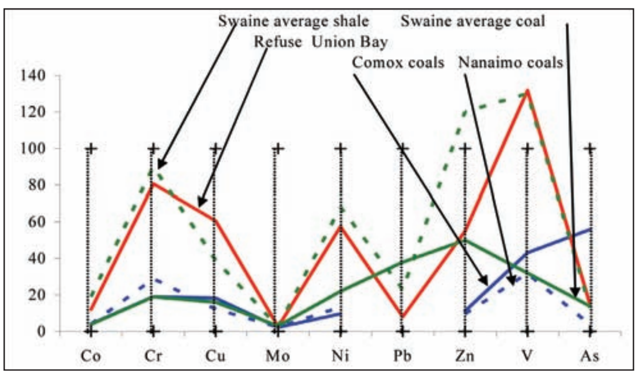


Figure 13: Comparison of trace metal data for Union Bay and Comox and Nanaimo coals.

Sized Data

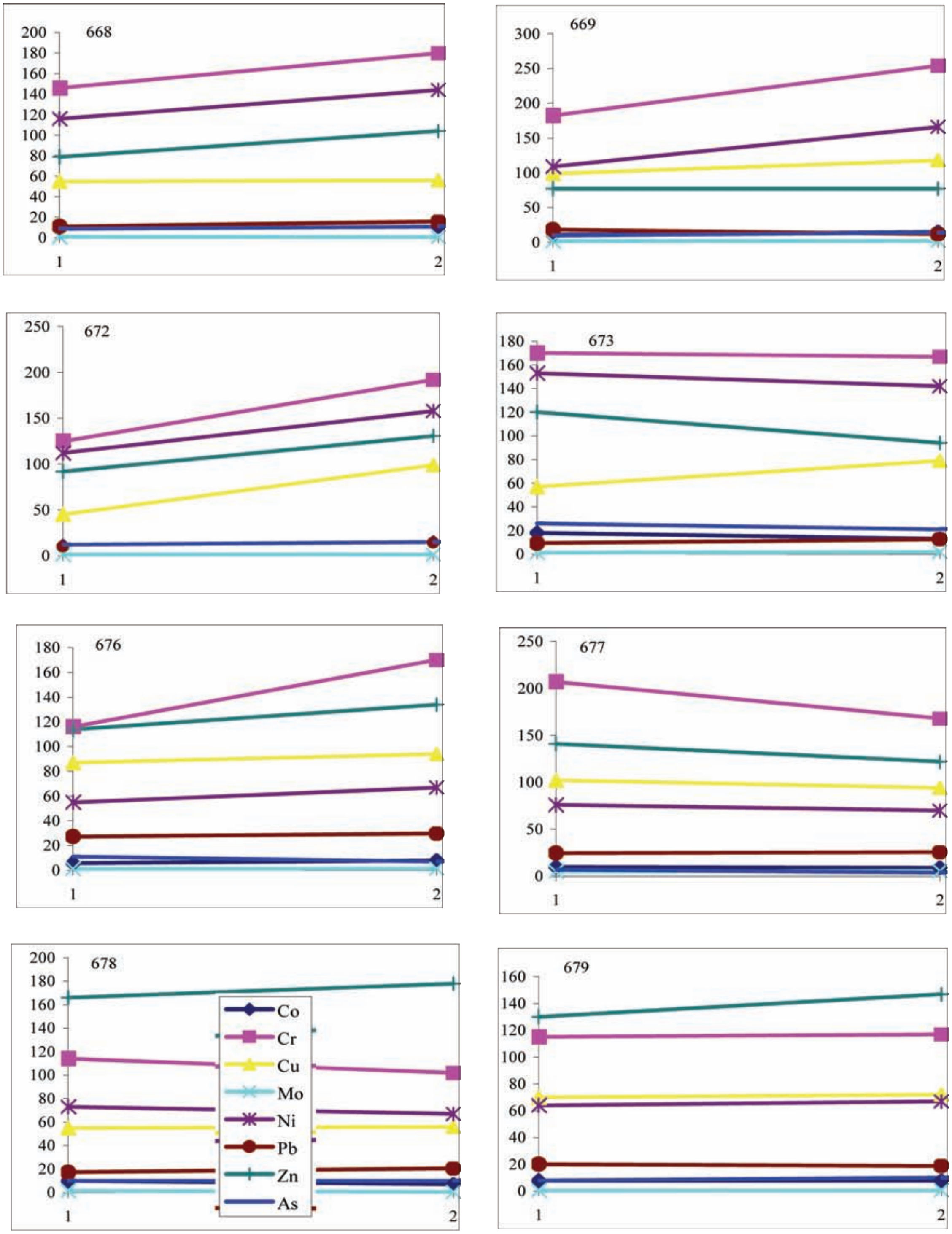
A number of samples were split, and one split from each sample was screened into coarse and fine fractions (8-mesh). Both the original split and the fine-fraction split were analysed by XRF and ICP-MS. Comparing analyses for the original and fine-fraction splits should provide indications of fractionation of elements by particle size and possible mobility of trace elements out of fine fractions. Data (Figure 14 a and b) do not indicate any consistent pattern of element distribution. Major element concentrations change little from the original split (numbered 1 on the x axis in the figures) to the fine-fraction split (numbered 2 on the x axis in the figures). Trace element concentrations are more variable but still do not provide a consistent pattern.

Heat Value

The heat value of coal is dependent on organic carbon and volatile matter contents of samples. It decreases with oxidation of coal and destruction of volatile matter, but generally the decrease is not large. In this study, the heat value of the samples has not been degraded, based on a plot of calorific value (dry basis) versus ash (dry basis) (Figure 15), which compares heat values for fresh coals from the Comox and Nanaimo Basins (Coal Quality Catalogue 1992) to the samples in this study. The zero-ash heat value for all samples averages about 7929 kcal/kg, compared to 7993 kcal/kg for fresh coal samples from Nanaimo and Comox coal basins. The main influences on heat value of coal are ash and moisture contents. A sample with 20% ash (dry basis) and 10% water would have a gross calorific value of 5555 kcal/kg (Figure 15). This is a useable heat value, though the ash chemistry becomes important, because boilers must handle and remove large quantities of fly ash or slag.

As an aside, it is important to understand the difference between measured heat values (gross as-received, or GAR) and useable heat (net as-received, or NAR). In a power plant, the moisture associated with the coal is heated and then converted to steam when the coal is burnt. This heat is generally lost, and this is part of the reason that NAR heating value is less than GAR heating value. A gram of water at 20 ºC will require 620 calories if it is heated and turned into steam. Consequently, coal with 10% moisture will lose, when burnt, about 62 calories because of water. This means that a 40% ash sample with about 5000 kcal/kg air-dried basis (adb) will actually have about 6% less useable heat, in part because there is 10% less material and in part because of the lost 62 calories.

Tidal samples from Union Bay appear to have higher heat values than other samples at comparable ash contents (Figure 15). These samples (644, 645, and 646) were collected from a flat area of beach covered by a prominent iron-oxide staining. The heat value may be influenced by recent organic matter.



y scale is ppm
X scale 1= sample as collected 2= fine fraction

Figure 14a: Comparison trace metal data from original samples and fine fraction of samples.

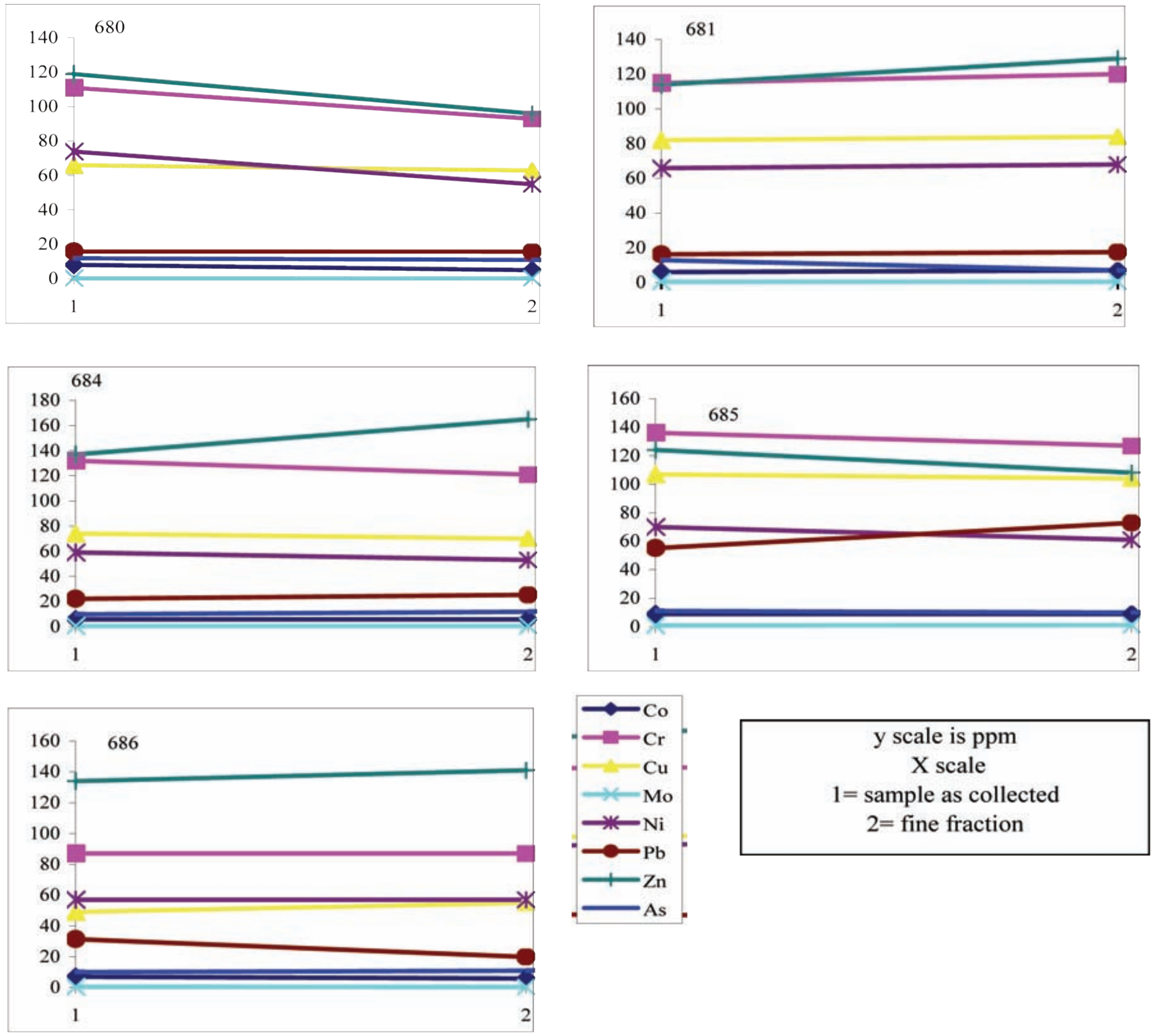


Figure 14b: Comparison trace metal data from original samples and fine fraction of samples.

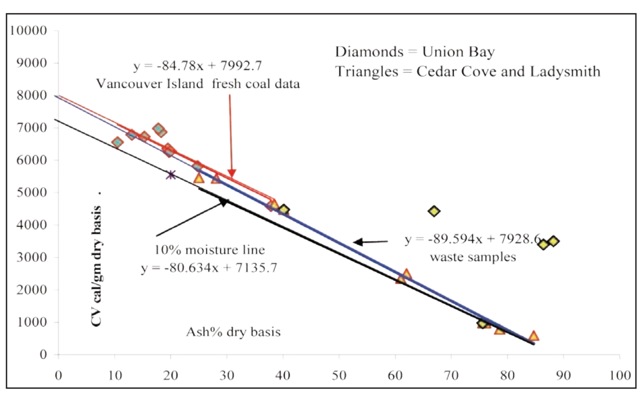


Figure 15: Heat value of fresh Vancouver Island coals and weathered samples from Union Bay, Cedar Cove, and Ladysmith Slag Point.

CONCLUSIONS

The data provide some background information on the major and trace element chemistry of the coal refuse material on and near beaches along the east coast of Vancouver Island. Generally, coal waste is fairly benign, unless it contains high concentrations of pyrite that can release trace metals and generate acid-rock drainage. Samples collected in this study generally do not have abnormally high concentrations of trace metals or high concentrations of pyrite. There is no indication that they are releasing metals into the environment. It is possible that all or most of the pyrite is already oxidized and trace metals released and migrated out of the samples.

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