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EVIDENCE FOR GEOTHERMAL TUNGSTEN AND GERMANIUM MINERALIZATION IN EOCENE COAL AND ASSOCIATED SEDIMENTS, FORT HAMLIN HILLS AREA, INTERIOR, ALASKA

by
James C. Barker

Geothermal spring (locality 'B,' figure 5, table 6) that, until now, has not been reported in any literature or maps.

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EVIDENCE FOR GEOTHERMAL TUNGSTEN AND GERMANIUM MINERALIZATION IN EOCENE COAL AND ASSOCIATED SEDIMENTS, FORT HAMLIN HILLS AREA, INTERIOR, ALASKA

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James C. Barker[1]

ABSTRACT

Eocene-age coal and associated mudstones near the Fort Hamlin Hills in central interior Alaska are highly enriched in tungsten and other metals. Coal is found in small, semi-closed basins along the Ray River to the west of the Fort Hamlin Hills and the Dall River. Metals are most concentrated in calcium-rich coal ash; tungsten, germanium, and lead are each found to range as high as 1 percent or more. In addition, gold, gallium, and uranium are generally elevated, and most samples contain anomalous zirconium and rare-earth elements. Coal in the Fort Hamlin Hills area has an apparent rank of high-volatile, lignite A to subbituminous B, and generally has a 6–10 weight percent ash yield. Maceral composition is dominated by vitrinite.

Higher metal values occur in high-sulfur (>1.4%) coals in the Ray River valley as compared to unmineralized low-sulfur (<0.2%) coal in the neighboring Dall River valley. Mudstones that lie stratigraphically above the coal deposits in the Dall River valley generally contain 50 to 190 ppm tungsten.

Microprobe studies suggest the mineralization found in coal of the Ray River mostly occurred in peat beds prior to, or concurrent with, diagenesis and coal formation. Mineralization is likely related to geothermal activity associated with rifting in a granitic terrane and volcanism. Water samples from present nearby hot springs contain anomalous levels of tungsten. Mineralization in peat accumulations or coal was likely accentuated due to Oligocene fissure basalts that entrapped the geothermal waters in the coal-forming section. Mudstones in the Dall River valley containing tungsten likely formed as Eocene-age lacustrine deposits in shallow lakes fed by geothermal water and intermittently covered by ash falls.

INTRODUCTION

The Fort Hamlin Hills region is located immediately north of the Yukon River, within the densely wooded rolling hills of northern Interior Alaska (fig. 1). The area is approximately 150 mi (241 km) northwest of Fairbanks via the Dalton Highway. The Alyeska Pipeline closely parallels the highway. While the study area extends from the bridge crossing the Yukon River north about 20 mi (32 km) to No Name Creek, most sampling was done along the Ray River, within 3 mi (5 km) of the Dalton Highway. It is densely vegetated and features very little bedrock exposure. Little was known of the geology prior to the pipeline construction in 1975–1977.

Investigations of mineral resources in the region, including this project, were conducted intermittently by the U.S. Bureau of Mines (USBM) between 1975 and 1989. This report, in process at the time of USBM's dissolution (1994), is one of a series of investigations to examine possible resources of strategic and critical minerals in Alaska.

Indications of high metal concentrations in coal ash were first detected in 1985 during a routine series of analyses of ash from various Alaskan coal deposits that are situated near or within metallogenic terranes. It was then decided to further investigate the unusual metal concentrations found in coal located in the Fort Hamlin Hills area.

Elsewhere in the world, the trace element content of coal ash has been studied as a possible future source of minerals. Although little is known relative to tungsten in coal, considerable attention has been given to germanium and uranium (Queneau and others, 1988). Some limited prototype production has occurred.

The following report benefited from the technical review contributed by several colleagues. The author is indebted to Gary Stricker, USGS, and Roger Burleigh and Robert Hoekzema, both formerly with the U.S. Bureau of Mines, for their critiques and helpful suggestions.

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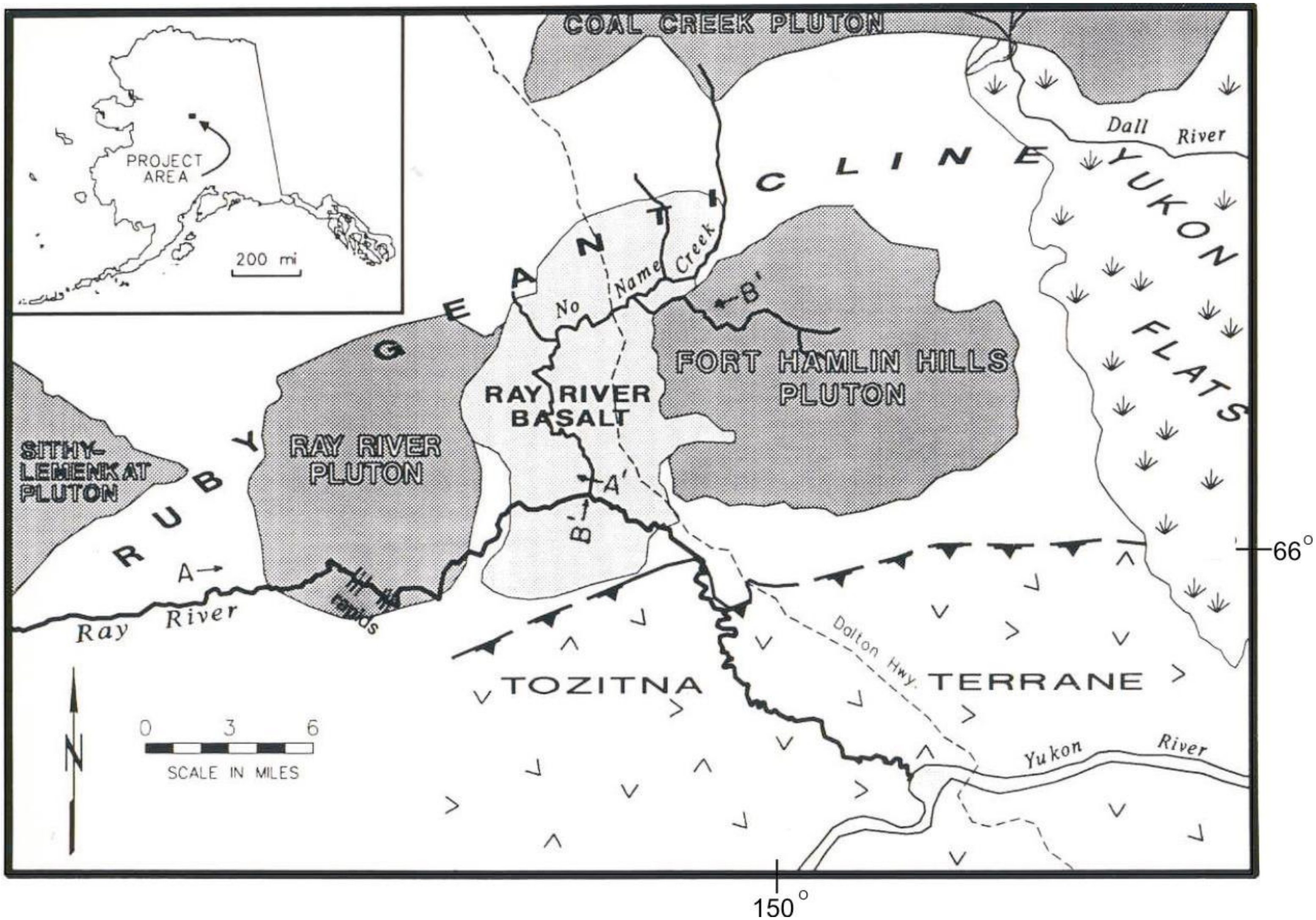


Figure 1. *Geologic setting of the Fort Hamlin Hills area.*

PHYSIOGRAPHY

The Fort Hamlin Hills form a gently rolling upland, marginal to the Yukon Flats. Coal-bearing sediments are found in adjacent small, semi-closed basins. Generally, an escarpment is observed where the Yukon Flats joins the marginal slopes, suggesting that an equivalent section extending under the Yukon Flats has subsided perhaps as much as a hundred meters or more. Streams entering the basin have all cut V-shaped canyons into the escarpment.

The entire region is covered with continuous, unbroken vegetation of muskeg and tundra with thick growths of alder, willow, aspen, and spruce forest, with accompanying dense underbrush. Vegetative growth is extremely cyclic and climaxes with spruce, which ultimately supports summer forest fires, burning as much as hundreds of thousands of acres at a time and destroying coal outcrops.

The area is underlain by discontinuous permafrost, however, permafrost will nearly always be found in all terrains except under active principal water channels, larger lakes, and highest elevations. Pingos and thaw lakes are occasionally observed on the marginal upland slopes and in highland valleys where thick deposits of ice-rich, fine-grained silt have accumulated.

The Fort Hamlin Hills and vicinity are within an intermontane region, noted for being one of the coldest (mean minimum January temperature of -28°F [–33°C] at Fort Yukon), warmest (mean maximum July temperature of 76°F [24.5°C]), and one of the driest areas of Alaska, only receiving approximately 8 in (20.3 cm) of annual precipitation (Williams, 1962).

METHODS

The Fort Hamlin Hills coal project extended over 6 years, during which time additional elements were discovered to be present other than those sought in the original samples. Consequently, several different analytical procedures and laboratories were ultimately utilized for an expanded list of elements. Quantitative data given in the tables are footnoted as to the analytical procedure used. In addition, semi-quantitative, multi-element scans of coal ash and geothermal water are given in the appendices.

Mudstone and tuffaceous samples were collected as channel samples across specific stratigraphic intervals. However, due to the lack of outcrop, the coal samples had to be collected as chips taken from random pieces of float on some gravel bars of the Ray River (fig. 2). Only one coal bed was found in outcrop, located on Coal Creek. Coal samples from gravel bars were carefully broken apart and washed of any entrained sand prior to laboratory preparation. Care was taken to limit sample collection to only relatively fresh coal cobbles that had not yet dried and slacked due to air exposure. Samples were placed in sealed plastic bags to preserve contained moisture.

In the laboratory the coal samples were pulverized, weighed, and dried. Splits were made for whole-coal analyses, grain mounts, and ashing by high temperature ashing procedures (ASTM, 1979). Samples were heated at 750°C for up to 15 hrs as necessary to produce 0.7–1.06 oz (20–30 g) of mineral ash.

In the field, geothermal water samples were tested for pH, vacuum filtered at 0.4 µm, and collected in 16.9 oz. (500 ml) sterile plastic bottles, then acidified ("fixed") with lab-grade nitric acid to avoid adsorption by the bottle walls.

PREVIOUS WORK

There is little information concerning trace element content in Alaskan coal, coal ash, or associated sediments. Rao (1968) reported on coals from the Alaska railbelt area and the North Slope, however, there were no samples from the Yukon River region. Among the elements Rao tested, elemental abundance for gallium, germanium, and lead in coal ash ranged from 19 to 48 ppm, 8.5 to 22 ppm, and 52 to 268 ppm, respectively. The coal was not analyzed for tungsten.

Coal occurrences in the Yukon Flats region, including the Fort Hamlin Hills area, are described and characterized by Barker (1981) and Barker and Goff (1986), however, no data on trace element values in coal ash were included. The 1981 report gave analytical data reporting anomalous tungsten values in mudstones in the Dall River valley located on the east side of the Fort Hamlin Hills and suggested possible similarities to Searles Lake, CA, where tungsten is associated with evaporitic sodium carbonate brine and lakebed mud. Sodium carbonate (trona) occurs on summer-time dry lakebeds along a northeast trend across the Yukon Flats (Barker, 1981; Clautice and Mowatt, 1981), beginning about 30 mi (48 km) east of the project area. The source of the trona deposits is presently unknown.

Regional mapping relevant to Tertiary through present geology in the region is compiled by Williams (1962). Geologic mapping at 1:63,360 scale specific to the Fort Hamlin Hills area was more recently completed by Barker (1991) in conjunction with assessment of tin placer potential in the Ray River watershed.

Figure 2. *Coal float found on certain river bars of the Ray River*

BEDROCK GEOLOGY

The Fort Hamlin Hills area includes several granitic plutons that intrude Paleozoic schist, phyllite, quartzite, greenstone, and limestone along the southeast flank of the Ruby Geanticline (fig. 1). The geanticline forms a broad northeast-trending belt of crystalline rock in north-central Alaska (Arth and others, 1989), which, near the Fort Hamlin Hills, is flanked on the south by north-thrusted rocks of the Tozitna Terrane (fig. 1).

As elsewhere in the Interior, bedrock exposure is scarce. The oldest rocks of the Ruby Geanticline are quartz–mica schist, light-colored quartzite, and phyllite, which exhibit thermal alteration in the vicinity of the granitic intrusions (fig. 1). These rocks are overlain by a younger Paleozoic quartzite and limestone unit that is altered to marble and calc-silicate rock near the plutonic contacts.

Granitic rocks (Kg) (fig. 1) generally underlie the higher terrain and may be continuous at shallow depth. They are separated from each other by approximately flat-lying flows of fissure basalt and Tertiary sedimentary rock, preserved in obscure graben-like basins. Major oxide analyses indicate the plutons are peraluminous calc-alkaline granite (Barker, 1991). The Fort Hamlin Hills, Sithylemenkat, Ray River, and Coal Creek plutons are considered to be among more than a dozen similar Cretaceous-age (105–115 ma) plutons in the Ruby batholith (Arth and others, 1989).

Tertiary-age, coal-bearing sedimentary rocks (Ts) include shale, tuffaceous mudstone with ash beds and tuff, arkosic sandstone and conglomerate, and lignitic coal. Mudstones and arenites generally contain carbonized plant fragments, and fossilized resin is common in coal. Regressive weathering of the Tertiary rock and particularly the susceptibility of coal to forest fires limit exposure of the Tertiary unit to only a few outcrops, however, pieces of coal float on gravel bars of the downcutting Ray and Dall Rivers suggest that Tertiary rocks underlie much of the valley floors.

The Tertiary-age rocks were largely deposited during the early- to mid-Tertiary. Interpretation of sparse outcrops suggests sedimentation was originally high-energy fluvial gravel that evolved into lower-energy fine-grained sediment deposition in lakebeds and peat bogs, which were cut by meander channels and intermittently covered by ash falls (fig. 3). The older Tertiary sediments are upward-fining sequences of well-rounded, quartz-pebble conglomerate and sandstone that are best exposed at Lat 66° 02’, Long 150° 16’, and also seen along Coal Creek. Possibly younger Tertiary rocks are exposed near Lake 392 (Lat 66° 00.5’, Long 150° 10’), where a bedrock knob is composed of arkosic conglomerate and shale. The youngest Tertiary section in the Ray River valley is exposed in an outcrop 2 mi (3.2 km) upstream of the mouth of No Name Creek, where a 50-ft-thick (15-m-thick) sequence of coaly volcanic ash and mudstone, carbon-rich volcaniclastic rock, coal, arkosic (granitic) sands, and semi-consolidated, white-weathering fluvial gravels are overlain by basalt. On Coal Creek, alternating beds of mudstone and water-lain tuff overlie an 18-ft-thick (5.5-m-thick) coal bed. A K-Ar age determination on an ash bed in this section gave an Eocene date of 38.6 ± 1.6 ma (fig. 3; Barker, 1981).

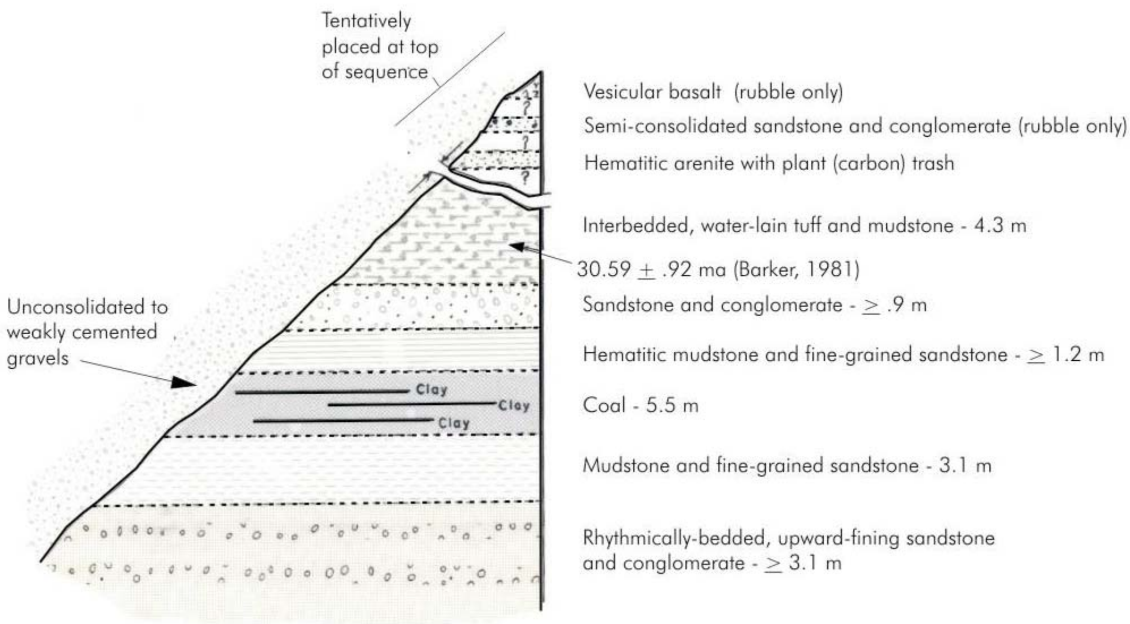


Figure 3. *Composite section of coal-bearing rocks at Coal Creek.*

Tertiary basalt lavas (fig. 4) form the youngest bedrock unit and are inferred to cover about 60 square mi (155 square km) of the Ray River drainage and a smaller area on the Dall River. Both the Ray and Dall rivers have breached the basalt flows and cut into the underlying pre-Tertiary rock units. Texture of the basaltic rock ranges from vesicular to massive, and compositions vary from olivine basalt to andesite. Vesicles are locally filled with calcite, quartz, or native sulfur. At the outcrop on the Ray River, 2 mi (3.2 km) upstream of No Name Creek, at least three flows of columnar jointed basalt are stacked together. The total section of basaltic flows is about 200 ft (65 m) thick, flat lying, and lies between 475 and 725 ft (150 and 235 m) in elevation.

Albanese (1987), who examined a basalt flow exposure in a road cut 3 mi (4.8 km) south of No Name Creek, suggested a tholeiitic or alkaline affinity comparable to basalts from extensional systems. The flows near No Name Creek, for which an age determination by K-Ar methods reported an Oligocene date of 30.59 ± 0.92 ma (Albanese, 1987), have no exposed source.

STRUCTURAL RELATIONSHIPS

The project area is included in the Ruby Geanticline crystalline terrane (Arth and others, 1989). Mafic volcanic rock, gabbro, and chert of the Tozitna Terrane abut the Ray River area to the south along a poorly exposed overthrust boundary (fig. 1). Evidence of this nearly flat-lying thrust fault can be viewed where the fault crosses the Ray River, where Jurassic andesite lies in fault contact on Paleozoic phyllites.

The Tertiary coal-bearing rocks have been structurally disrupted by apparent dip-slip faulting that has created a series of small, obscure, graben-like, stepped basins containing the Tertiary rocks. An example of a dip-slip fault contact between the basalt and older Tertiary sediments is visible in the outcrop 2 mi (3.4 km) above the mouth of No Name Creek, and others can be inferred from aerial photography. Consequently, the coal-bearing unit is found at decreasing elevations toward the center of graben-like features between the plutons (fig. 4). Each of these basins contains Tertiary coal-bearing rock near, or below, the elevation of the valley floor as indicated by local concentrations of coal rubble only on gravel bars. An interpretive cross-section shown in fig. 4 demonstrates the structural relationships as viewed along the valleys of No Name Creek and the Ray River. In the intervening area between the Fort Hamlin and Ray River plutons, Tertiary rock or rubble occurs in basins at progressively lower elevations of 425, 400, and 375 ft (140, 130, and 120 m). Coal is also found on gravel bars at 625 ft (200 m) immediately west of the Ray River pluton and at 350 ft (115 m) near the Tozitna Terrane overthrust.

Much of the inferred extent of Ts is, or was formerly, overlain by basalt flows. The base of the Tertiary basalt flows could only be examined in the previously mentioned Ray River outcrop, where it overlies Tertiary coaly sediments and exhibits a carbonaceous contaminated basal zone. A quenched fracture stockwork, including thin (0.1 in, 2 mm) selvages of obsidian and traces of phosphate staining, occurs at the river level and signifies the abrupt end of organic accumulation in a wet peat bog.

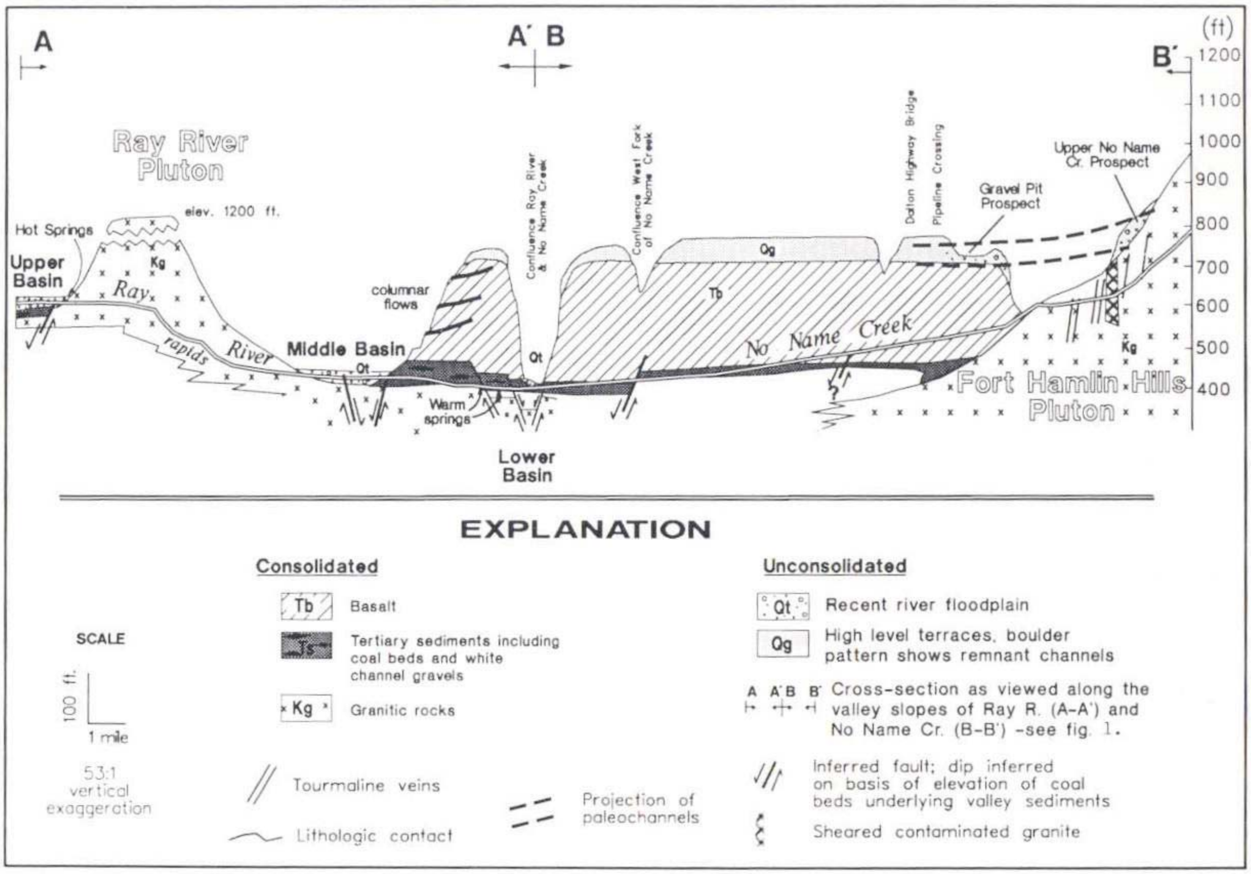


Figure 4. *Valley slope profile.*

CHARACTERIZATION OF COAL

Coal occurrences in the Ray and Dall River basins are characterized by Barker (1981). Coal samples collected during this project were submitted to the University of Alaska, Mineral Industry Research Laboratory (MIRL), Dr. P.D. Rao, Supervisor, for standard ASTM tests and analyses as specified and reported in the following tables and polished section petrography. Most samples examined are bright, subbituminous vitreous coal that breaks with a concoidal fracture; other pieces of coal are dull black to dark gray due to high ash content. Apparent rank of coal in the Fort Hamlin Hills area is similar to, or higher than, elsewhere in Interior Alaska (Merritt and Hawley, 1986) and varies from lignite A to subbituminous B, with heating value generally between 9,000 and 12,000 Btu on a moisture-free basis (table 1). Reflectance tests usually give values of 0.33 to 0.45. In polished sections, coal specimens appear to be largely vitrinite with small irregular areas and broken fragments of cellular fusinite. Isolated masses of macrinite indicate drier woody source material.

Ash yield by weight of most coal samples is 6–10 percent, however, some coal specimens were found to contain much higher levels of ash, up to 40 percent (e.g., sample location 13 with 20 percent ash, table 1). A few specimens were found with interbedded black vitreous, low-ash coal, and dull gray-black, high-ash coal.

The Dall River coal is lower in sulfur than coal found along the Ray River. Typical of most Alaskan coal (Merritt and Hawley, 1986), the Dall River coal deposits contain 0.22–0.24 percent total sulfur (three samples tested, Barker, 1981). Six Ray River samples tested for sulfur show a marked contrast (table 1, fig. 5) and, although they are similar in other measured parameters, total sulfur ranges from 1 to 2 percent on a moisture-free basis.

Table 1. Proximate analyses[1] of coal from Ray River.

Sample Number	Map Location Number	Basis	Moisture, %	Ash, %	Volatile Matter, %	Fixed Carbon, %	Heating Value, BTU/lb	Total Sulfur
RM24723	16	1	27.47	2.41	36.08	34.05	9049	1.31
		2		3.32	49.74	46.94	12476	1.80
		3			51.45	48.55	12904	1.86
RM24727	18	1	27.94	4.74	35.53	31.79	8539	1.05
		2		6.57	49.31	44.12	11851	1.46
		3			52.78	47.22	12684	1.56
RM24726	19	1	26.49	7.00	33.64	32.87	8033	1.49
		2		9.52	45.76	44.72	10928	2.02
		3			50.58	49.42	12078	2.24
RM24725	20	1	26.91	7.25	33.87	31.97	7807	1.05
		2		9.92	46.34	43.74	10679	1.43
		3			51.44	48.56	11857	1.59
PB10386	7	1	--	--	--	--	--	--
		2		10.49	43.87	45.64	10371	1.54
		3			49.01	50.99	11598	1.72
PB10384	13	1	--	--	--	--	--	--
		2		20.39	24.81	54.80	9403	1.11
		3			31.17	68.83	11823	1.39

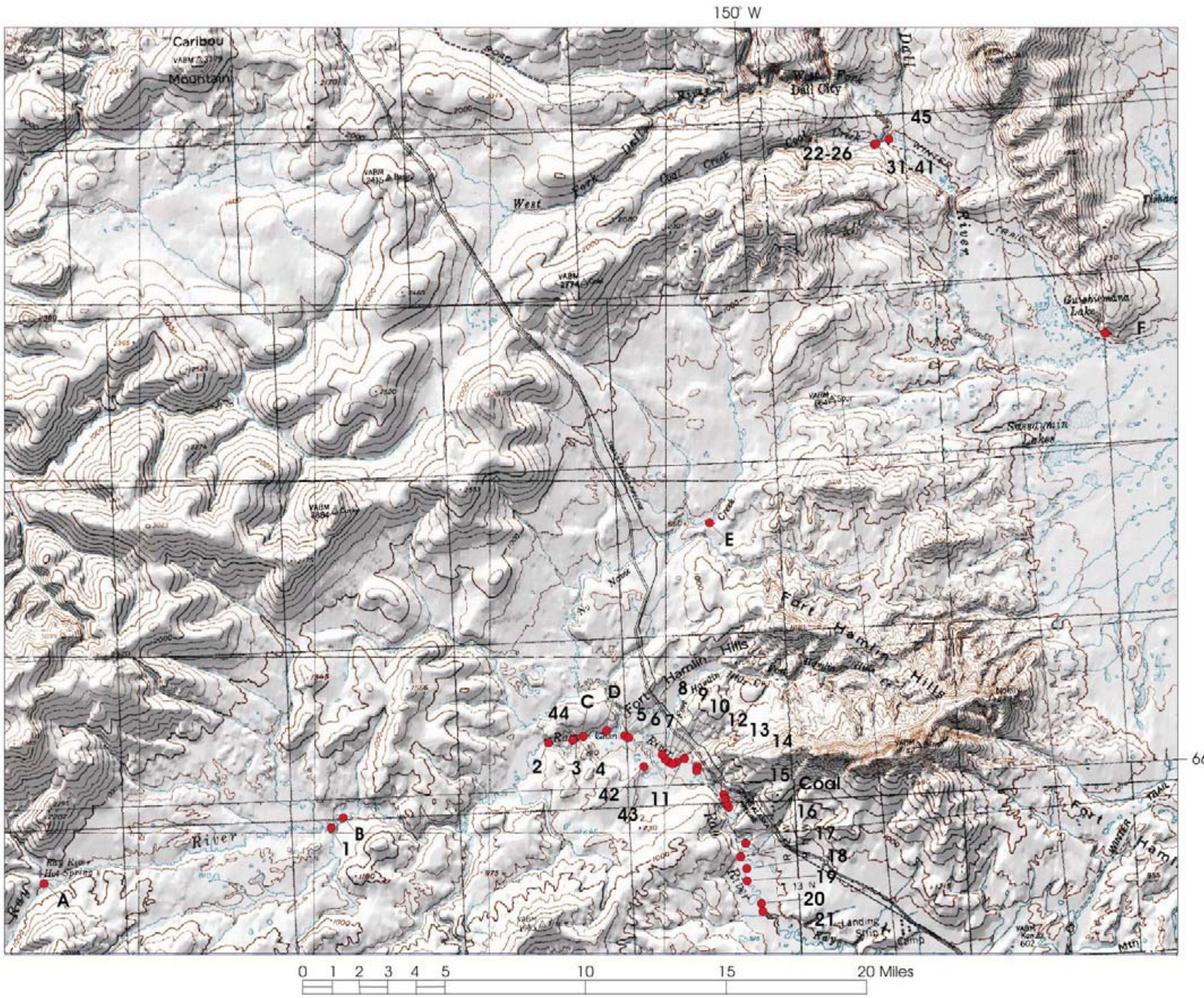
Basis Legend: 1 = as received
2 = moisture free
3 = dry, ash free
-- = not analyzed

[1] Proximate analyses of coal determined by University of Alaska Mineral Industries Research Laboratory, using standard ASTM testing procedures

GEOCHEMISTRY OF TERITARY COAL AND MUDSTONE

Valkovic (1983) noted that elemental concentrations in coal reflect the elemental composition of the coal-forming material, properties of the depositional environment, and processes that were active during the coal-forming period. The abnormal metal concentrations found in the Fort Hamlin Hills area reflect metal uptake by either live vegetative material or at some point during the coal-forming period (tables 2 and 3, appendices A and B). Ash prepared from coal samples collected as float in the Ray River streambed can also be characterized as high calcium (>10 percent Ca, appendix B).

Mudstones in the Dall River vicinity and at least one site in the Ray River valley are notably manganese stained and radioactive (200–400 cps relative to a background of about 50 cps). Manganese content ranges from 1,000 to 4,000 ppm (table 4). Uranium content up to 50 ppm accounts for the observed radioactivity (Barker, 1981). In the Dall River valley, mudstone intervals can be readily distinguished from tuff beds by the latter's lower radiometric response. No discrete uranium minerals could be distinguished by X-ray diffraction.



A Geothermal spring. Analyses in Table 5.

12 Sample location. Analyses in Tables 1-4 and Appendices A-C

Coordinates of all samples in Table 6.

Figure 5. *Sample location map.*

Table 2. Trace element analyses (in ppm) of whole coal and coal ash from the Ray River basin.

Map Location Number	Sample Number	Coal Ash[1]						Whole Coal				
		% Ash	W	Pb[2]	U[3]	Ga	Ge	W[4]	Pb[4]	U[3]	Ga	Ge[2]
1	RM26004	14.68	2,300[4]	332	3,090[5]	820[2]	12,200[6]	--	--	--	--	--
2	RM26097	5.95	11,000[6]	248	94[5]	70[2]	700[2]	375	17	5.4	--	50
3	RM27598	--	1,000[4]	325	155	--	<5[2]	175	79	46.8	--	<5
4	RM25739	--	1,900[3]	--	--	--	--	26	--	13.0	--	<10
5	RM25445	6.70	3,790[5]	375	322	--	322[7]	--	--	--	--	--
6	RM25446	8.70	2,730[5]	255	171	--	1,433[7]	--	--	--	--	--
7	PB10386	9.00	3,420[3]	--	467	--	<310[3]	--	--	--	--	--
8	RM26098	10.09	7,400[4]	120	450[5]	110[2]	300[2]	325	16	35.3	--	20
9	RM25447	8.10	5,190[5]	970	311	--	143[7]	--	--	--	--	--
10	RM25448	15.90	1,660[5]	18,800[6]	299	--	108[7]	--	--	--	--	--
11	RM27560	--	--	--	--	--	--	90	28	28.2	--	70
12	RM25449	39.10	424[5]	1,000	147	--	48[7]	--	--	--	--	--
13	PB10384	18.00	85[3]	--	78	--	<230[3]	--	--	--	--	--
14	RM25450	6.20	308[5]	5,400	44	--	18[7]	--	--	--	--	--
15	RM26358	6.38	3,700[4]	54	52[7]	92[2]	140[2]	65	12	4.5	--	30
16	RM24723	3.32	19,400[4]	133	--	53[7]	IS[8]	--	--	--	--	--
17	RM27563	--	3,690[6]	--	--	--	--	125	8	15.7	--	70
18	RM24727	6.57	14,900[4]	50	--	137[7]	900[6,8]	--	--	--	--	--
19	RM24726	9.52	5,500[4]	554	--	181[8]	100[6,8]	--	--	--	--	--
20	RM24725	9.92	1,900[7]	<2	--	133[8]	<100[6,8]	--	--	--	--	--
21	RM27564	--	7,130[6]	--	--	--	--	275	10	27.7	--	150

IS = insufficient sample material
-- = not analyzed

1 percent ash determined on moisture-free basis
2 analyzed by atomic absorption spectrography
3 analyzed by neutron activation
4 analyzed by colorimetric procedure
5 analyzed by x-ray fluorimetric procedure
6 assay by chemical extractions
7 analyzed by inductively coupled plasma procedure
8 analyzed by DC plasma emission

Table 3. Trace element analyses (in ppm) of coal ash from the Dall River basin.

Map Location Number	Sample Number	% Ash[1]	W[2]	Pb[3]	U[2]	Ga	Ge[4]
22	HZ25636	5.52	205	280	29.5	--	<10
23	HZ25638	--	9	350	71.9	--	<10
24	HZ25639	--	23	200	30.2	--	<10
25	HZ25641	5.22	18	310	6.6	--	24
26	HZ25642	18.87	210	280	7.7	--	38

-- = not analyzed
[1] percent ash determined on moisture-free basis
[2] analyzed by neutron activation
[3] analyzed by atomic absorption spectrography
[4] analyzed by inductively coupled plasma procedure

The mudstone is interbedded with units of water-lain tuffs, generally 0.1 to 1.0 ft (3.5 to 30.5 cm) thick. The rocks are phosphatic; a mudstone sample analyzed for major oxides contained 1.60 percent P_2O_5 and 3.1 percent CaO (Barker, 1981, sample HZ10272), and similar rocks in the Hodzana River valley, 40 mi (64 km) to the east, contain spheroids of vivianite [$Fe_3(PO_4)_2 \cdot 8H_2O$] and bedded zeolite. Mudstone near the Dall River is also cut by 0.04-in-thick (1-mm–thick) veinlets containing hydroxylapatite [$Ca_5(PO_4)_3(OH)$].[2]

Mineralized coal was found only in the Ray River valley. Because coal does not outcrop, it is not possible to evaluate correlation of metal content to coal stratigraphy. Analytical results from 21 samples of Ray River coal (table 2 and appendices A and B) demonstrate that while tungsten and, to a lesser extent, germanium are highly concentrated in most samples, other metals (rare earth elements, gold, yttrium, zirconium) are more variable and may suggest vertical zonation or some local concentration phenomena.

Concentration of tungsten in coal ash shows no positive correlations to the mineral matter in the coal. Percent ash is inversely related to the tungsten content in the coal (fig. 6). Studies elsewhere have shown metal values in coal concentrate in the macerals (vitrinite), not in the inorganic mineral material (Eskenazy, 1982; Queneau and others, 1988). In the Fort Hamlin Hills area, coal samples that are diluted with abundant ash contain correspondingly less organic material and consequently have lower metal values.

Other elements appear to be horizontally zoned at a larger scale. For instance, lead is strongly present in samples in the upstream portion of the Ray River valley.

[2] Analyses by X-ray diffraction, Nam Veach, Alaska Division of Geological & Geophysical Surveys

Table 4a. Trace metal concentrations in mudstone and tuffaceous sediments.

Map Location Number	Sample Number	Analyses[1], ppm												
		Au	As	Ba	La	Ce	Mo	Mn	Sm	W	U	Zn	Zr	Y
31	HZ25647	L	52	400	75	180	8	--	14	190	23	L	700	60[2]
32	HZ25643	L	42	770	58	160	4	--	10	64	14	L	L	39[2]
33	HZ15530	--	43	5,841	12	23	--	760	3	94	5	--	243	--
34	HZ15529	--	58	L	73	173	--	4,159	16	105	25	284	170	--
35	HZ15531a	L	51	490	76	260	9	--	14	69	31	L	L	66[2]
36	HZ15531b	--	71	L	85	221	--	3,566	19	73	30	L	161	--
37	HZ15535	L	52	620	64	180	--	--	14	51	30	L	L	51[2]
38	HZ15533	--	97	742	78	163	--	1,581	14	68	28	233	168	--
39	HZ15536	--	30	234	31	68	--	--	5	L	6	L	86	--
40	HZ25637	L	118	370	8	21	3	--	2.6	L	4	L	L	L[2]
41	HZ15578	L	27	5,200	211	290	L	--	35	130	16	L	890	--
42	RM27184	--	--	--	60	--	--	--	-	18	13	--	--	--
43	RM27559	--	--	--	--	--	--	1,400	--	60[2]	23	--	--	--
44	RM26038	L	--	--	--	--	--	--	--	140[2]	6	--	--	33
45	HZ15576	--	87	L	89	174	--	4,197	18	105	26	288	167	--
Detection Limit		.005	1	100	5	10	2	100	0.1	2	0.5	100	10	1

[1] analyses by neutron activation procedure, except Y by inductively coupled plasma or as otherwise noted
[2] analyses by x-ray fluorescence
-- not analyzed
L less than detection limit; lower limits are matrix affected and may be higher in specific samples

Table 4b. Descriptions of mudstone and tuffaceous sediment samples.

Map Location Number	Description
31 – 41	See figure 3, Dall River area; samples 31-39 are from individual mudstone beds from the "interbedded, water lain tuff and mudstone" unit. Samples 40 & 41 are from mudstone rubble of unknown position in the section.
42	Mudstone rubble in slump, Ray River area, near Lake 392.
43	Thermally altered and brittle laminated shale, volcanic rubble nearby, Ray River area, near Lake 392.
44	Coarse-grain composition of angular pyroclastics, quartz pebbles, and soft tar-like carbonaceous matter, Ray River 2 miles upstream of No Name Creek.
45	Grab sample mudstone, confluence of Coal Creek and Ray River.

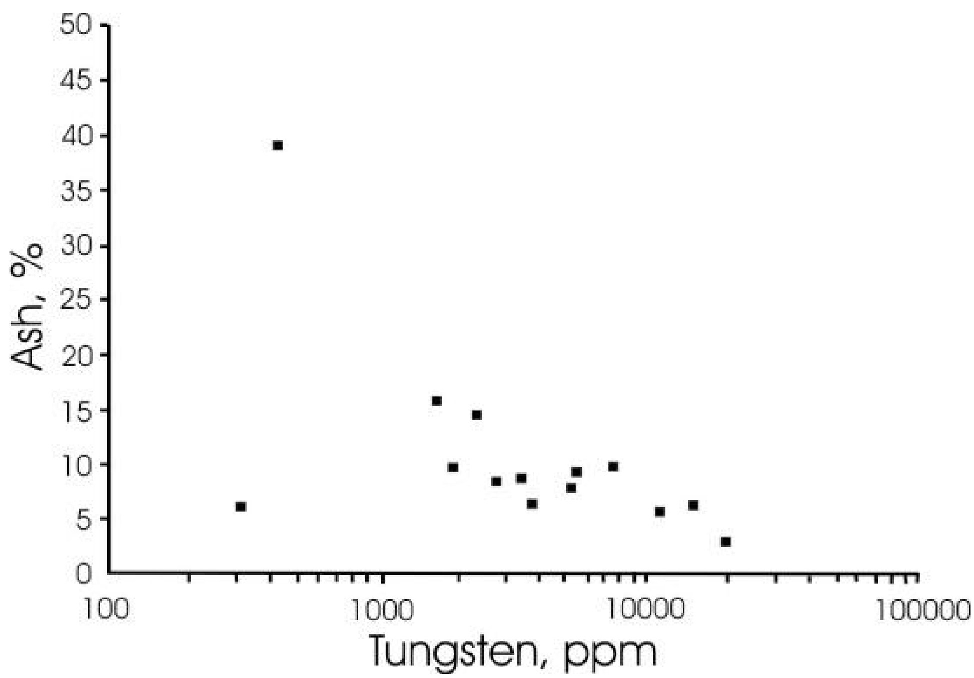


Figure 6. *Plot indicating an inverse relationship between ash and tungsten.*

CHARACTER OF GEOTHERMAL WATERS

A northeast alignment of six geothermal seeps and springs occurs in the Fort Hamlin Hills area (fig. 5); farther to the west, hot springs at Kilolitna and Istahlana also align with this trend. Five of the sites were sampled to determine if tungsten, lead, uranium, and possibly other metals are contained as mobile metal ions in geothermal waters[3]. Geothermal site E (fig. 5) had insufficient flow to permit collection of a non-turbid sample, so no sample

[3] Samples from map locations A, F-1, and F-2 were provided by S. Liss, Alaska Division of Geological & Geophysical Surveys

was collected. Analytical data for tungsten, lead, and uranium are given in table 5, and multi-element analyses are included as Appendix C. Spring waters are basic (pH 8 to 9) and contain minor concentrations of alkali metals.

Very little is published regarding concentration of tungsten in natural waters. Ground waters from siliceous igneous rocks generally are relatively low in mineral content. Hall and others (1988) studied the tungsten and molybdenum content of natural spring waters (cold and thermal) in the South Nahanni area of Northwest Territories, Canada. This area includes major scheelite skarn tungsten deposits (for example, the Cantung deposit). Some samples were located near tungsten occurrences. Anomalous areas were defined by the authors as >15 µ/l tungsten. Primary tungsten minerals (scheelite and wolframite) are resistant to chemical weathering, however, tungsten as WO_4^{-2} can be quite mobile in increasing alkaline conditions (Hall and others, 1988). Geothermal springs in the Fort Hamlin Hills area contain up to 200 µ/l tungsten (table 5, five of nine samples tested contain more than 200 µ/l).

High calcium content in Ray River coal ash (appendix B, all samples exceeded detection level of 10 percent Ca) suggests a calcic alkaline groundwater paleo-environment preceding or during the coal forming process.

Table 5. Analyses[1] of geothermal water samples (in µg/l).

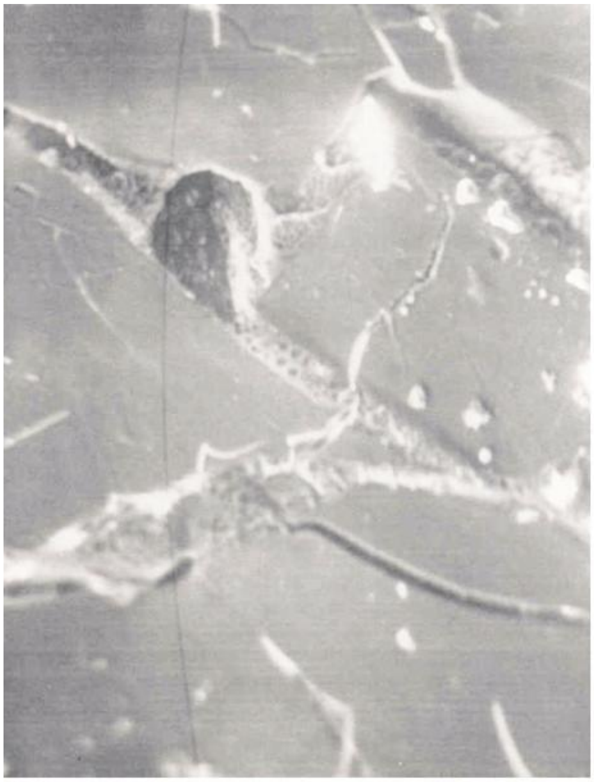
Map Location Number	Sample Number	Description	W	Pb	U
A	26360	Estimated total flow is 650 l/min; maximum temperature 44.2ºC; pH=8.7; at least 4 seeps.	L	L	L
B-1	26362	Estimated total flow is unknown but as large or larger than at sample A, numerous seeps along gravel bar for about 400 ft approximately along a trend of 310º; maximum temperature 63ºC; pH 8.6 at sample site.	200	L	L
B-2	26001	See B-1 above, temperature 62ºC at sample site; pH 8.7.	200	16	0.08
B-3	26003	See B-1 above, temperature 22ºC at sample site; pH 8.0. This seep is a warm pool of red-brown colored water that is favored by wildlife.	200	16	10.03
C	25735	Minor seeps on left limit river bank, estimated flow 5-10 l/min from several seeps along 100 ft; maximum temperature 18ºC; pH 7.6.	40	L	L
D	25734	Iron-stained seep below left-limit gravel bank, very minor flow mixed with snowmelt; maximum temperature 5ºC, pH 5.8.	L	L	0.46
E		Very minor seep with no flow; maximum temperature 12ºC, no sample possible.	N	N	N
F-1	26361	Swampy area 500 ft by 300 ft with 14 separate springs; total flow estimated at 430 l/min; maximum temperature 55ºC (this sample), pH 8.6.	200	L	1.0
F-2	26364	See F-1 above, this sample site temperature 54.8ºC, pH 8.	200	L	L
Detection Limit			20	4	0.05

[1]analyses by Chemex Labs, Inc., Sparks, NV, using inductively coupled plasma – atomic emission spectrography except U by fluorimetric procedure.
L = less than detection limit
N = no analysis

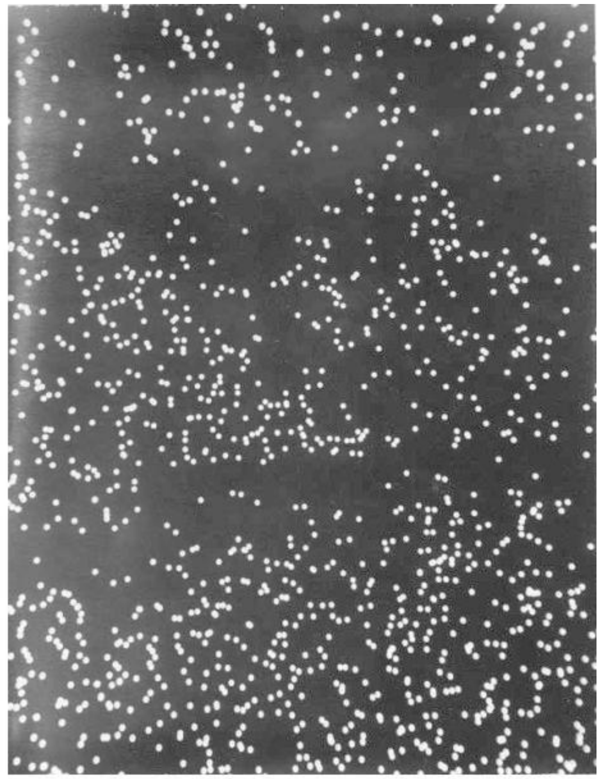
MICROPROBE AND SEM STUDIES

Microprobe and scanning electron microscope (SEM) examinations of coal grain-mounts were undertaken to determine if specific elements are concentrated in minerals along secondary fractures and voids, or are uniformly distributed throughout the coal, suggesting mineralized waters circulated through plant material or peat bogs prior to diagenesis. X-ray image scans[4] of samples with map numbers 5, 6, and 9 (fig. 5) show germanium randomly distributed throughout specimens 5 and 6 and unrelated to bedding, fractures, or voids. Similarly, widely dispersed concentrations of tungsten were found in sample map numbers 6 and 9, but again they did not correlate to post-diagenetic fluid pathways. SEM examination of map number 5 using backscattered electron detection showed numerous bright specks identified as lead-containing particles (fig. 7). X-ray image scans[5]of coal from map numbers 10 and 14 (fig. 5) for gold, silver, copper, zinc, uranium, thorium, and rare earth elements found these elements widely dispersed and did not find any areas of concentration in any of the specimens. Conversely, X-ray scans for lead found numerous unidentified lead-containing particles, some of which occur on fracture surfaces. Figures 7e, 8, and 9 show typical lead particles in fractures, indicating secondary lead mineralization. The accompanying X-ray image scans for sulfur, calcium, and tungsten (fig. 7) demonstrate these elements are disseminated within the coal structure. Figure 8 shows the concentration of elemental lead peripheral to a larger grain containing Fe and S (probably pyrite); however, no localized concentrations of tungsten or germanium were found.

[4] Analyses by J. Watson, Analyst, Albany Research Center, U.S. Bureau of Mines, Albany, OR 97321
[5] Lee Eminhizer, Analyst, Pennsylvania State University, University Park, PA 16802

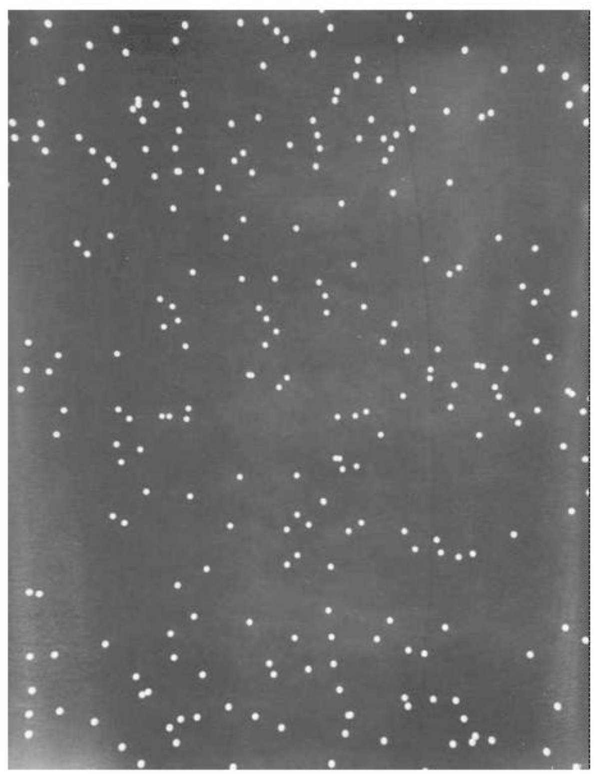


(a) Scanning Electron Microscope (SEM) photo of coal sample Rm25445, map no. 5



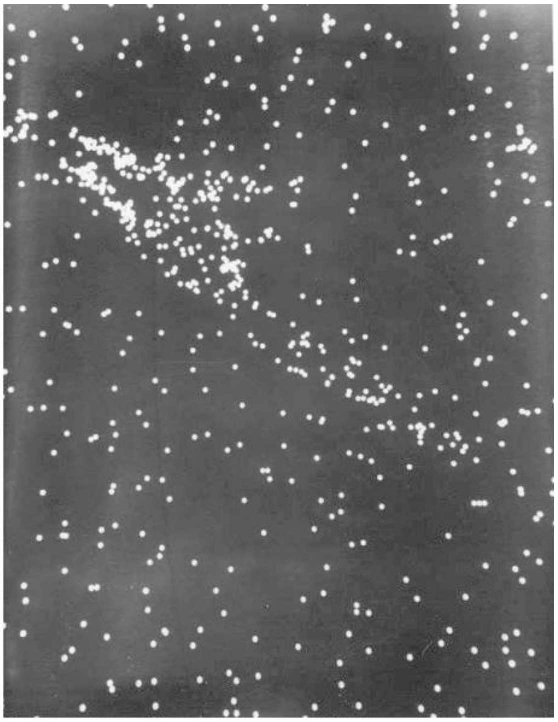
(b) X-ray plot of calcium (Ca)

(c) X-ray plot of sulfur (S)

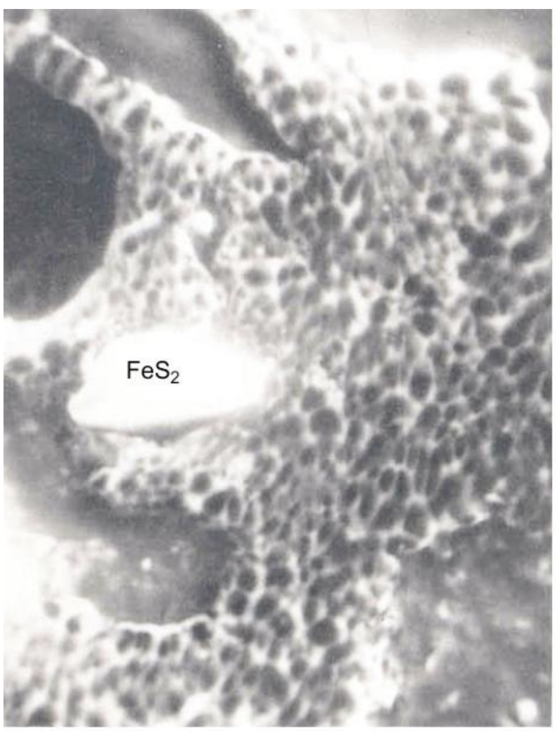


(d) X-ray plot of tungsten (W)

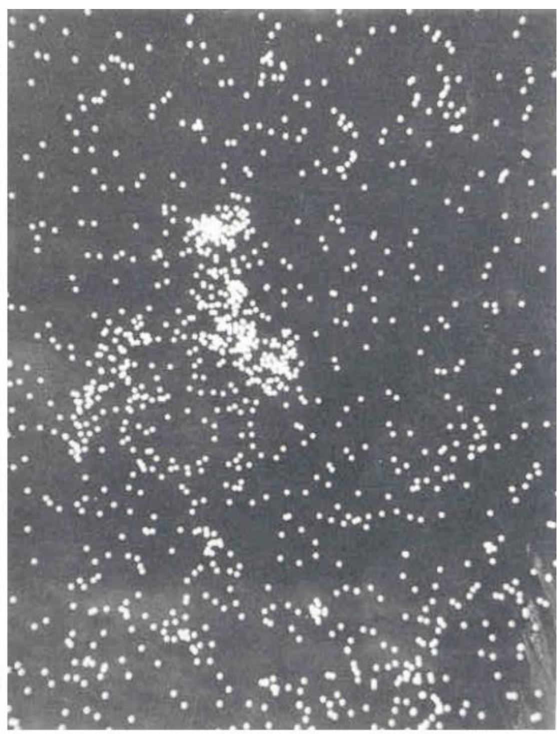
Figure 7a-e. *Photomicrograph of coal sample no. 5 and X-ray plots of Ca, S, W, and Pb.*



(e) X-ray plot of lead (Pb)

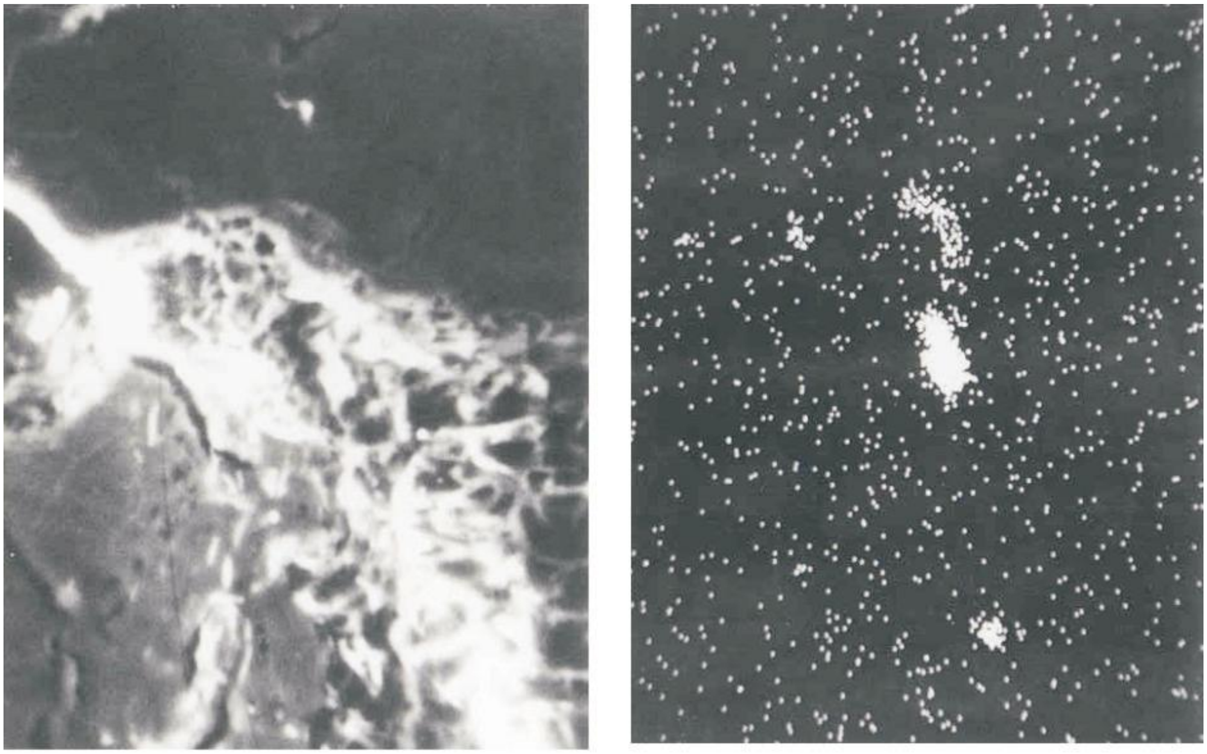


(a) Scanning Electron Microscope (SEM) photo of coal sample Rm25448, map no. 10.



(b) X-ray plot of lead (Pb)

Figure 8a-b. *Photomicrograph of coal sample no. 10, showing a grain of pyrite (FeS_2) and X-ray plot of Pb.*



(a) Scanning Electron Microscope (SEM) photo of coal sample Rm25450, map no. 14.

(b) X-ray plot of lead (Pb)

Figure 9a-b. *Photomicrograph of coal sample no. 14, showing crystal-like particles of Pb in fracture zone and X-ray plot of Pb.*

DISCUSSION AND CONCLUSIONS

Although the Fort Hamlin Hills area is extensively covered with recent surficial deposits and vegetation, mapping and analytical data indicate an extensional terrane in which obscure graben-like basins have preserved coal-bearing sedimentary rocks. The occurrence of layered alkaline fissure basalts, the geochemistry of the Tertiary sediments, geothermal activity with associated anomalous mobile metal ion content, and the stepped elevations of the Tertiary-age coal beds are consistent with an interpreted formation of at least limited rifting and graben formation between several Cretaceous granitic plutons. Tertiary basalt flows, approximately 200 ft (61 m) thick or more and covering about 60 square mi (155 square km) have been downcut by the present stream pattern, indicative of further subsidence relative to the highlands.

Trace metal values, particularly tungsten, are highly concentrated in coal beds underlying the Ray River. Nearby coal beds in the Dall River valley are not similarly mineralized, however, the overlying lacustrine mudstone and water-lain tuff unit is enriched in tungsten. Because geothermal springs and seeps in the area presently contain anomalous levels of mobile tungsten, it is likely that calcic paleo-geothermal activity, possibly more active in the past than now, either concentrated metals including tungsten in plant material at the time, or circulated in former peat bogs beneath the capping basalt flows. An inverse relationship between percent ash and ppm tungsten in Ray River coal ash samples indicates the tungsten in coal is associated with the organic macerals rather than terrestrial mineral matter. Coal diluted with abundant ash contains correspondingly less metal-bearing maceral material.

It is unclear why the Dall River coal beds are not similarly mineralized, however, the timing of mineralized geothermal waters in the area and the overlying mudstone/ash accumulations may be responsible.

Data suggest that a lake fed by geothermal waters, possibly with some similarities to Searles Lake, California (Ririe, 1989; Carpenter and Garrett, 1959), formed in the Dall River–Coal Creek area, thus accounting for the water-lain nature of the mineralized mudstones and tuff. Present-day mud and brine at Searles Lake contain up to 118 ppm WO_3. The Dall River carbonaceous lacustrine mudstones are enriched in tungsten (up to 190 ppm), uranium (up to 50 ppm), and other trace metals; veinlets of a hydrate apatite were identified, as well as vivianite and zeolite beds. Further study of deposition, geochemistry, and paleo-climate is suggested.

In the Ray River watershed the coal section was covered by basalt flows. The basalt flows provided the opportunity for a closed aquifer in which underlying metal-bearing geothermal springs could saturate the coal-forming beds. Microprobe study of Ray River coal specimens indicates metals (except lead) are diffused throughout the coal at molecular levels and do not show post-diagenesis concentration along bedding or fracture surfaces. Lead, conversely, at least partially concentrates along fractures, indicating a phase of secondary mineralization. Up to 1.9 percent tungsten, 1.9 percent lead, and 1.2 percent germanium are found in ash prepared from Ray River coal.

Significant concentrations of tungsten in coal have been noted in at least two other sites in the world. Both feature geologic settings similar to the Fort Hamlin Hills area. At Death Valley on Alaska's Seward Peninsula, a coal-bearing Eocene section is exposed in a graben partially overlain by basalt flows (Dickinson and others, 1987). Sandstone is mineralized with secondary uranium, and lignite contains up to 360 ppm tungsten on a whole coal basis (Stricker and Affolter, 1988). Drainage into and under the Death Valley basalt emanates from the Darby Mountains granitic pluton where vein-type uranium mineralization occurs (Foley and Barker, 1986).

The second site is in southern Bulgaria, at the Pirin and Mugla coal fields (Eskenazy, 1982). Tungsten concentrations up to 4,335 ppm are measured in coal ash, with the highest values found near the base of the coal beds. Eskenazy (written communication), suggests that the tungsten mineralization is associated with nitrogen-bearing thermal waters containing detectable tungsten that flow from geothermal springs in the vicinity of tungsten-mineralized granitoids. A similar geothermal correlation to tungsten is discussed by Ririe (1989).

The occurrence of germanium in coal ash is somewhat more common worldwide, although rarely at the concentration levels found in coal ash from the Fort Hamlin Hills area. An example is located north of Vancouver, where lignite and carbonaceous sandstone, termed "brown beds," contain 50 to 60 ppm germanium (Queneau and others, 1988). It was noted that germanium was highly concentrated in vitrinite (0.2 to 0.5 percent), and the vitrinite could be concentrated by flotation techniques.

Because nearly all samples collected from the Ray River basin contain highly anomalous levels of tungsten and other metals, it is likely that a substantial resource is present from which coal and rare metals may be extracted. Drilling of this resource is necessary for further quantification. Although none of the samples from the nearby Dall River basin contained metal values high enough to be of economic interest, further exploration there is warranted.

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Appendix A-1. Multi-element analyses by neutron activation of coal ash[1], Ray River coal samples.

Sample / Map Location Nos.	Au, ppb	Sb, ppm	As, ppm	Ba, ppm	Br, ppm	Cd, ppm	Ce, ppm	Cs, ppm	Cr, ppm	Co, ppm	Eu, ppm	Hf, ppm	Ir, ppb	Fe, pct	La, ppm	Lu, ppm	Mo, ppm	Ni, ppm	Rb, ppm
RM25445/5	38	170.0	1030.0	2200	2.8	<19	641.0	22.0	300	47	<3	<5	<120	8.5	226	20.0	119	110	64
RM25446/6	21	179.0	551.0	1100	<2.0	<18	579.0	14.0	190	140	8	6	<110	13.0	209	15.0	215	1470	41
RM25447/9	79	296.0	418.0	1500	<2.0	<23	340.0	2.0	210	26	<4	<6	<140	10.0	100	20.0	96	390	18
RM25448/10	61	3330.0	2590.0	<620	110.0	<61	570.0	7.4	<310	40	<15	<12	<370	8.2	220	29.9	91	<85	91
RM25449/12	<14	486.0	286.0	410	15.0	<16	686.0	34.0	71	19	5	7	<50	2.0	295	10.0	43	<24	130
RM25450/14	204	2710.0	1690.0	1200	82.0	<47	160.0	<2.7	<240	58	12	<9	<280	6.5	58	8.5	76	140	<46
RM24723/16	222	339.0	980.0	520	29.0	<29	100.0	<0.5	550	41	2	<5	<100	3.3	37	4.8	330	120	<14
RM24725/20	<17	59.3	527.0	<1200	6.1	<24	200.0	23.0	91	26	3	9	<50	5.7	86	7.0	130	130	69
RM24726/19	1870	234.0	874.0	<670	15.0	<30	820.0	26.0	250	88	4	<4	<100	6.9	280	6.0	185	200	74
RM24727/18	56	118.0	897.0	<1500	14.0	<35	230.0	3.4	<100	210	<1	<5	<120	9.4	84	14.0	630	320	<19

(continued)	Sm, ppm	Sc, ppm	Se, ppm	Ag, ppm	Na, pct	Ta, ppm	Te, ppm	Tb, ppm	Th, ppm	Sn, ppm	W, ppm	U, ppm	Yb, ppm	Zn, ppm	Zr, ppm	Cu, ppm	Sr, ppm	Y, ppm	
RM25445/5	33.70	46.8	<13	<6	0.35	3.6	<160	8.0	260.0	<380	3790	322.0	38	160	1500	210	--	--	
RM25446/6	53.90	53.3	<12	<6	0.25	1.8	<80	13.0	102.0	<350	2730	171.0	61	170	1600	95	--	--	
RM25447/9	26.80	43.5	<16	<6	<0.20	2.2	<130	9.2	192.0	<470	5190	311.0	50	180	1900	79	--	--	
RM25448/10	49.20	37.3	<45	86	<1.60	<2.1	<230	8.0	226.0	<1500	1660	299.0	130	<320	<2400	132	--	--	
RM25449/12	62.80	31.3	<11	<5	0.67	3.7	<57	10.0	149.0	<370	424	147.0	38	140	1700	40	--	--	
RM25450/14	18.00	42.5	<34	37	<1.50	<1.6	<180	3.1	51.6	<1200	308	44.0	77	390	<1700	129	--	--	
RM24723/16	14.90	36.3	<13	<2	0.20	4.1	<47	6.6	95.1	<400	>2000	101.0	29	<200	1500	1021	812	278	
RM24725/20	20.70	75.9	<11	<5	0.19	5.0	<51	9.1	234.0	<350	>2000	342.0	56	<100	<980	153	464	468	
RM24726/19	67.60	53.7	<14	<6	0.22	2.2	<50	14.0	124.0	<420	>2000	183.0	40	490	<790	3709	380	405	
RM24727/18	20.50	68.6	<15	<5	0.16	3.4	<71	13.0	213.0	<420	>2000	411.0	96	<100	<1200	199	531	856	

[1] Analyses by Bondar-Clegg Co. Ltd., Vancouver, B.C., using instrumented neutron activation; exceptions: copper by atomic absorption and strontium and yttrium by inductively coupled plasma.

-- = not analyzed

Appendix A-2. Multi-element analyses by neutron activation of coal ash[1], Dall River coal samples.

Sample / Map Location Nos.	Au, ppb	Sb, ppm	As, ppm	Ba, ppm	Br, ppm	Cd, ppm	Ce, ppm	Cs, ppm	Cr, ppm	Co, ppm	Eu, ppm	Hf, ppm	Ir, ppb	Fe, pct	La, ppm	Lu, ppm	Mo, ppm	Ni, ppm	Rb, ppm
HZ25636/22	<8	68.6	207.0	5800	3.7	<5	300.0	0.8	66	28	6	7	<50	9.4	190	3.4	22	570	<12
HZ25638/23	27	95.0	361.0	4600	6.7	<5	270.0	3.1	65	39	3	4	<50	9.0	120	5.0	10	310	16
HZ25639/24	<7	77.6	215.0	3700	3.2	<5	250.0	<0.5	52	140	3	<1	<50	13.0	130	3.0	17	790	<13
HZ25641/25	23	58.4	178.0	10700	3.6	<11	250.0	<0.5	<52	28	4	10	<50	7.2	120	2.0	55	360	<14
HZ25642/26	5	39.8	204.0	490	2.6	<5	55.0	8.7	200	8	<1	7	<50	2.5	37	0.8	6	<20	36

(continued)	Sm, ppm	Sc, ppm	Se, ppm	Ag, ppm	Na, pct	Ta, ppm	Te, ppm	Tb, ppm	Th, ppm	Sn, ppm	W, ppm	U, ppm	Yb, ppm	Zn, ppm	Zr, ppm	Cu, ppm	Sr, ppm	Y, ppm	
HZ25636/22	37.40	24.9	<5	<5	0.21	<0.5	<32	5.8	10.0	<220	205	29.5	18	<100	<520	82	--	--	
HZ25638/23	28.90	17.0	<5	<4	0.23	<0.5	34	4.8	18.0	<230	39	71.9	15	150	550	177	--	--	
HZ25639/24	28.00	17.0	<5	<4	<0.07	0.5	<30	4.3	5.9	<200	23	30.2	14	210	<500	74	--	--	
HZ25641/25	32.40	29.6	<5	<5	0.23	1.0	<34	5.1	15.0	<230	18	6.6	18	150	<580	56	--	--	
HZ25642/26	4.90	31.8	<5	<2	0.22	1.5	<10	0.7	16.0	<100	210	7.7	4	100	410	28	--	--	

[1] Analyses by Bondar-Clegg Co. Ltd., Vancouver, B.C., using instrumented neutron activation, except copper, which was analyzed by atomic absorption.

-- = not analyzed

Appendix B. Multi-element analyses by ICP of coal ash, Fort Hamlin Hills region (presentation conformed to Appendix A).

Sample / Map Location Nos.	Au, ppb	Sb, ppm	As, ppm	Ba, ppm	Br, ppm	Cd, ppm	Ce, ppm	Cs, ppm	Cr, ppm	Co, ppm	Eu, ppm	Hf, ppm	Ir, ppb	Fe, pct	La, ppm	Lu, ppm	Mo, ppm	Ni, ppm	Rb, ppm
RM24723/16	--	258	904	460	--	<1	--	--	307	48	--	--	--	4.58	37	--	307	183	--
RM24725/20	--	40	472	346	--	<1	--	--	58	40	--	--	--	7.58	98	--	165	131	--
RM24726/19	--	205	876	300	--	2	--	--	88	107	--	--	--	>10.00	265	--	219	246	--
RM24727/18	--	82	987	271	--	<1	--	--	70	254	--	--	--	>10.00	106	--	610	370	--

(continued)	Sm, ppm	Sc, ppm	Se, ppm	Ag, ppm	Na, pct	Ta, ppm	Te, ppm	Tb, ppm	Th, ppm	Sn, ppm	W, ppm	U, ppm	Yb, ppm	Zn, ppm	Zr, ppm	Cu, ppm	Sr, ppm	Y, ppm	
RM24723/16	--	--	--	4.4	0.19	<1	16	--	--	<20	>2000	--	--	<1	1004	1021	812	278	
RM24725/20	--	--	--	2.4	0.34	33	19	--	--	<20	1905	--	--	151	573	153	464	468	
RM24726/19	--	--	--	5.8	0.37	<1	23	--	--	56	>2000	--	--	1018	578	3709	380	405	
RM24727/18	--	--	--	2.5	0.29	9	32	--	--	<20	>2000	--	--	185	578	199	531	856	

(continued)	Pb, ppm	Bi, ppm	Mn, pct	V, ppm	Li, ppm	Ga, ppm	Ti, pct	Al, pct	Mg, pct	Ca, pct	K, pct	Nb, ppm	W[1], ppm	Ge[2], ppm					
RM24723/16	<2	31	0.77	>2000	19	91	1.15	2.86	2.74	>10.00	0.15	29	>2000	>2000					
RM24725/20	133	<5	0.36	711	42	53	0.69	6.74	1.40	>10.00	0.59	37	>2000	>2000					
RM24726/19	554	6	0.25	915	136	90	0.58	6.20	1.19	>10.00	0.73	52	>2000	>2000					
RM24727/18	50	<5	0.97	469	18	137	0.56	4.41	2.02	>10.00	0.30	23	>2000	>2000					

[1] analyzed by neutron activation
[2] analyzed by D.C. plasma emission
-- = not analyzed

Appendix C. Multi-element analyses of geothermal water samples[1], Fort Hamlin Hills region.

Element	Units	Map Locations								Detection Limit
		A	B-1	B-2	B-3	C	D	F-1	F-2	
Mo	µg/L	<20	<20	10	14	<2	<2	<20	<20	2
Zn	µg/L	<20	<20	8	780	14	4	<20	<20	2
P	µg/L	<200	<200	20	300	40	100	<200	<200	20
Bi	µg/L	<40	<40	<4	<4	4	20	<40	<40	4
Cd	µg/L	<10	<10	<1	<1	3	<1	<10	<10	1
Co	µg/L	<20	<20	2	2	4	4	<20	<20	2
Ni	µg/L	<20	<20	<2	4	4	<2	<20	<20	2
Ba	µg/L	<200	<200	<20	60	20	20	<200	<200	20
Fe	mg/L	<2.0	<2.0	<0.2	2.4	0.6	<0.2	<2.0	<2.0	0.2
Mn	µg/L	<20	<20	2	360	130	250	<20	<20	2
Cr	µg/L	<20	<20	<2	<2	<2	32	<20	<20	20
Mg	mg/L	<2.0	<2.0	0.2	3.8	28	1.8	<2.0	<2.0	.2
V	µg/L	<20	<20	<2	12	<2	<2	<20	<20	2
Al	mg/L	<2.0	<2.0	<0.2	0.2	<0.2	<0.2	<2.0	<2.0	0.2
Be	µg/L	<10	<10	<1	<1	<1	<1	<10	<10	1
Ca	mg/L	2.0	2.0	3.2	22	28	5.4	2.0	2.0	0.2
Cu	µg/L	<20	<20	4	290	<2	6	<20	<20	2
Ag	µg/L	<10	<10	<1	<1	<1	<1	<10	<10	1
Ti	mg/L	<2.0	<2.0	<0.2	<0.2	<0.2	<0.2	<2.0	<2.0	0.2
Sr	µg/L	20	20	28	70	155	18	40	40	2
Na	mg/L	68	90	87	135	77	3.2	115	115	0.2
K	mg/L	2.0	2.0	2.0	1.8	6.4	2.8	4.0	4.0	0.2

Note: No sample was taken at map location E.
[1] analyses by Chemex Labs, Inc., Sparks, NV, using inductively coupled plasma – atomic emission spectrography.

Appendix D. Coordinates of sample locations.

Map No.	Northing	Easting	Latitude	Longitude
1	7320234	610970	65.9852	-150.556
2	7325076	623381	66.0240	-150.278
3	7325280	624831	66.0253	-150.246
4	7325280	624822	66.0253	-150.246
5	7325506	627737	66.0261	-150.182
6	7325400	627972	66.0251	-150.177
7	7324394	629869	66.0153	-150.136
8	7324141	630048	66.0130	-150.133
9	7324002	630254	66.0116	-150.128
10	7323891	630465	66.0106	-150.124
11	7323990	630709	66.0114	-150.118
12	7324180	631141	66.0129	-150.108
13	7323749	631871	66.0087	-150.093
14	7323513	631862	66.0066	-150.093
15	7322136	633390	65.9936	-150.061
16	7319371	634647	65.9683	-150.036
17	7318601	634366	65.9615	-150.043
18	7317954	634713	65.9556	-150.036
19	7317233	634720	65.9491	-150.037
20	7315951	635538	65.9373	-150.020
21	7315491	635640	65.9331	-150.018
22	7359105	641980	66.3211	-149.831
23	7359105	641980	66.3211	-149.831
24	7359111	641980	66.3211	-149.831
25	7359111	641980	66.3211	-149.831
26	7359111	641980	66.3211	-149.831
31	7359143	642088	66.3214	-149.828
32	7359143	642088	66.3214	-149.828
33	7359143	642088	66.3214	-149.828
34	7359143	642088	66.3214	-149.828
35	7359143	642088	66.3214	-149.828
36	7359143	642088	66.3214	-149.828
37	7359143	642088	66.3214	-149.828
38	7359143	642088	66.3214	-149.828
39	7359143	642088	66.3214	-149.828
40	7359143	642088	66.3214	-149.828
41	7359143	642088	66.3214	-149.828
42	7323739	628830	66.0099	-150.160
43	7323732	628823	66.0098	-150.160
44	7325233	624766	66.0249	-150.248
45	7359408	642819	66.3234	-149.812
A	7317068	594576	65.9621	-150.919
B	7320814	611649	65.9902	-150.541
C	7325466	625377	66.0267	-150.234
E	7337583	632583	66.1324	-150.063
F	7348379	655184	66.2187	-149.550
D	7325778	626701	66.0290	-150.205
coal	7321411	633687	65.9870	-150.055
coal	7321665	633580	65.9893	-150.057
coal	7321896	633456	65.9915	-150.060