United States Department of the Interior
Geological Survey

Water Leachability of Elements From the Low-Temperature Ash of Bituminous Coal Samples

by

Marta R. Krasnow, Robert B. Finkelman, Curtis A. Palmer, William M. D'Angelo

Open-file Report 96-511

This report is preliminary and has not been reviewed for conformity with U.S. geological Survey editorial standards and stratigraphic nomenclature.

Water Leachability of Elements From the Low-Temperature Ash of Bituminous Coal Samples

Marta R. Krasnow, Robert B. Finkelman, Curtis A. Palmer, William M. D'Angelo

U.S. Geological Survey Reston, VA 22092

Abstract

Forty-one samples of low-temperature ash from bituminous coal were leached with hot (80° C) distilled water, to determine the leachability of elements in the low-temperature ash of coal. The leachates were analyzed by inductively-coupled atomic emission spectroscopy and by ion chromatography. In general, only small amounts (<20 percent) of Al, Ba, Mn, Na, Ti, P, and F were leached from the low-temperature ash. These elements are probably predominantly associated with stable inorganic phases in the coal or they formed water insoluble phases during the low-temperature ashing process.

Moderate amounts (10-59 percent) of Fe were leached from most low-temperature ash (LTA) samples. Leachable sulfur (as sulfate) in the LTA is equivalent to more than 75 percent of the sum of the organic sulfur + sulfate sulfur as determined in the coal. It is inferred that some of the leachable Fe and S is attributable to pyrite which was oxidized during the low-temperature ashing process.

Modest amounts (25-75 percent) of Mg were leached from most LTA samples. The leachable Mg is possibly derived from organically-bound Mg and from ion-exchangeable Mg in clays. Water-soluble Sr appears to be uniformly high. The leachable Sr may have been derived from organically-bound Sr or from water-soluble Sr-sulfates in the coal. There are only small amounts

of leachable Cl and N, perhaps because these elements were volatilized during low-temperature ashing.

Introduction

Low-temperature (LT) ashing of coal has been a procedure in favor with coal scientists since it was introduced by Gluskoter (1965). In this procedure a plasma of radio-frequency activated oxygen is passed over ground coal. The activated oxygen plasma reacts with the carbon in the coal to form CO_2. Temperatures in the LT asher are believed to be less that 200° C under normal operating conditions (Miller, 1984).

The low-temperature ashing procedure remains the most effective method for removing organic matter from coal with minimum alteration of the minerals in the coal. Some of the possible effects of LT ashing on the minerals in coal, including oxidation of pyrite and removal of water from gypsum, are discussed by Miller (1984). One aspect of the low-temperature ashing procedure not discussed is the fate of the organically-bound elements such as Ca, S, Se, and Cl.

A better understanding of how elements behave during the low-temperatureashing process may provide insights into the elements modes of occurrence in coal. Finkelman and others (1990) postulated that salts (bromides, selenates, etc.) formed during the LT ashing process of low rank coals. To determine if salts are formed during the LT ashing of bituminous coals a set of 41 bituminous coal samples were LT ashed and the resultant ash was leached with hot (80° C) distilled water. The leachates were quantitatively analyzed for the elements listed in Tables 2, 3, and 4 by inductively-coupled plasma optical emission spectroscopy and by ion chromatography.

This report describes the results for LT ash derived from 41 bituminous coal samples from the Appalachian coal basin. Information on sample identification and origin appears in Table 1. Results of the quantitative chemical analyses of the elements in the coal samples are located in Table 2. The percentages of the elements leached from the LT ash by hot water appear in Table 3.

Experimental Methods

Approximately 10 grams of coal that had undergone quantitative elemental analysis using techniques similar to those described by Golightly and Simon (1989) were low-temperature ashed using an IPC Model 4000[1] low-temperature asher. Ashing continued until the ash reached a constant mass. Slightly more than 0.1 grams of the LTA was then placed in a polystyrene-conical-bottom centrifuge tube. Fifty ml of hot water (80°C) was added and the resulting slurry was shaken by hand to insure that the material was properly dispersed in the water and that no material adhered to the bottom of the tube. The tube was then placed on a mechanical shaker for 18 hours at room temperature.

The sample was allowed to settle and was then centrifuged at 2500 rpm for 15 minutes. The decanted-filtered solution was analyzed by inductively coupled argon plasma-atomic emission spectroscopy (ICAP-AES) for selected major and trace elements and by ion chromatography (IC) for selected anions.

---

[1] Any use of trade, product, or firm names is for descriptive purposes only and does not constitute an endorsement by the U.S. Government.

The results from the quantitative chemical analyses of the leachates together with quantitative elemental data determined on the unleached coal were used to determine the percent of the element leached from the LTA. This calculation assumes that volatilization of trace elements has not occurred during the ashing process; this assumption is probably valid for all elements except those that are the most volatile such as Br, Se, and Hg (Finkelman and others, 1990). The concentrations of the elements determined in the whole coal were recalculated to a LTA basis for all elements except NO_3 and SO_4. The nitrate (NO_3) values in the LTA were calculated from the N values determined by ultimate analysis, assuming that all nitrogen (Table 2) was converted to nitrate in the low temperature asher. The SO_4 content in the LTA was calculated as the sum of sulfate and organic sulfur (calculated on a sulfate basis) determined in coal samples in accordance with ASTM test method D2492 (ASTM, 1994). The SO_4 calculation assumes that pyrite is not oxidized in the low temperature ash; this assumption is probably not valid (Miller 1984), but the amount of oxidation is small in most cases.

The total amount of element (E_{wtsol}) or anion (A_{wtsol}) in solution was calculated by multiplying the concentration of the element (C_{Esol}) or anion (C_{Asol}) by the total weight of the solution (W_{sol}):

1a). $E_{wtsol} = C_{Esol} \text{ x } W_{sol}$

1b). $A_{wtsol} = C_{Asol} \text{ x } W_{sol}$

The total amount of each element (E_{wtLTA}) or anion (A_{wtLTA}) in the LTA was calculated by first dividing the concentration of the element in the whole coal (C_{Ewc}) or anion (C_{Awc}) by the percent of the LTA (%LTA) in the sample and multiplying by the weight of the LTA (wtLTA).

2a). $E_{wtLTA} = (C_{Ewc} / \%LTA) \times wtLTA$

2b). $A_{wtLTA} = (C_{Awc} / \%LTA) \times wtLTA$

The percent leached (data of Table 3) was then obtained as follows:

3a). $\%L = (E_{wtsol} / E_{wtLTA}) \times 100$

3b). $\%L = (A_{wtsol} / A_{wtLTA}) \times 100$

These equations assume that there is no volatilization of elements during the low-temperature ashing procedure. Finkelman and others (1990) examined 10 coals of different rank and found that only Br, Se and Hg showed volatility under low-temperature ashing conditions. If an element was volatile, %L would be low because E_{wtLTA} would be an upper limit.

The %L reported in Table 3 were rounded to the nearest whole number. Qualified values reported in Table 3 were rounded up for "less than" values or down for "greater than" values and were generally the result of qualified values reported for C_{Esol}. There are two exceptions: 1) When the actual calculated value was less than 0.5 percent leached, as is commonly the case for nitrite, the value is rounded up less than 1; 2) when a value was calculated to be greater than 150 % leached, as is the case for 12 analyses for Ca, the value is reported as <150 %. In addition, less than values calculated to be greater than 100 % , i.e. < 130 %, were reported as < 100 %.

Results of Hot Water Leaching of LTA Samples

Aluminum - Less than 10 % of the Al as determined in the coal samples was leached from

27 of the 41 LTA samples. In contrast, 15 to 48 % of the Al was removed from the seven Kittanning coal samples from Conshockton Co., Ohio.

Aluminum in coal is commonly found in clays and other alumino-silicate minerals. These refractory phases should be unaffected by the low-temperature ashing process. Thus, most of the Al in the LTA should not be in a leachable form. Some plants, however, used Al as a structural element for support (Bouska, 1981). Some of this organically-bound Al may be retained in the organic fraction of the coal. During low-temperature ashing the organically associated Al may form amorphous, water soluble phases similar to those reported by Guven and Finkelman (1984) in their transmission electron microscopic examination of LTA for an Illinois No. 6 coal sample. We cannot offer an explanation of why there is so much water soluble Al in the LTA samples from Conshockton Co., Ohio.

Barium - Less than 36% of the Ba in the coal was leached from all 41 LTA samples. Less than 10% was extracted from 29 of these samples. Only two nonqualified values (5 and 19 %) were obtained for Ba extraction. Barium in bituminous coal is believed to be primarily associated with barite ($BaSO_4$) (Finkelman, 1981), a stable non water-soluble phase.

<u>Calcium</u> - More than 75% of the Ca was removed from 38 of the 41 LTA samples. Data for 12 of these samples indicate that more than 150% of the Ca in the coal was removed. Analytical data indicated that no Ca was present in the water blanks. We are unable to explain the excessive amounts of water soluble Ca.

<u>Iron and Sulfur</u> - Less than 10% of the Fe was leached from 5 samples, 10-25% was leached from 19 samples, and 26-59% was leached from 17 samples. Water soluble Fe could come from several sources. There may be some water-soluble Fe-bearing phases, such as iron

sulfates, in the coal. Small amounts of Fe in bituminous coal may be organically bound (Heard and Senftle, 1984). During low-temperature ashing the organically-bound Fe may form water-soluble phases. Another possibility is that the low-temperature ashing process will oxidize iron sulfides (Miller, 1984) thereby generating water-soluble iron sulfates.

We assumed that the organic sulfur (Table 2) in the coal is oxidized to form water soluble sulfates during the low-temperature ashing process. We found that more than 75% of the sum of organic sulfur plus sulfate sulfur in the coal was leached as sulfate from 31 of the 41 LTA samples; more than 150% was leached from 12 of these samples. The abundance of leachable Fe and S (especially those samples in which more than 150% of the SO_4 and organic sulfur in the coal was leached) indicates that some pyrite may be oxidized during LT ashing. There is a positive but not high correlation between leachable Fe and SO_4 ($r= 0.32$, $n= 41$, significant at 95% confidence level).

Magnesium - The proportion of Mg leached from these samples was consistent: between 25 and 75% of the Mg was leached from 35 of 41 samples. Between 25 and 87% of the Mg was leached from all but two samples but more than 100% Mg was leached from the remaining two samples.

Perhaps some of the leachable Mg was extracted from exchangeable clays. Mg associated with the organic matter in the coal may have formed water soluble sulfates during low-temperature ashing. Nevertheless, the proportion of water-soluble Mg appears to be high.

Manganese -" Less than" values were reported on 24 of 40 samples and greater than values for 3 samples. Of the 13 samples for which nonqualified values were reported, 12 were in the range of 40-100% leached. Most Mn in bituminous coal is inferred to be associated with siderite and should not form water-soluble phases in the LTA (Swaine, 1992). Manganese in lignites is largely associated with the organic matter. Some organically-bound Mn may be retained in the bituminous coal. However, it is surprising that 15 LTA samples had greater than 40% water-soluble Mn. Palmer and others (1993) found that more than 60 % of the Mn was leached by ammonium acetate from the LTA from two bituminous coal samples.

Sodium - "Less than" values were reported for 33 of the 41 LTA samples. The eight non-qualified values ranged from 10 to 70 %. Whereas Na in low-rank coal is commonly associated with the organic matter (Finkelman, 1993), in bituminous coal much of the Na probably is associated with clay. Some Na may be attributed to Na ions in pore water (Demir and others, 1986). The water leachable Na may have been derived from ion-exchangeable clays or from small amounts of organically-bound Na. It may also have been extracted from sodium ions that had been in pore water. There does not appear to be any correlation between the amount of leachable Na and leachable Cl. This lack of correlation could be due, in part, to volatilization of organically bound Cl during low-temperature ashing (see chlorine below).

Strontium - Between 25 and 75% of the Sr was leached from 29 of the 41 LTA samples. No LTA sample had less than 12% Sr leached by the hot water. Strontium in coal occurs in several different forms such as carbonates, phosphates, or in association with organic matter (Finkelman, 1993). Strontium sulfates may also be present. Leachable Sr may be derived from organically bound Sr in the coal or from water-soluble Sr-sulfates. However, these sources cannot account for the uniformly high proportion of water soluble Sr in these samples.

Titanium - Less than 10 % of the Ti was leached from 32 of 36 samples for which data were reported. The maximum leachable Ti was 17%. These results are consistent with the association of Ti in coal with water-insoluble minerals such as rutile and anatase (Finkelman, 1981).

Phosphorus - Less than 10% of the P was leached from 39 of 40 samples for which data were reported; 13% was leached from one sample. These data indicate that phosphorous in bituminous coal is associated with a water-insoluble mineral phase or that P forms a water-insoluble mineral phase during low-temperature ashing. Finkelman (1978) suggested that P was associated with rare-earth element phosphates such as monazite and xenotime.

Chlorine - Less than 23 % of the Cl was leached from 38 of 40 samples for which data were reported. Chlorine in coal is believed to occur in association with the organic matter or as ions in the pore water (Demir and others, 1986). During low-temperature ashing this Cl could form water soluble phases such as chlorides. Small amounts of Cl are associated with minerals such as apatite. The relatively low leachable Cl values may be due to volatilization of Cl during the low-temperature ashing process (Finkelman and others, 1990).

Fluorine - Non-qualified values were obtained on only 5 samples. These ranged from 13 to 54% Less than 10% of the F was extracted from 35 of 40 samples for which data were reported. The maximum F leached was 30%. Fluorine in coal is probably associated with the inorganic constituents such as apatite and clay.

Nitrate - Less than 10% of the NO_3 was leached from 40 of the 41 samples. Nitrogen in coal is inferred to be primarily organically-bound (Bouska, 1981). During low-temperature ashing some of the N may be fixed in the ash as nitrates. Because most nitrates are water soluble, the relatively low proportion of leachable NO_3 indicates that much of the N may have volatilized during the LT ashing process.

Conclusions

Few water soluble compounds are formed during low-temperature ashing of bituminous coal. Most of the elements studied (Al, Ba, Mn, Na, Ti, P, and F) likely were associated with refractory mineral phases that were unaffected by the low-temperature ashing process. Several elements (Br, Cl, N, and perhaps some F) are volatile even at the low temperatures achieved during low-temperature ashing and were lost during the process.

Pyrite may be partially oxidized during the low-temperature ashing process, forming water-soluble iron sulfates. Organic sulfur may also be oxidized to form water-soluble sulfates, accounting for the high proportion of water-soluble sulfur in the low-temperature ash.

The high proportion (>100 percent) of water-soluble Ca, Mg and Sr suggest contamination by the water used for leaching, however, blanks run did not indicate any Ca, Mg or Sr. Similarly, repeated analysis of the whole coal and the leaches do not indicate any systematic errors. We cannot account for the high proportion of water-soluble Ca, Mg, and Sr in the low-temperature ash of these samples at this time.

Results from water leaching of the LTA indicates that this approach is not an effective method for determining the mode of occurrence of elements in coal.

References

ASTM, 1994, D2492 Test Method for Forms of Sulfur in Coal, 1994 Annual Book of ASTM Standards. Vol. 05.05 Gaseous Fuels; Coal and Coke. American Society for Testing and Materials, Philadelphia, 492 p.

Bouska, V., 1981, Geochemistry of Coal. Elsevier, Amsterdam, 284 p.

Demir, I, Chou, C.-L., Cahill, R. A., and Chaven, C., 1986, Modes of occurrence of sodium and chlorine in Illinois coals from selected mines. Geological Society of America Abstracts with Programs, v. 18, no. 6, Abstract 87598, p. 583.

Finkelman, R. B., 1978, Determination of trace element sites in the Waynesburg coal by SEM analysis of accessory minerals. Scanning Electron Microscopy, v. 1978, pt. 1, p. 143-148.

Finkelman, R. B., 1981, Modes of occurrence of trace elements in coal. U.S. Geological Survey Open-File Report 81-99, 312p.

Finkelman, R. B., Palmer, C. A., Krasnow, M. R., Aruscavage, P. J., Sellers, G. A., and Dulong, F. T., 1990, Combustion and leaching behavior of elements in the Argonne Premium Coal Samples. Energy Fuels, v. 4, p. 755-766.

Finkelman, R. B., 1993, Trace and minor elements in coal. In Organic Geochemistry, M. H. Engel and S. A. Macko, eds. Plenum Press, New York, p. 593-607.

Gluskoter, H. J., 1965, Electronic low temperature ashing of bituminous coal. Fuel, v. 44, no. 4, p. 285-291.

Golightly, D. W. and Simon, F. O., eds., 1989, Methods for sampling and inorganic analysis of coal. U.S. Geological Survey Bulletin 1823, 72 p.

Guven, N. and Finkelman, R. B., 1984, Analysis of the low-temperature ash from the interlaboratory sample by analytical electron microscopy. In Interlaboratory comparison of mineral constituents in a sample from the Herrin (No. 6) coal bed from Illinois, R. B. Finkelman, F. F. Fiene, R. N. Miller, and F. O. Simon, eds. U.S. Geological Survey Circular 932, p. 34-37.

Heard, I. and Senftle, F. E., 1984, Oxidation of anthracite with H_2O_2 via the Fenton reaction. Fuel, v. 63, p. 221-226.

Miller, R. N., 1984, The methodology of low-temperature ashing. In Interlaboratory comparison of mineral constituents in a sample from the Herrin (No. 6) coal bed from Illinois, R. B. Finkelman, F. F. Fiene, R. N. Miller, and F. O. Simon, eds. U.S. Geological Survey Circular 932, p. 9-15.

Palmer, C. A., Krasnow, M. R., Finkelman, R. B., and D'Angelo, W. M., 1993, An evaluation of leaching to determine modes of occurrence of selected toxic elements in coal. Journal of Coal Quality, V. 12, no. 4, p. 135-141.

Swaine, D. J., 1992, Trace elements in coal. Butterworths, London, 278 p.

Weast, R. C., (Ed.), 1980, CRC Handbook of Chemistry and Physics. CRC Press, Boca Raton, p. B-84

TABLE 1. SAMPLE IDENTIFICATION FOR 41 BITUMINOUS COAL SAMPLES

Sample Number	State	County	Formation	Coal Bed
W249816	AL	Walker	Pottsville	Blue Creek
W249821	PA	Washington	Pittsburgh	Redstone Coal
W249826	AL	Walker	Pottsville	Nickel Plate
W249843	OH	Conshockton	Alleghany	Middle Kittaning
W250116	PA	Badford	Freeport	Kelly Rider
W250117	PA	Clearfield	Kitanning	Middle Kittanning
W250118	PA	Somerset	Freeport	Upper Freeport
W250119	PA	Clearfield	Kittanning	Middle Kittanning
W250120	PA	Clearfield	Kittanning	Upper Kittanning
W250121	PA	Jefferson	Kittanning	Middle Kittanning
W250122	PA	Cambria	Freeport	Lower Freeport
W250123	PA	Clearfield	Freeport	Lower Freeport
W250124	OH	Guernsen	Alleghany	Upper Freeport
W250125	OH	Noble	Monongahela	Meiga Creek #9
W250126	OH	Conshockton	Alleghany	Lower Kittanning #5
W250127	OH	Conshockton	Alleghany	Middle Kittanning #6
W250128	OH	Conshockton	Alleghany	Lower Kittanning $5
W250129	OH	Conshockton	Alleghany	Lower Kittanning
W250130	OH	Conshockton	Alleghany	Lower Kittanning #5
W250134	OH	Holmes	Alleghany	Lower Kittanning
W250135	OH	Holmes	Alleghany	Brookville #4
W250136	OH	Holmes	Alleghany	Brookville #4
W250137	OH	Start	Pottsville	Lower Markar
W250138	OH	Tuscarawas	Alleghany	Middle Kittanning #6

TABLE 1(CON'T). SAMPLE IDENTIFICATION FOR 41 BITUMINOUS COAL SAMPLES

Sample Number	State	County	Formation	Coal Bed
W250139	OH	Holmes	Alleghany	Lower Kittanning #5
W250140	OH	Holmes	Allegheny	Brrokville #4
W250142	PA	Washington	Pittsburgh	Radson Coal
W250143	PA	Westmoreland	Glenshaw	Mahonong
W250144	PA	Westmoreland	Kittanning	Middle Kittanning
W250145	PA	Westmoreland	Glenshaw	Mohaning
W250146	PA	Somerset	Freeport	Lower Freeport
W 250147	PA	Elk	Freeport	Upper Freeport
W250148	PA	Elk	Kittanning	Middle Kittanning
W250149	PA	Elk	Kittanning	Middle Kittanning
W250150	PA	Elk	Kittaning	Middle Kittanning
W250151	PA	Elk	Kittanning	Middle Kittanning
W250152	PA	Buttler	Freeport	Lower Freeport
W250153	PA	Butler	Freeport	Upper Freeport
W247663	MD	Garrett	Glenshaw	Lower Barkestown
W247666	MD	Garrett	Glenshaw	Lower Barkestown
W249646	PA	Garrett	Glenshaw	Lower Barkestown

TABLE 2. SELECTED TRACE ELEMENT DATA FOR 41 BITUMINOUS COAL SAMPLES

	SAMPLE NUMBERS											
ELEMENTS (%)	**W-249816**	**W-249821**	**W-249826**	**W-249843**	**W-250116**	**W-250117**	**W-250118**	**W-250119**	**W-250120**	**W-250121**	**W-250122**	**W-250123**
Al	1.8	1.1	1.7	0.7	0.7	0.3	0.8	0.4	1.0	0.64	0.37	0.70
Ca	0.09	0.04	0.2	0.4	0.04	0.2	0.06	0.07	0.09	0.04	0.08	0.09
Fe	0.3	1.3	0.4	1.4	0.3	0.2	1.1	1.7	0.8	0.3	0.31	1.5
Mg	0.09	0.06	0.07	0.2	0.01	0.06	0.02	0.02	0.07	0.02	0.04	0.02
Na	0.03	0.05	0.05	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01
Ti	0.09	0.08	0.08	0.05	0.02	0.02	0.03	0.03	0.03	0.04	0.03	0.02
ELEMENTS (PPM)												
Ba	150	33	380	110	130	130	22	330	390	380	130	230
Mn	21	25	26	110	11	43	6	14	29	102	32	110
P	420	38	58	52	280	37	0.31	0.41	0.41	15	610	0.21
Sr	220	31	110	34	89	10	26	110	102	30	34	67
ANION (%)												
Cl	0.04	2.5	0.01	0.007	0.05	7.2	6.8	0.07	1.1	0.02	0.03	1.9
F	0.009	0.01	0.004	0.005	0.006	0.01	3.8	0.004	5.4	0.003	---	2.0
NO3	8.4	7.5	8.0	5.7	7.1	6.2	6.2	6.2	6.2	6.2	4.9	6.2
SO4	1.6	1.6	1.6	3.8	2.6	1.5	1.7	2.4	2.7	2.3	1.4	2.3
S-FORMS & N (%)												
Pyritic Sulfur	0.05	1.25	0.26	0.68	0.05	0.02	0.75	1.85	0.13	0.08	0.07	1.17
Organic Sulfur	0.52	0.51	0.51	1.2	0.84	0.48	0.56	0.49	0.88	0.74	0.45	0.74
Sulfate Sulfur	0.01	0.02	0.01	0.10	0.01	0.03	0.01	0.31	0.01	0.01	0.01	0.01
Nitrogen	1.9	1.7	1.8	1.3	1.6	1.4	1.4	1.4	1.4	1.4	1.1	1.4
ASH (%)												
HTA	12.7	8.5	11.8	8.3	8.1	4.5	11.2	10.0	10.9	7.3	3.9	8.1
LTA	15.0	13.0	11.5	18.1	14.2	7.7	19.2	17.9	19.0	11.5	8.0	14.0
Starting Weight (g)	0.107	0.105	0.101	0.181	0.113	0.112	0.113	0.120	0.117	0.119	0.116	0.114

Data are on an as received basis. [HTA = high-temperature (550 deg. C) ash; LTA = low-temperature (< 200 deg. C) ash].

TABLE 2 (cont). SELECTED TRACE ELEMENT DATA FOR 41 BITUMINOUS COAL SAMPLES

	SAMPLE NUMBERS											
ELEMENTS (%)	**W-250124**	**W-250125**	**W-250126**	**W-250127**	**W-250128**	**W-250129**	**W-250130**	**W-250134**	**W-250135**	**W-250136**	**W-250137**	**W-250138**
Al	1.0	1.9	0.8	0.5	1.6	1.2	0.6	0.8	2.0	1.6	1.4	0.9
Ca	0.04	0.2	0.11	0.2	0.09	1.0	0.2	0.09	0.2	0.2	0.06	0.08
Fe	1.0	1.4	4.9	1.3	2.8	4.2	4.6	1.8	1.3	1.3	1.0	2.0
Mg	0.04	0.20	0.02	0.05	0.03	0.04	0.05	0.02	0.06	0.05	0.02	0.002
Na	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.03	0.03	0.03	0.02	0.02
Ti	0.04	0.08	0.07	0.02	0.06	0.1	0.03	0.05	0.1	0.08	0.05	0.05
ELEMENTS (PPM)												
Ba	17	430	310	140	210	200	240	100	306	89	18	130
Mn	7	410	24	97	36	58	68	19	39	27	7	20
P	26	55	71	28	53	61	25	---	164	23	67	< 14
Sr	32	96	50	36	44	76	61	29	226	53	40	21
ANION (%)												
Cl	0.07	0.02	0.06	0.04	0.06	0.07	0.01	0.07	0.1	0.08	0.04	0.2
F	0.002	0.005	0.01	0.01	0.01	0.01	0.01	0.002	0.005	0.01	0.01	0.002
NO3	7.1	5.3	5.8	6.6	6.6	5.8	6.2	7.1	6.6	6.2	7.1	7.1
SO4	2.0	5.3	8.5	5.2	5.6	5.6	7.2	4.1	3.8	5.0	1.7	3.8
S-FORMS & N (%)												
Pyritic Sulfur	0.54	1.78	4.26	0.95	2.58	4.67	3.64	1.98	1.08	1.48	0.82	2.02
Organic Sulfur	0.94	1.74	2.34	1.73	1.86	1.82	2.32	1.35	1.25	1.64	0.55	1.24
Sulfate Sulfur	0.01	0.01	0.50	0.01	0.01	0.06	0.09	0.01	0.01	0.01	0.01	0.01
Nitrogen	1.6	1.2	1.3	1.5	1.5	1.3	1.4	1.6	1.5	1.4	1.6	1.6
ASH (%)												
HTA	5.6	13.3	12.2	5.4	12.0	14.6	10.3	7.3	13.3	10.9	7.9	6.9
LTA	9.1	19.1	19.8	11.8	19.6	17.8	17.6	11.6	19.3	15.7	12.1	9.5
Starting Weight (g)	0.101	0.112	0.112	0.113	0.116	0.123	0.115	0.116	0.105	0.106	0.108	0.124

Data are on an as received basis. [HTA = high-temperature (550 deg. C) ash; LTA = low-temperature (< 200 deg. C) ash].

TABLE 2 (cont). SELECTED TRACE ELEMENT DATA FOR 41 BITUMINOUS COAL SAMPLES

	SAMPLE NUMBERS											
ELEMENTS (%)	**W-250139**	**W-250140**	**W-250142**	**W-250143**	**W-250144**	**W-250145**	**W-250146**	**W-250147**	**W-250148**	**W-250149**	**W-250150**	**W-250151**
Al	0.8	0.7	1.9	0.7	2.2	0.7	1.0	1.4	1.2	1.5	1.0	1.2
Ca	0.12	0.52	0.05	0.1	0.08	0.1	0.09	0.10	0.07	0.08	0.06	0.5
Fe	0.9	0.2	1.8	2.4	0.9	3.0	0.6	2.8	0.6	2.5	0.5	0.6
Mg	0.03	0.04	0.04	0.02	0.04	0.02	0.02	0.03	0.02	0.03	0.03	0.03
Na	0.01	0.02	0.02	0.02	0.01	0.01	0.03	0.03	0.03	0.03	0.01	0.02
Ti	0.05	0.02	0.09	0.01	0.1	0.02	0.07	0.07	0.03	0.06	0.04	0.04
ELEMENTS (PPM)												
Ba	19	46	49	67	130	24	20	28	18	45	83	49
Mn	29	8.6	30	15	8	21	5	3	6	28	15	11
P	44	42	< 30	210	33	41	21	75	27	<20	33	45
Sr	32	42	49	67	56	31	62	64	120	150	63	55
ANION (%)												
Cl	0.03	0.03	0.04	0.22	0.20	0.20	0.11	0.07	0.07	0.1	0.09	0.07
F	0.007	0.002	0.004	0.003	0.004	0.005	0.004	0.01	0.01	0.01	0.01	0.01
NO3	7.1	6.6	6.6	6.2	5.3	5.8	6.2	5.8	5.8	6.2	6.2	5.8
SO4	4.0	4.0	2.4	2.4	2.6	1.6	1.7	1.7	1.5	3.2	3.0	2.8
S-FORMS & N (%)												
Pyritic Sulfur	1.18	0.21	2.64	2.01	0.32	3.34	0.14	1.96	0.52	1.60	0.24	0.38
Organic Sulfur	1.33	1.32	0.33	0.80	0.86	0.53	0.56	0.39	0.42	1.04	0.97	0.88
Sulfate Sulfur	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.19	0.07	0.01	0.02	0.07
Nitrogen	1.6	1.5	1.5	1.4	1.2	1.3	1.4	1.3	1.3	1.4	1.4	1.3
ASH (%)												
HTA	6.9	6.6	13.2	7.0	13.6	8.1	6.1	9.8	7.1	9.4	5.9	6.3
LTA	11.5	10.2	19.7	11.8	16.1	13.8	8.7	16.2	9.4	14.8	9.2	9.6
Starting Weight (g)	0.114	0.114	0.117	0.117	0.119	0.114	0.102	0.133	0.112	0.119	0.101	0.112

Data are on an as received basis. [HTA = high-temperature (550 deg. C) ash; LTA = low-temperature (< 200 deg. C) ash].

TABLE 2 (cont). SELECTED TRACE ELEMENT DATA FOR 41 BITUMINOUS COAL

	SAMPLE NUMBERS		
ELEMENTS (%)	**W-250152**	**W-250153**	**W-247663***
Al	0.96	0.7	0.8
Ca	0.07	0.06	0.1
Fe	1.1	3.8	0.8
Mg	0.02	0.03	0.03
Na	0.01	0.005	0.02
Ni	---	---	18
Ti	0.05	0.04	---
ELEMENTS (PPM)			
Ba	86	20	38
Co	---	---	7.4
Cr	---	---	9.4
Mn	5	27	8
P	320	32	370
Sc	---	---	2
Sr	190	36	78
ANION (%)			
Cl	0.16	0.11	0.08
F	0.01	0.01	0.01
NO3	6.2	5.8	6.7
SO4	2	3	3
S-FORMS & N (%)			
Pyritic Sulfur	0.86	2.89	0.67
Organic Sulfur	0.86	0.71	0.63
Sulfate Sulfur	0.01	0.01	0.29
Nitrogen	1.4	1.3	1.51
ASH (%)			
HTA	6.6	8.5	6.5
LTA	13.0	16.1	8.7
Starting Weight (g)	0.112	0.101	0.508

Data are on an as received basis. [HTA = high-temperature (550 deg. C) ash; LTA = low-temperature (< 200 deg. C) ash].

*Data for W-247663 was used as origninal material for samples W-247663, W-247666 and W-249646 which were ashed from the same original sample.

TABLE 3. PERCENTAGE OF ELEMENT LEACHED FROM LTA BY HOT WATER . (Calculated by subtracting the amount of the element determined in the leachate from the amount of the element determined in the whole coal on an LTA basis.)

	SAMPLE NUMBERS											
ELEMENTS	**W-249816**	**W-249821**	**W-249826**	**W-249843**	**W-250116**	**W-250117**	**W-250118**	**W-250119**	**W-250120**	**W-250121**	**W-250122**	**W-250123**
Al	5	5	2	48	6	10	2	13	6	4	67	3
Ba	5	19	< 2	< 5	< 5	< 3	< 5	< 23	< 3	< 1	< 3	< 3
Ca	110	110	81	> 150	> 150	> 150	> 150	> 150	> 150	> 150	> 150	140
Fe	8	32	10	38	4	7	40	59	31	7	13	32
Mg	51	28	36	130	39	77	51	120	43	49	87	79
Mn	100	50	40	140	< 100	56	< 100	> 150	< 56	130	98	< 11
Na	70	< 13	< 12	< 50	< 63	< 35	< 43	< 38	< 41	< 42	< 1	< 62
P	100	< 100	< 100	< 100	< 100	< 100	< 14	< 9	< 10	< 16	< 29	< 15
Sr	16	61	54	73	21	> 150	33	75	48	80	61	64
Ti	15	< 5	< 7	10	< 13	< 11	< 14	< 15	14	< 7	7	< 16
ANION												
Cl	4	< 23	< 5	---	6	< 1	< 1	< 6	< 2	10	6	< 1
F	30	13	54	---	< 57	< 14	< 1	< 100	< 100	< 100	---	< 2
NO3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	1	< 1	< 1
SO4	120	> 150	80	34	27	18	75	130	73	39	> 150	90
% MASS LOSS	37.4	23.8	19.8	59.7	33.6	26.8	15.9	21.7	6.8	11.8	44.8	18.4

The < symbol indicates the concentration was below the detection limit of the value given in that sample.

The > symbol indicates that the calculated value for percent loss exceeded the value given. No values greater than 150 percent were reported.

The --- indicates the element was not determined.

TABLE 3 (cont). PERCENTAGE OF ELEMENT AND MASS LEACHED FROM LTA BY HOT WATER

	SAMPLE NUMBERS											
ELEMENTS	**W-250124**	**W-250125**	**W-250126**	**W-250127**	**W-250128**	**W-250129**	**W-250130**	**W-250134**	**W-250135**	**W-250136**	**W-250137**	**W-250138**
Al	14	11	37	27	15	22	37	12	5	8	6	6
Ba	< 26	< 2	< 3	< 4	< 4	< 4	< 4	< 5	< 4	< 9	< 3	< 30
Ca	> 150	140	77	> 150	150	100	150	110	130	140	140	100
Fe	26	30	55	43	22	47	46	18	21	33	21	24
Mg	31	39	50	72	46	29	57	49	53	48	49	39
Mn	< 100	4	< 73	91	< 47	< 25	56	< 48	71	< 48	< 100	---
Na	22	< 53	< 40	52	28	24	< 39	< 17	< 31	< 25	< 28	< 20
P	< 100	< 100	< 100	< 100	< 100	< 100	< 100	----	< 100	< 100	< 100	---
Sr	68	53	35	72	76	29	63	69	12	55	43	74
Ti	5	6	17	17	7	8	< 12	< 5	< 4	< 5	< 6	< 5
ANION												
Cl	4	< 100	10	6	19	5	21	10	17	5	20	4
F	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 37	< 100	< 100
NO3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
SO4	> 150	130	> 150	140	95	> 150	150	97	110	110	> 150	110
% MASS LOSS	33.3	33.9	78.6	49.6	35.3	56.9	64.3	41.4	29.5	35.8	30.6	37.1

The < symbol indicates the concentration was below the detection limit of the value given in that sample.

The > symbol indicates that the calculated value for percent loss exceeded the value given. No values greater than 150 percent were reported.

The --- indicates the element was not determined.

TABLE 3 (cont). PERCENTAGE OF ELEMENT AND MASS LEACHED FROM LTA BY HOT WATER

	SAMPLE NUMBERS											
ELEMENTS	**W-250139**	**W-250140**	**W-250142**	**W-250143**	**W-250144**	**W-250145**	**W-250146**	**W-250147**	**W-250148**	**W-250149**	**W-250150**	**W-250151**
Al	11	19	4	3	1	3	2	2	3	4	5	3
Ba	< 26	< 10	< 18	< 8	< 6	< 26	< 24	< 23	< 22	< 14	< 6	< 9
Ca	96	>150	120	110	120	96	110	120	110	130	> 150	130
Fe	28	21	42	26	13	27	15	19	17	4	19	10
Mg	48	87	28	26	26	25	41	40	72	47	44	35
Mn	52	< 100	< 56	< 69	< 100	< 58	< 100	< 100	< 100	< 44	< 61	< 78
Na	< 50	< 22	< 42	< 26	< 68	< 61	< 16	< 21	< 13	< 21	< 46	< 21
P	< 100	< 100	---	< 100	< 100	< 100	< 100	< 100	< 100	---	< 100	< 100
Sr	62	64	35	23	48	78	52	76	13	41	49	39
Ti	< 5	< 16	< 5	< 100	< 4	< 12	< 4	< 5	< 6	< 5	< 7	< 6
ANION												
Cl	21	12	32	7	10	7	< 1	5	16	3	2	< 3
F	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100
NO3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
SO4	99	130	> 150	> 150	75	> 150	84	> 150	110	89	49	31
% MASS LOSS	36.0	56.1	35.0	40.2	17.6	48.2	22.5	22.6	23.2	21.8	27.7	23.2

The < symbol indicates the concentration was below the detection limit of the value given in that sample.

The > symbol indicates that the calculated value for percent loss exceeded the value given. No values greater than 150 percent were reported.

The --- indicates the element was not determined.