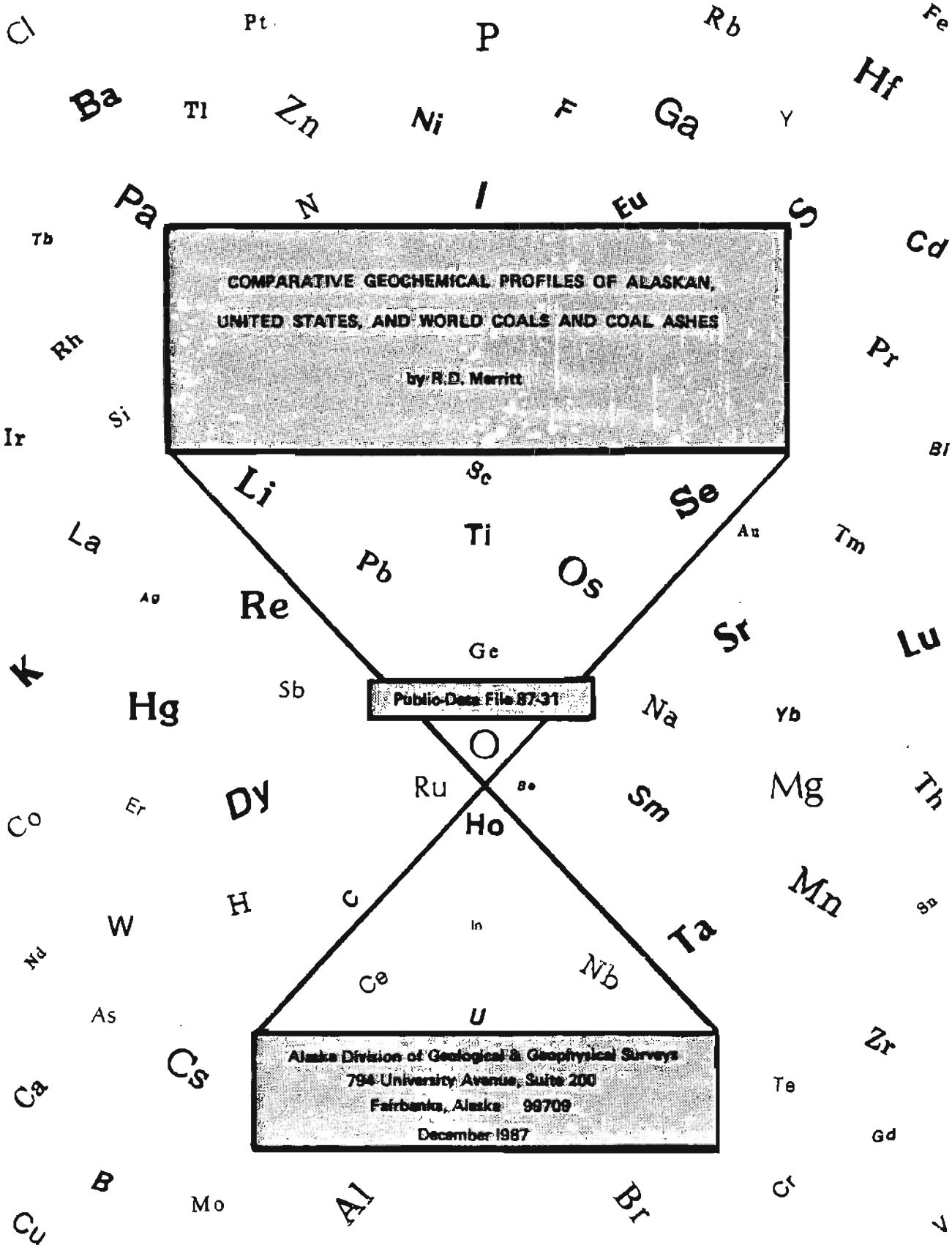
COMPARATIVE GEOCHEMICAL PROFILES OF ALASKAN, UNITED STATES, AND WORLD COALS AND COAL ASHES
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COMPARATIVE GEOCHEMICAL PROFILES OF ALASKAN, UNITED STATES, AND WORLD COALS AND COAL ASHES

by
R.D. Merritt

INTRODUCTION

The purpose of this report is to compare the geochemical nature of Alaskan, U.S., and world coals. As presently known, the chemical constitution of coal includes at a minimum 78 elements in varying ranges of concentration (fig. 1). Only brief consideration is given here to the major elements composing the structure of coal. More detailed data is presented relating to the trace- or minor-element components of coal. And in fact, this report emphasizes the trace-element geochemistry of Alaskan coals compared to U.S. and world coals.

There exists very little data concerning the concentrations of certain trace elements in Alaskan, U.S., and world coals. In these cases, the insufficient data base does not permit an estimate to be made as to the representative range in concentration; in these instances, no estimate (N.E.) is made.

Because Alaskan coals have been less explored, sampled and analyzed than other U.S. and world coals, the geochemical data base is relatively poorer. Based on current knowledge, it is believed that the concentrations of trace elements in Alaskan coals generally fall in the ranges found for other coals. Rao (1968) concluded that for the trace elements of environmental concern, none were present in abnormally greater amounts in Alaskan coals than in other U.S. or world coals. It also appears that: 1) the concentration of minor elements is typically lower in the ash of low-rank than high-rank Alaskan coals; and 2) minor-element concentrations in coal ashes do not vary appreciably from one Alaskan coal field to another (Rao, 1968).

A brief discussion of trace-element geochemistry of coal follows. Thereafter, comparative profiles are presented for 78 elements that make up the chemical constitution of Alaskan, U.S., and world coals. This report summarizes the geochemical data base as it currently exists. Although an abundant amount of research has been conducted concerning the geochemical nature of coal, the elemental profiles presented in this report show that a great deal is yet to be learned. Additionally, it can be easily noted from the report where gaps in the current data base exist and where further detailed research will be required in the future.

TRACE-ELEMENT GEOCHEMISTRY OF COAL

Trace or minor elements are present in coal in very small concentrations and may be toxic or potentially toxic substances (U.S. Department of Energy, 1978). These elements are typically measured in parts per million or even parts per billion (Averitt, 1975). Coals contain a wide variety of trace or minor elements including small quantities of essentially all metallic and nonmetallic elements (Averitt, 1961).

[1]DGGS, 794 University Avenue, Suite 200, Fairbanks, Alaska 99709.

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	VIIIB	VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	NOBLE GASES
1 H 1.008																	2 He 4.003
3 Li 6.939	4 Be 9.012											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.183
11 Na 22.990	12 Mg 24.312											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.064	17 Cl 35.453	18 Ar 39.948
19 K 39.102	20 Ca 40.08	21 Sc 44.956	22 Ti 47.90	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.847	27 Co 58.933	28 Ni 58.71	29 Cu 63.54	30 Zn 65.37	31 Ga 69.72	32 Ge 72.59	33 As 74.922	34 Se 78.96	35 Br 79.909	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.905	40 Zr 91.22	41 Nb 92.906	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.4	47 Ag 107.87	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.90	54 Xe 131.30
55 Cs 132.91	56 Ba 137.34	57 La 138.91	72 Hf 178.49	73 Ta 180.95	74 W 183.85	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.09	79 Au 196.97	80 Hg 200.59	81 Tl 204.37	82 Pb 207.19	83 Bi 208.98	84 Po (210)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89 Ac (227)	104	105													

58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.35	63 Eu 151.96	64 Gd 157.25	65 Tb 158.92	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
90 Th 232.04	91 Pa (231)	92 U 238.03	93 Np (237)	94 Pu (242)	95 Am (243)	96 Cm (247)	97 Bk (249)	98 Cf (251)	99 Es (254)	100 Fm (253)	101 Md (256)	102 No (253)	103 Lr (257)

Figure 1. Periodic table showing those elements making up the chemical constitution of coal and for which detailed profiles are presented in this report.

Major oxides compose 93 to 98 percent of the total weight of coal ash (Selvig and Gibson, 1956). The remaining few percent is made up mostly of about 25 different minor elements. The usual concentrations of minor inorganic or trace constituents in the earth's crust are quite low, but very rare mineable deposits of certain trace elements exist (U.S. Department of Energy, 1978). Indeed, one of the main reasons for studying trace elements in coal is the possibility of recovering certain elements in commercial quantities. In addition, trace elements have been used as indicator elements for geological investigations (Stach and others, 1982) and have been applied to correlating coal seams (McClung and Geer, 1979).

Gluskoter and others (1977) established the following generalizations relating to elemental concentrations based on chemical analyses of whole coal samples: 1) Elemental concentrations were highest in coals of the Appalachian region, intermediate in Illinois basin coals, and lowest in Western U.S. coals; 2) the elements exhibiting the largest ranges in concentration occurred in distinct mineral phases (as sulfide and sulfate minerals, for example) in the coals. Conversely, elements exhibiting narrow ranges in concentration or smaller standard deviations were associated with silicate minerals or found in organic combination in coal; 3) most of the elemental concentrations in coals are lower than the clarke values of the elements; 4) different benches of a coal seam can show wide variations in elemental concentrations; 5) concentrations of elements are more commonly found at the top and/or bottom of coal seams; 6) fine-grained sedimentary rocks intimately associated with the coals---roof shales, underclays, and partings---contain significantly higher concentrations of most elements than the coals themselves; and (7) the relative organic affinity of elements can be established by analyzing washed samples at specific gravity fractions.

Trace elements are introduced into coal in one of four different ways: 1) As an inert material washed into the coal swamp at the time of plant accumulation; 2) as a chemical precipitate from swamp water; 3) as a minor constituent of original plant cells; or 4) as a later addition, introduced after coal formation primarily by downward and laterally moving ground water (Averitt, 1961). Weathering processes may significantly increase the minor element content in coal (Zubovic and others, 1966a,b).

Rapid subsidence during sedimentation results in lower trace element contents in coals (Horne and other, 1978). Slow subsidence favors higher contents of chemically precipitated material. Coals of the lower delta plain environment show a highly irregular pattern of trace-element distribution (Horne and others, 1978).

Mineral matter of coal can be defined broadly to include all inorganic elements. Several trace and minor elements have been identified as occurring in discrete mineral phases in coal (Ruch and others, 1974). Trace elements in coal can be concentrated in various trace minerals rather than incorporated in major or minor mineral components (Meyers, 1982).

Coal-quality evaluations should include detailed and regional analyses of the inorganic constituents (Altschuler and Johnston, 1976). Trace-element characterization should involve a systematic study of trace-element

assemblages (Meyers, 1982). A significant problem in the analysis of trace elements is that there has not been any coal standards available until recent years (Gluskoter, 1975).

Gluskoter and others (1977) showed that most of the trace elements in coal had inorganic affinities. Trace elements in the inorganic group are separable from the coal substance because of the higher specific gravity of the host minerals (Cavallaro and others, 1978). Certain trace elements are associated with the organic phase of coal (Rao, 1976). Elements with high organic affinity are more or less concentrated in the washed or clean coal (Stach and others, 1982).

From mine to utilization, various trace contaminants in coal are released into the environment. The soluble forms of trace elements can be released into the environment by aqueous leaching of coals or their residues (Wewerka and others, 1976). Environmental considerations are among the main reasons for trace-element analysis of coals. Trace-element analysis has assumed added importance relative to coal utilization and environmental impact, and trace elements have become an increasingly important factor in environmental laws.

Trace metals can be transported long distances through air and water and passed along the food chain with little change in chemical properties (U.S. Department of Energy, 1978). Many of the trace elements are not toxic in their elemental form, but their ions and compounds can be quite harmful (U.S. Department of Energy, 1978). Potentially toxic trace elements include mercury, arsenic, lead, cadmium, selenium, and fluorine (Berkowitz, 1979).

The trace components of coal are complexed with organic matter and are only isolated by combustion (Berkowitz, 1979). When coal is burned, most of the minor elements are concentrated in the ash (Averitt, 1975). During combustion at high temperatures, the more volatile trace elements can vaporize to exit the boiler in a gaseous state, or they may form particulates which are then entrained in the exhaust (Averitt, 1975; U.S. Department of Energy, 1978). Certain elements may become condensed or adsorbed on the surface of fly-ash emissions or other entrained particulate matter (Mraw and others, 1983). The pollutants include some toxic trace elements along with more inert gaseous products.

Little documentation exists concerning the pollution effects of high levels of trace elements from the burning of coals. As more coal is consumed in the future, trace elements will be emitted in greater quantities. As coal consumption and fossil-fuel combustion increases, these trace pollutants and their effects will cause increasing concern (U.S. Department of Energy, 1978). Because of this growing concern over air quality, analytical studies of trace elements in coal have been accelerated.

In some cases, the trace constituents of fly ash have been shown to represent a serious public-health hazard (Berkowitz, 1979). The presence of trace elements in fly ash from combustion processes, especially in the respirable size fractions, is considered to be potentially hazardous (Mraw and others, 1983).

Some minor and trace elements may be critical factors in process technology (Altschuler and Johnston, 1976). Trace elements in coal can cause technological difficulties including various effects on combustion processes and equipment (Stach and others, 1982).

Coal-quality factors, including trace-element geochemistry, will assume greater importance in the future marketplace (Orheim, 1979). Because of the greater weight placed on coal-quality criteria, the market will resultantly become more selective.

PROFILE 1 - ALUMINUM

Symbol: Al Atomic number: 13 Atomic weight: 26.9815

	Coal	Ash
Alaska	1,000-70,000 ppm	N.E.
U.S.	3,000-35,000 ppm	50,000-220,000 ppm
World	4,000-31,000 ppm	N.E.

Aluminum is an important metallic element that is only found in combination. It is the most abundant element in the earth's crust. Aluminum is a major inorganic element in the mineral constituents of coal. It is mainly associated with the aluminosilicate group of minerals. Aluminum oxide is one of the major constituents of coal ash. Aluminum has an important effect on the use of coal in combustion and cokemaking.

Turekian and Wedepohl (1961) reported the following average aluminum concentrations in common sedimentary rocks: shales, 80,000 ppm; sandstones, 25,000 ppm; and carbonates, 4,200 ppm.

World Coals

Wewerka and others (1976) reported a range in aluminum content of 0.4 to 3.1 percent in coal. The U.S. National Committee for Geochemistry (1980) cited a worldwide average aluminum content in coal of 1.0 percent. Abernethy and Gibson (1963) reported an average aluminum concentration of 10,440 ppm in coal.

United States Coals

Aluminum has been found to range from 0.43 to 3.04 percent in U.S. coals and to exhibit an average concentration of 1.4 percent (Los Alamos Scientific Laboratory, 1976; U.S. National Committee for Geochemistry, 1980). Sharkey and others (1975) found that aluminum occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 3,000 to 23,000 ppm. Swanson and others (1976) reported an average concentration of 1.1 percent aluminum in 601 U.S. whole-coal samples. Concentrations of aluminum in U.S. coals by rank are: anthracite, 2.0 percent, bituminous, 1.4 percent; subbituminous, 1.0 percent; and lignite, 1.6 percent. Aluminum content in ashes of U.S. coals has been found to range from 5.3 to 21.2 percent (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Swanson and others (1976) reported a geometric mean content of 1.3 percent aluminum in 331 Appalachian region whole-coal samples. Gluskoter and others (1977) found a geometric mean of 1.6 percent aluminum in 23 Appalachian region coals.

Interior region. Swanson and others (1976) cited a geometric mean aluminum content of 0.77 percent in 194 Interior region whole-coal samples. Gluskoter and others (1977) reported a geometric mean of 1.2 percent aluminum in 113 Illinois basin whole-coal samples.

Western region. Swanson and others (1976) reported a geometric mean of 0.59 percent aluminum in 93 Western region whole-coal samples and a geometric mean of 1.6 percent aluminum for 34 Texas coals. Gluskoter and others (1977) found a geometric mean aluminum content of 0.88 percent in 29 Western U.S. whole-coal samples.

Alaska Coals

Based on samples of six coal beds from the Tyonek Formation, Beluga field, Affolter and Stricker (1984) found that the concentration of aluminum varied directly with the ash content of the coals.

Affolter and others (1981) reported geometric mean aluminum concentrations of 0.97 percent, 1.1 percent, 1.2 percent, and 0.76 percent in whole-coal samples of the Healy (20), Kenai (10), Seldovia (34) and Utukok River (54) Quadrangles, respectively. Compared to aluminum contents in 410 Powder River region coal samples, the aluminum contents of coals of the Healy, Kenai, and Seldovia Quadrangles are significantly higher. Compared to aluminum contents in 295 Rocky Mountain province coal samples, the aluminum contents of Utukok River Quadrangle coals are significantly lower.

PROFILE 2 - ANTIMONY

Symbol: Sb Atomic number: 51 Atomic weight: 121.75

	Coal	Ash
Alaska	0.05-10 ppm	N.E.
U.S.	0.1-20 ppm	25-250 ppm
World	0.05-10 ppm	N.E.

Antimony is a metallic element that is used in a wide variety of alloys. It is one of the elements associated with both organic and inorganic matter, but is more closely allied with organic fractions (Ruch and others, 1974). Up to 50 percent of antimony is lost in low-temperature ash. It can be enriched on the surfaces of fly-ash particles from coal-fired plants (Mraw and others, 1983). Anomalously high antimony can result in samples from core holes contaminated by drilling fluids and drill pipe.

Antimony shows a moderate enrichment factor of 5.5X in coal ash compared to its average estimated concentration in the earth's crust (U.S. National Committee for Geochemistry, 1980). Turekian and Wedepohl (1961) reported the following average antimony concentrations in common sedimentary rocks: shales, 1.5 ppm; sandstones, 0.0X ppm; and carbonates, 0.2 ppm. Orheim (1979) reported the following clarke values for antimony: earth's crust, 0.2 ppm; soil, 0.5 ppm; plant ash, 1.0 ppm; and water 0.001 ppm.

World Coals

Abernethy and Gibson (1963) found an average antimony content of 0.5 ppm in coal. The U.S. National Committee for Geochemistry (1980) reported an average worldwide concentration of 3.0 ppm antimony in coal.

United States Coals

Sharkey and others (1975) found that antimony occurred in 92 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration of <0.1 to 2 ppm. Los Alamos Scientific Laboratory (1976) cited an antimony range in concentration of 0.2 to 9 ppm in U.S. coals. Swanson and others (1976) found an average content of 0.7 ppm antimony in 601 U.S. whole-coal samples. The U.S. National Committee for Geochemistry (1980) reported an average antimony concentration in U.S. coals of 1.1 ppm.

The U.S. National Committee for Geochemistry (1980) gave mean concentrations of antimony in U.S. coals of various rank as follows: anthracite, 0.9 ppm; bituminous, 1.4 ppm; subbituminous 0.7 ppm; and lignite 0.7 ppm. A range in antimony content of <40 to 230 ppm has been reported for U.S. coal ashes (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Swanson and others (1976) reported a geometric mean content of 0.8 ppm antimony in 331 Appalachian region whole-coal samples. Gluskoter and others (1977) reported a geometric mean content of 1.1 ppm antimony in 23 Appalachian region coals.

Interior region. Swanson and others (1976) reported a geometric mean content of 0.8 ppm antimony in 194 Interior region whole-coal samples. Gluskoter and others (1977) cited a geometric mean content of 0.81 ppm antimony in 113 Illinois basin whole-coal samples.

Western region. Swanson and others (1976) reported a geometric mean content of 0.4 ppm antimony in 93 Western region whole-coal samples and a geometric mean content of 0.7 ppm antimony in 34 Texas coals. Gluskoter and others (1977) found a geometric mean content of 0.45 ppm antimony in 29 Western U.S. coals.

Alaska Coals

Compared to other U.S. coals, the content of antimony is low in Alaskan coals.

Northern Alaska province. Conwell and Triplehorn (1976) found an average concentration of 1.3 ppm antimony in a Kukpuk River whole-coal sample and 2.1 ppm antimony in a Cape Thompson coal. Affolter and others (1981) reported a range of 0.05 to 0.64 ppm antimony in 54 Utukok River Quadrangle whole-coal samples and a geometric mean content of 0.1 ppm antimony.

Cook Inlet-Susitna province. Merritt (1985b) found a mean concentration of 1.1 ppm antimony in 19 Matanuska Valley coal-ash samples. Affolter and others (1981) reported a range in antimony of 0.2 to 1.3 ppm for 10 Kenai Quadrangle whole-coal samples and a geometric mean of 0.6 ppm. They also reported a range in antimony of 0.2 to 3.7 ppm for 34 Seldovia Quadrangle coals and a geometric mean of 1.0 ppm. Conwell (1977) reported a range in antimony concentration of 0.4 to 1.9 ppm for seven Beluga field whole-coal samples and a mean of 1.0 ppm.

Nenana province. Affolter and others (1981) cited a range in antimony concentration of 0.3-8.1 ppm in 20 Healy Quadrangle whole-coal samples and a geometric mean content of 1.3 ppm. Affolter and Stricker (1987) found an average antimony content of 0.2 ppm for two whole-coal samples of Seam No. 3, Usibelli Mine.

Alaska Peninsula province. Conwell and Triplehorn (1978) reported an average concentration of antimony of 0.6 ppm in eight Alaska Peninsula whole-coal samples.

PROFILE 3 - ARSENIC

Symbol: As Atomic number: 33 Atomic weight: 74.9216

	Coal	Ash
Alaska	0.5-25 ppm	N.E.
U.S.	0.5-110 ppm	20-600 ppm
World	0.5-100 ppm	10-8,000 ppm

Arsenic is a highly poisonous metallic element. It is a common minor element in coal, and is mainly associated with the sulfide group of minerals, especially arsenopyrite (FeAsS). High-pyrite coals usually contain higher concentrations of arsenic than other coals. Lesser amounts of arsenic are contained in the clay minerals and organic matter of coal (Averitt, 1975). Arsenic is generally inorganically combined in coal, and is one of the elements showing least organic affinity. It is typically concentrated in the mineral matter of coal (Ruch and others, 1974).

Arsenic is one of the elements of chief environmental concern in coal; it is generally toxic to plant and animal life at relatively low concentrations (Ruch and others, 1974). Although over 95 percent of arsenic is retained in low-temperature ash (Ruch and others, 1974), it can be volatilized during coal combustion and released from coal-fired plants. It can be enriched on the surfaces of fly-ash particles emanating from coal-fired plants (Mraw and others, 1983). Arsenic may precipitate in the superheater tubes of boilers, in stacks and dust chambers. With pyrite removal from coal, arsenic emissions are significantly lowered (Averitt, 1975).

Arsenic is present in coal in concentrations significantly greater than its clarke value (Gluskoter and others, 1977). It shows a moderate enrichment factor of 8.3X in coal ash compared to its average estimated concentration in the earth's crust (U.S. National Committee for Geochemistry, 1980). Turekian and Wedepohl (1961) reported the following arsenic concentrations in common sedimentary rocks; shales, 13 ppm; sandstones, 1 ppm; and carbonates, 1 ppm. Orheim (1979) reported the following clarke values for arsenic: earth's crust, 2 ppm; soil, 5 ppm; plant ash, 4 ppm; and water, 0.003 ppm.

World Coals

Abernethy and Gibson (1963) reported an average arsenic content of coal of 4.45 ppm. The U.S. National Committee for Geochemistry (1980) cited a worldwide average arsenic concentration in coal of 5 ppm. Berkowitz (1979) cited a maximum concentration of arsenic in coal ash of 8,000 gm/ton and an average concentration of 500 gm/ton.

United States Coals

Sharkey and others (1975) found that arsenic occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 1 to 10 ppm. Los Alamos Scientific Laboratory (1976) reported an arsenic range of 0.5 to 106 ppm in U.S. whole coals, and 21 to 570 ppm in coal ashes. Swanson and others (1976) found a geometric mean arsenic content of 7.5 ppm in 601

U.S. whole-coal samples. The U.S. National Committee for Geochemistry (1980) cited a U.S. average arsenic concentration of 15 ppm in coal.

Appalachian region. Swanson and others (1976) reported a geometric mean content of 11 ppm arsenic in 331 Appalachian region whole-coal samples. Gluskoter and others (1977) reported a geometric mean content of 15 ppm arsenic in 23 Appalachian region coals.

Interior region. Swanson and others (1976) reported a geometric mean content of 12 ppm arsenic in 194 Interior region whole-coal samples. Gluskoter and others (1977) reported a geometric mean content of 7.4 ppm arsenic in 113 Illinois basin coals.

Western region. Swanson and others (1976) reported a geometric mean content of 2 ppm arsenic in 93 Western region coals and a geometric mean content of 5 ppm arsenic in 34 Texas coals. Gluskoter and others (1977) reported a geometric mean content of 1.5 ppm arsenic in 29 Western U.S. coals.

Alaska Coals

Compared to other U.S. coals, the content of arsenic in Alaskan coals is generally lower or similar.

Northern Alaska province. Conwell and Triplehorn (1976) found an average concentration of 3.5 ppm arsenic in a Kukpuk River whole-coal sample and 21 ppm arsenic in a Cape Thompson coal. Affolter and others (1981) reported a range of 0.7 to 8.1 ppm arsenic in 54 Utukok River Quadrangle whole-coal samples and a geometric mean content of 2.0 ppm.

Cook Inlet-Susitna province. Merritt (1985b) found a mean concentration of 5.4 ppm arsenic in 31 Matanuska Valley coal-ash samples. Affolter and others (1981) reported a range in arsenic of 2 to 5 ppm for 10 Kenai Quadrangle whole-coal samples and a geometric mean of 3.4 ppm. They also reported a range in arsenic of 2 to 25 ppm for 34 Seldovia Quadrangle coals and a geometric mean of 7.2 ppm. Conwell (1977) reported a range in arsenic concentration of 2.0 to 7.5 ppm for seven Beluga field whole-coal samples and a mean content of 4.8 ppm.

Nenana province. Affolter and others (1981) cited a range in arsenic concentration of 1 to 10 ppm in 20 Healy Quadrangle whole-coal samples and a geometric mean content of 2.6 ppm. Affolter and Stricker (1987) found an average arsenic concentration of 2.2 ppm for two whole-coal samples of Seam No. 3, Usibelli Mine.

Alaska Peninsula province. Conwell and Triplehorn (1978) reported an average concentration of arsenic of 6.6 ppm in eight Alaska Peninsula whole-coal samples.

PROFILE 4 - BARIUM

Symbol: Ba Atomic number: 56 Atomic weight: 137.34

	Coal	Ash
Alaska	100-3,000 ppm	3,000-18,000 ppm
U.S.	<100-2,000 ppm	100-15,000 ppm
World	N.E.	0-50,000 ppm

Barium is an alkaline-earth metallic element that generally occurs in association with the mineral barite ($BaSO_4$) in coals. Barium oxide (BaO) usually exhibits significant, but not large, concentrations in the ash of some coals. Barium in coal results primarily from the remaining constituents of original plant cells, but secondary amounts appear to result from enrichment by circulating ground water (Averitt, 1961).

Barium occurs in appreciably greater concentration in coal than its estimated average concentration in the earth's crust (Averitt, 1961). Turekian and Wedepohl (1961) reported the following average barium concentrations in common sedimentary rocks; shales, 580 ppm; sandstones, XO ppm; and carbonates, 10 ppm. Orheim (1979) reported the following clarke values for barium: earth's crust, 425 ppm; soil, 500 ppm; plant ash, 280 ppm; and water 0.03 ppm.

World Coals

Abernethy and Gibson (1963) found an average barium content of 65 ppm in coal. The U.S. National Committee for Geochemistry reported an average worldwide concentration of 500 ppm barium in coal.

United States Coals

Sharkey and others (1975) found that barium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 20 to 1,600 ppm. Los Alamos Scientific Laboratory (1976) cited a barium range in concentration in ash of U.S. coals of 0.01 to 1.39 percent, and listed average barium concentrations in ashes of U.S. coals of various ranks as follows: anthracite, 866 ppm; low-volatile bituminous, 740 ppm; medium-volatile bituminous, 896 ppm; high-volatile bituminous 1,253 ppm; and sub-bituminous and lignite, 5,027 ppm.

Swanson and others (1976) found an average content of 137.7 ppm barium in 601 U.S. whole-coal samples. The U.S. National Committee for Geochemistry (1980) reported an average barium concentration in U.S. coals of 150 ppm.

Appalachian region. Swanson and others (1976) reported a geometric mean content of 70 ppm barium in 331 Appalachian region whole-coal samples. Gluskoter and others (1977) reported a geometric mean content of 170 ppm barium in 14 Appalachian region coals.

Interior region. Swanson and others (1976) reported a geometric mean content of 30 ppm barium in 194 Interior region whole-coal samples.

Gluskoter and others (1977) cited a geometric mean content of 75 ppm barium in 56 Illinois basin whole-coal samples.

Western region. Swanson and others (1976) reported a geometric mean content of 300 ppm barium in 93 Western region whole-coal samples and a geometric mean content of 150 ppm barium in 34 Texas coals. Gluskoter and others (1977) found a geometric mean content of 430 ppm barium in 22 Western U.S. coals.

Alaska Coals

Compared to other U.S. coals, the content of barium in Alaskan coals tends to be higher.

Northern Alaska province. Rao (1968) reported an average concentration of 670 ppm barium in 12 Northern Alaska whole-coal samples; the total average barium concentration in ash samples of the same coals was 6,915 ppm. Conwell and Triplehorn (1976) found an average concentration of 2,000 ppm barium in a Kukpuk River coal-ash sample and 1,000 ppm barium in a Cape Thompson coal. Rao and Wolff (1981) reported 470 ppm barium in a Wainwright subbituminous B whole-coal sample, and 7,900 ppm barium in the ash of the same coal. They also reported a barium content of 210 ppm for a Meade River subbituminous B whole-coal sample, and 4,800 ppm barium in the ash of the same coal. Affolter and others (1981) reported a range of 100 to 2,000 ppm barium in 54 Utukok River Quadrangle whole-coal samples and a geometric mean content of 700 ppm barium.

Cook Inlet-Susitna province. Rao (1968) reported an average barium concentration of 623 ppm in 22 Matanuska Valley whole-coal samples and 4,454 ppm barium in ash samples of the same coals. Merritt (1985b) found a mean concentration of 579 ppm barium in 22 Matanuska Valley coal-ash samples. Rao and Wolff (1981) found that the lower seam (hvb rank), Castle Mountain Mine, contained 620 ppm barium on a whole-coal basis and 3,400 ppm in coal ash.

Rao (1968) reported an average concentration of 282 ppm barium in eight Kenai field whole-coal samples; coal ash of the same samples contained an average barium content of 2,925 ppm. Rao and Wolff (1981) cited a barium content of 520 ppm in a sample of the subbituminous C-ranked Cabin bed, Kenai field; the sample showed an ash concentration of 5,500 ppm barium. Affolter and others (1981) reported a range in barium of 500 to 700 ppm for 10 Kenai Quadrangle whole-coal samples and a geometric mean of 500 ppm. They also reported a range in barium of 150 to 1,000 ppm for 34 Seldovia Quadrangle whole-coal samples and a geometric mean of 500 ppm. Merritt and others (1987) found that the average concentration of barium in the ash of 31 Kenai field coals was 3,198 ppm.

Conwell (1977) reported a range in barium concentration of 3,000 to 10,000 ppm for ash samples of seven Beluga field coals and a mean content of 6,860 ppm barium. Rao and Wolff (1981) found that a whole-coal sample of the subbituminous C-ranked Waterfall Seam, Beluga field contained 490 ppm barium; ash of the same coal contained 5,200 ppm barium. They found that a

whole-coal sample of the Sunflower Creek seam, a lignite, contained 230 ppm barium, and that ash of the same coal contained 5,600 ppm barium. Rao and Smith (1987) reported the average concentration of barium in five coal seams of the Chuitna district, Beluga field, and showed that barium content in coal ash generally decreases downsection. From youngest to oldest, the coals contained the following barium contents: Blue Seam (15 samples), 8,473 ppm; Red 3 Seam (13 samples), 9,342 ppm; Red 2 Seam (26 samples), 6,781 ppm; Red 1 Seam (16 samples), 6,138 ppm; and Purple Seam (5 samples); 4,720 ppm.

Rao and Wolff (1981) found relatively high barium contents in Broad Pass field lignite. A Coal Creek seam showed 2,200 ppm barium on a whole-coal basis and 11,000 ppm barium in coal ash.

Nenana province. Rao (1968) found an average barium content of 255 ppm in 25 Nenana basin whole-coal samples and 2,604 ppm in ash samples of the same coals. Rao and Wolff (1981) reported a relatively high barium content in upper Lignite (Hosanna) Creek, Jarvis Creek, and Little Tonzona River coals. An average of six Nenana basin samples including the No. 2, No. 4, No. 6 (2 splits), Moose, and Caribou seams, all of subbituminous C rank, showed 932 ppm barium on a whole-coal basis and 8,283 ppm barium in coal ash. Affolter and others (1981) cited a range in barium concentration of 150 to 1,500 ppm in 20 Healy Quadrangle whole-coal samples and a geometric mean content of 500 ppm. Affolter and Stricker (1987) found an average barium content of 505 ppm for two whole-coal samples of Seam No. 3, Usibelli Mine.

Rao (1968) reported that three whole-coal samples of Jarvis Creek field seams contained an average barium content of 576 ppm; ash samples of the same coals contained an average 6,043 ppm barium. Rao and Wolff (1981) reported that a subbituminous C-ranked seam from Ober Creek, Jarvis Creek field contained 1,700 ppm barium on a whole-coal basis and 15,000 ppm barium in coal ash. Belowich (1987) cited an average barium concentration of 660 ppm in 27 Jarvis Creek field whole-coal samples.

Alaska Peninsula province. Conwell and Triplehorn (1978) reported an average concentration of barium of 675 ppm in eight Alaska Peninsula whole-coal samples.

Gulf of Alaska province. Rao (1968) reported an average barium concentration of 111 ppm in five Bering River field whole-coal samples and 4,288 ppm in ash samples of the same coals. Smith and Rao (1987) reported an average concentration of 1,850 ppm barium in 20 Bering River field coal-ash samples.

PROFILE 5 - BERYLLIUM

Symbol: Be Atomic number: 4 Atomic weight: 9.0122

	Coal	Ash
Alaska	0.2-10 ppm	N.E.
U.S.	0.05-330 ppm	0-1,100 ppm
World	N.E.	10-1,000 ppm

Beryllium is a metallic element that forms small highly charged ions (high ionic potential; Zubovic and others, 1966a,b). It is commonly associated with silicate minerals. Turekian and Wedepohl (1961) reported the following average beryllium contents in common sedimentary rocks: shales, 3 ppm; sandstones, 0.X ppm; and carbonates, 0.X ppm. Orheim (1979) cited the following clarke values for beryllium: earth's crust, 2.8 ppm; soil, 0.8 ppm; and plant ash, 1.2 ppm. Averitt (1975) estimated beryllium's concentration in the earth's crust at 2 ppm. It is found as a minor element in nearly all coal beds.

Beryllium is present in coal ash in vastly greater concentration than its estimated average concentration in the earth's crust. It appears that there is a greater enrichment of beryllium in coals of low ash (Averitt, 1975).

Beryllium is introduced into coal at the time of peat formation, and is derived from eroding areas of beryllium-bearing rocks (Averitt, 1975). Beryllium tends to be concentrated near the source areas of a coal basin (Zubovic, 1966). It is mostly found in the vitrinitic components of coal. There is no appreciable beryllium in the inert constituents of coal (Averitt, 1975).

Beryllium is one of the elements of chief environmental concern in coal. It is generally toxic to plant and animal life at relatively low concentrations (Ruch and others, 1974). It can be enriched in some coals such that upon further concentration in ash or other products, may become environmentally hazardous (Altschuler and Johnston, 1976).

Beryllium is one of the elements showing greatest organic affinity; it is concentrated in clean-coal fractions (Ruch and others, 1974). On combustion, it is generally retained in high-temperature ash, and over 95 percent is retained in low-temperature ash (Ruch and others, 1974).

World Coals

Beryllium exhibits a worldwide average concentration of 3 ppm (Swanson and others, 1976; U.S. National Committee for Geochemistry, 1980). Berkowitz (1979) reported a maximum concentration of beryllium in coal ash of 1,000 gm/ton and an average concentration of 300 gm/ton.

United States Coals

Sharkey and others (1975) found that beryllium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 0.4 to 3 ppm. Los Alamos Scientific Laboratory (1976) reported a range in beryllium concentration in U.S. coals at 0-31 ppm. Zubovic and others (1979) cited a range for beryllium in U.S. coals of 0.05-330 ppm. Beryllium exhibits a geometric mean in U.S. coals of 1.4 ppm and an arithmetic mean of 2.0 ppm (Swanson and others, 1976; Zubovic and others, 1979; and U.S. National Committee for Geochemistry, 1980). Estimated geometric mean beryllium contents by rank are as follows: anthracite, 1.5 ppm; bituminous, 2.0 ppm; subbituminous 0.7 ppm; and lignite, 2.0 ppm (Swanson and others, 1976).

Los Alamos Scientific Laboratory (1976) reported a range in beryllium concentration in ashes of U.S. coals at 0 to 1,100 ppm, and estimated geometric mean contents by rank as follows: anthracite, 9 ppm; low-volatile bituminous, 16 ppm; medium-volatile bituminous, 13 ppm; high volatile bituminous, 17 ppm; and subbituminous and lignite, 6 ppm.

Appalachian region. Los Alamos Scientific Laboratory (1976) reported an average concentration of 2.5 ppm beryllium in 73 Appalachian region whole-coal samples. Swanson and others (1976) reported a geometric mean content of 2 ppm beryllium in 331 Appalachian region whole-coal samples. Gluskoter and others (1977) reported a geometric mean content of 1.1 ppm beryllium in 23 Appalachian whole-coal samples.

Interior region. Los Alamos Scientific Laboratory (1976) reported a geometric mean content of 2.5 ppm beryllium in 53 Interior region whole-coal samples. Swanson and others (1976) reported a geometric mean content of 1.5 ppm beryllium in 194 Interior region coals. Gluskoter and others (1977) reported a geometric mean content of 1.6 ppm beryllium in 113 Illinois basin coals.

Western region. Los Alamos Scientific Laboratory (1976) reported an average concentration of 1.1 ppm beryllium in 48 Western and Southwestern Interior U.S. whole-coal samples, and an average content of 1.5 ppm beryllium in 51 Northern Great Plains coals. Swanson and others (1976) reported a geometric mean content of 0.3 ppm beryllium in 93 Western region coals and a geometric mean content of 2 ppm beryllium in 34 Texas coals. Gluskoter and others (1977) reported a geometric mean content of 0.35 ppm beryllium in 20 Western U.S. coals.

Alaska Coals

There exists an abundant amount of data relating to beryllium concentrations in Alaskan coals and coal ashes. In general, compared to other U.S. coals, the content of beryllium is low in Alaskan coals.

Northern Alaska province. Rao (1968) found the concentration of beryllium in 12 Northern Alaska whole-coal samples to average <0.8 ppm, and in ashes of the same coals, beryllium averaged <6.2 ppm. Conwell and Triplehorn

(1976) found 70 ppm beryllium in a Kukpuk River coal-ash sample, and 15 ppm beryllium in a Cape Thompson coal-ash sample. Affolter and others (1981) determined a range of 0.1 to 5 ppm beryllium in 54 Utukok River Quadrangle coals and a geometric mean content of 0.3 ppm.

Cook Inlet-Susitna province. Rao (1968) reported an average beryllium concentration of 0.7 ppm in 22 Matanuska Valley whole-coal samples, and an average content of 5.1 ppm beryllium in ashes of the same coals. Merritt (1985b) found a mean content of 0.9 ppm beryllium in coal-ash samples of 31 Matanuska Valley coals.

Rao (1968) reported an average beryllium concentration of <0.9 ppm in eight Kenai field whole-coal samples and <2.5 ppm beryllium in ash-samples of the same coals. Affolter and others (1981) found a range in beryllium content of <0.2 to 1.5 ppm in 10 Kenai Quadrangle whole-coal samples and a geometric mean content of 0.5 ppm; in 34 Seldovia Quadrangle coals, they reported a range in beryllium content of <0.2 to 1.5 ppm and a geometric mean content of 0.3 ppm. Merritt and others (1987) reported an average beryllium content of 2.3 ppm in 31 Kenai field coal-ash samples.

Conwell (1977) reported a range in beryllium content from 3 to 10 ppm in ash samples of seven Beluga field coals and a mean content of 7 ppm. Based on samples of six coal beds from the Tyonek Formation, Beluga field, Affolter and Stricker (1984) found that the concentration of beryllium varied directly with the ash content of the coals. Rao and Smith (1987) determined from coal seams of the Chuitna district, Beluga field, that the average concentrations of beryllium increased downsection in coal-ash samples. By seam, they showed the following contents: Blue Seam (15 samples), 4.0 ppm; Red 3 Seam (13 samples), 4.3 ppm; Red 2 Seam (26 samples), 5.4 ppm; Red 1 Seam (16 samples), 7.7 ppm; and Purple Seam (5 samples), 8.5 ppm.

Nenana province. Rao (1968) cited an average beryllium content of <0.3 ppm in 25 whole-coal samples of the Nenana basin; the average in ash samples of the same coals was <2.5 ppm. In three Jarvis Creek field raw coal samples, Rao (1968) found an average beryllium concentration of <0.3 ppm, and in ash samples of the same three coals, he found an average beryllium content of <2.6 ppm. Affolter and others (1981) found a range in beryllium content of <0.2 to 3.0 ppm in 20 Healy Quadrangle whole-coal samples and a geometric mean content of 0.2 ppm. Affolter and Stricker (1987) found an average beryllium concentration of 0.19 ppm in two whole-coal samples of the No. 3 Seam, Usibelli Mine. Belowich (1987) reported an average beryllium content of 0.7 ppm in 27 Jarvis Creek field whole-coal samples. Merritt (1985b) cited a general factor of enrichment for beryllium of 1.4X based on its content in Nenana basin coal-ash samples.

Gulf of Alaska province. Rao (1968) reported an average beryllium concentration of <0.2 ppm in five Bering River field whole-coal samples; ash samples of the same coals showed an average beryllium content of <3.8 ppm. Smith and Rao (1987) found an average beryllium concentration of 10.5 ppm in ash samples of 20 Bering River field coals.

PROFILE 6 - BISMUTH

Symbol: Bi Atomic number: 83 Atomic weight: 208.980

	Coal	Ash
	N.E.	N.E.
Alaska		
U.S.	<0.1-1 ppm	1-900 ppm
World	0.1-10 ppm	1-500 ppm

Bismuth is a highly diamagnetic metallic element used to form various alloys. It occurs in coal in appreciably greater concentration than its estimated average concentration in the earth's crust (Averitt, 1975).

World Coals

Berkowitz (1979) reported a maximum bismuth concentration in coal ash of 200 gm/ton and an average concentration of 20 gm/ton. The U.S. National Committee for Geochemistry (1980) cited a worldwide average bismuth concentration in coal of 5.5 ppm.

United States Coals

Sharkey and others (1975) found that bismuth occurred in only 31 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration in these coals from <0.1 to 0.2 ppm. Bismuth content in U.S. coal ashes ranges from 1 to 900 ppm (Los Alamos Scientific Laboratory, 1976). The U.S. average concentration of bismuth is 0.7 ppm on a whole-coal basis (U.S. National Committee for Geochemistry, 1980).

Alaska Coals

Bismuth was not detected in ash samples of Kukpuk River and Cape Thompson coals from northern Alaska (Conwell and Triplehorn, 1976).

PROFILE 7 - BORON

Symbol: B Atomic number: 5 Atomic weight: 10.811

	Coal	Ash
Alaska	5-300 ppm	90-4,000 ppm
U.S.	1-400 ppm	25-7,000 ppm
World	1-500 ppm	10-3,000 ppm

Boron is a semi-metal that forms small highly charged ions (that is, exhibits high ionic potential). It is associated with complex aluminum-silicate minerals as illite and tourmaline. It is one of the elements showing greatest organic affinity, and tends to be concentrated in clean coal fractions (Ruch and others, 1974). Some boron in coal was derived from original plant constituents (Averitt, 1961). Boron's concentration in coals may be the result of greater marine influence during and following coal-swamp development (Gluskoter and others, 1977). It tends to be concentrated near the source areas of a coal basin (Zubovic and others, 1966a) and in surface and near-surface soils supporting the growth of plants (Averitt, 1975). Boron is retained in high-temperature ash (Ruch and others, 1974). Excessive boron makes a coal unsuitable for the production of reactor graphite (Stach and others, 1982).

Boron is present in coal ash in concentrations significantly greater than its clarke value (Gluskoter and others, 1977). It shows a moderate enrichment factor of 5X in coal compared to its average concentration in the earth's crust (U.S. National Committee for Geochemistry, 1980). Turekian and Wedepohl (1961) reported the following average boron concentrations in common sedimentary rocks: shales, 100 ppm; sandstones, 35 ppm; and carbonates, 20 ppm. Orheim (1979) reported the following clarke values for boron: earth's crust, 10 ppm; soil, 10 ppm; plant ash, 700 ppm; and water, 4.6 ppm.

World Coals

The U.S. National Committee for Geochemistry (1980) reported an average worldwide content of boron in whole coal samples of 85 ppm. Berkowitz (1979) reported a maximum concentration of boron in coal ash of 3,000 gm/ton, and an average concentration of 600 gm/ton.

United States Coals

Sharkey and others (1975) found that boron occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 1 to 230 ppm. Others have reported a range in boron content from 1.2 to 356 ppm in U.S. whole-coal samples (Los Alamos Scientific Laboratory, 1976). Swanson and others (1976) reported an average concentration of 60 ppm in 601 U.S. whole-coal samples, and the U.S. National Committee for Geochemistry (1980) reported an average concentration of 50 ppm.

Los Alamos Scientific Laboratory (1976) cited a range of 30 to 6,500 ppm boron in U.S. coal-ash samples, and also gave mean concentrations of boron in ashes of U.S. coals of various rank as follows: anthracite, 90 ppm; low-volatile bituminous, 123 ppm; medium-volatile bituminous, 218 ppm; high-volatile bituminous, 770 ppm; and subbituminous and lignite, 1,010 ppm.

Appalachian region. Los Alamos Scientific Laboratory (1976) reported an average concentration of 25 ppm boron in 73 Appalachian region whole-coal samples. Swanson and others (1976) reported a geometric mean content of 20 ppm boron in 331 Appalachian region whole-coal samples. Gluskoter and others (1977) reported a geometric mean content of 28 ppm boron in 23 Appalachian region coals.

Interior region. Los Alamos Scientific Laboratory (1976) reported an average concentration of 96 ppm boron in 53 Interior region whole-coal samples. Swanson and others (1976) reported a geometric mean content of 50 ppm boron in 194 Interior region coals. Gluskoter and others (1977) reported a geometric mean content of 98 ppm boron in 99 Interior region coals.

Western region. Los Alamos Scientific Laboratory (1976) reported an average concentration of 33 ppm boron in 48 Western and Southwestern Interior U.S. whole coal samples, and an average content of 116 ppm boron in 51 Northern Great Plains coals. Swanson and others (1976) reported a geometric mean content of 70 ppm boron in 93 Western region coals and a geometric mean content of 100 ppm boron in 34 Texas coals. Gluskoter and others (1977) reported a geometric mean content of 48 ppm boron in 27 Western region coals.

Alaska Coals

There exists an abundant amount of data relating to boron concentrations in Alaskan coals and coal-ashes. In general, compared to other U.S. coals, the content of boron in Alaska tends to be lower.

Northern Alaska province. Rao (1980) found the concentration of boron in Cape Beaufort region coals to be within the range of other U.S. coals; he determined a range of 26 to 181 ppm boron in 38 whole-coal samples and a mean content of 76 ppm. Rao and Wolff (1981), though, found 'anomalously high' concentrations of boron in two Cretaceous coals from northern Alaska. A subbituminous B seam from the Wainwright area had a mean concentration of 250 ppm boron, and a high-volatile bituminous coal from Sagwon Bluffs had a mean content of 110 ppm boron. Affolter and others (1981) determined a range of 20 to 100 ppm boron in 43 Utukok River Quadrangle coals and a geometric mean content of 50 ppm.

Conwell and Triplehorn (1976) found 300 ppm boron in a Kokuk River coal-ash sample, and 200 ppm in a Cape Thompson coal-ash sample. Rao (1980) reported a range of 96 to 2,500 ppm boron in ashes of 38 Cape Beaufort region coals and a mean content of 446 ppm. In the ash of the Wainwright sub-bituminous B coal, Rao and Wolff (1981) found a boron concentration of 4,100 ppm, and in the ash of the Sagwon Bluffs high-volatile C bituminous coal they found a boron content of 180 ppm.

Cook Inlet-Susitna province. Rao and Wolff (1981) reported a boron content of 20 ppm in the lower seam (hvb), Castle Mountain Mine, Matanuska field, and 72 ppm in a Premier Mine seam (hvb rank), Matanuska field. Coal-ash samples of the same two coals showed boron concentrations of 110 ppm and 470 ppm, respectively. Merritt (1985b) found a mean content of 75 ppm in coal-ash samples of 31 Matanuska field coals.

In the Kenai field, Rao and Wolff (1981) reported a boron content of 43 ppm in a whole-coal sample of subbituminous C Cabin bed; they reported a boron concentration of 380 ppm in an ash sample of the same coal. Affolter and others (1981) found a range in boron content of 10 to 70 ppm in 10 Kenai Quadrangle coals and a geometric mean content of 20 ppm; in 34 Seldovia Quadrangle coals, they reported a range in boron content of 5 to 70 ppm and a geometric mean content of 20 ppm.

Rao and Wolff (1981) reported a boron concentration of 13 ppm for a whole-coal sample of the subbituminous C Waterfall Seam of the Beluga field. They found a boron content of 14 ppm in a whole-coal sample of a Sunflower Creek, Yentna field lignite seam. Ash samples of the same two coals revealed boron concentrations of 130 ppm and 345 ppm, respectively. Conwell (1977) reported a range of 50 to 300 ppm in ash samples of seven Beluga field coals and a mean content of 127 ppm. Merritt (1987) found a range in boron content of <10 to 55 ppm in 66 Susitna lowland samples and an average content of <54 ppm. In a Coal Creek, Broad Pass field lignite, Rao and Wolff (1981) reported a whole-coal boron concentration of 19 ppm and an ash concentration of 96 ppm.

Nenana province. Rao and Wolff (1981) found anomalously high concentrations of boron in two Nenana basin samples. They analyzed six whole-coal samples including Seam Nos. 2, 4, and 6 (3 splits) and the Caribou Seam, all of subbituminous C rank; they reported a mean boron concentration of 59 ppm. Affolter and Stricker (1987) found an average boron concentration of 24 ppm in two whole-coal samples of the No. 3 Seam, Usibelli Mine. They reported a range of 15 to 100 ppm in 20 Healy Quadrangle whole-coal samples and a geometric mean content of 30 ppm. Rao and Wolff (1981) reported a boron concentration of 15 ppm in an Ober Creek, Jarvis Creek field whole-coal sample, and a boron content of 45 ppm in a subbituminous C coal sample of the main seam, Little Tonzona River field.

Merritt (1985a) reported a general factor of enrichment of 55X for boron in Nenana basin coal-ash samples. Rao and Wolff (1981) found an average boron concentration of 467 ppm in ash samples of six Nenana basin subbituminous C coals, including Seam Nos. 2, 4, and 6 (3 splits) and the Caribou Seam. The mean content of boron in the ash of the Ober Creek, Jarvis Creek field subbituminous C coal was 130 ppm. An ash sample of the main seam (sub C rank) Little Tonzona River field, revealed a boron concentration of 330 ppm (Rao and Wolff, 1981).

Alaska Peninsula province. Conwell and Triplehorn (1978) found an average boron concentration of 255 ppm in eight ash samples of coals from the Herendeen Bay and Chignik fields.

Yukon-Koyukuk province. Rao and Wolff (1981) reported a boron content of 280 ppm in a whole-coal sample of the main seam (hvb rank), Tramway Bar field. An ash sample of the same coal had a boron content of 670 ppm.

PROFILE 8 - BROMINE

Symbol: Br Atomic number: 35 Atomic weight: 79.909

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	0.5-60 ppm	N.E.
World	0.1-100 ppm	N.E.

Bromine is a volatile nonmetallic element with 100 percent being lost during low-temperature ashing (Ruch and others, 1974). Turekian and Wedepohl (1961) reported the following bromine concentrations in common sedimentary rocks: shales, 4 ppm; sandstones, 1 ppm; and carbonates, 6.2 ppm.

World Coals

Abernethy and Gibson (1963) reported an average bromine content in coal of 3.7 ppm.

United States Coals

Sharkey and others (1975) found that bromine occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 1 to 23 ppm. Others have cited a range in bromine content in U.S. coals from 4 to 52 ppm (Los Alamos Scientific Laboratory, 1976). The U.S. average concentration of bromine in coal is 2.6 ppm according to the U.S. National Committee for Geochemistry (1980).

Appalachian region. Gluskoter and others (1977) reported a geometric mean bromine content of 8.9 ppm in 23 Appalachian region whole-coal samples.

Interior region. Gluskoter and others (1977) reported a geometric mean bromine content of 10 ppm in 113 Illinois basin whole-coal samples.

Western region. Gluskoter and others (1977) reported a geometric mean bromine content of 2.1 ppm in 29 Western U.S. whole-coal samples.

Alaska Coals

Merritt (1985b) reported a mean bromine content of 27 ppm in ash samples of 30 Mantanuska Valley coals.

PROFILE 9 - CADMIUM

Symbol: Cd Atomic number: 48 Atomic weight: 112.40

	Coal	Ash
Alaska	.05-1 ppm	<1-30 ppm
U.S.	<0.01-65 ppm	N.E.
World	N.E.	1-100 ppm

Cadmium is a metallic element that occurs chiefly in ores of zinc, copper, and lead. It is most typically associated with the sulfide mineral group, especially sphalerite---(Zn,Cd)S. Turekian and Wedepohl (1961) reported the following average cadmium contents in common sedimentary rocks: shales, 0.3 ppm, sandstones, 0.0X ppm, and carbonates, 0.035 ppm. Orheim (1979) reported the following clarke values for cadmium: earth's crust, 0.2 ppm; soil, 0.5 ppm; plant ash, 0.1 ppm, and water, 0.0001 ppm. Cadmium shows a moderate enrichment factor in coal ash of 6.5X compared to its average estimated composition in the earth's crust (U.S. National Committee for Geochemistry, 1980).

Cadmium is one of the elements of chief environmental concern in coal; it is generally toxic to plant and animal life at relatively low concentrations (Ruch and others, 1974). Cadmium can be enriched in some coals such that upon further concentration in ash or other products, it may become environmentally hazardous (Altschuler and Johnston, 1976).

Cadmium is generally inorganically combined in coal and is one of the elements showing least organic affinity (Ruch and others, 1974). It tends to be concentrated in the mineral matter or heavier specific gravity fraction of coal (Cavallaro and others, 1978).

Cadmium can be released from coal-combustion sources and enriched on the surfaces of fly-ash particles from coal-fired plants (Mraw and others, 1983). It is generally retained in high-temperature ash and over 90 percent is retained in low-temperature ash (Ruch and others, 1974).

Whole Coals

Abernethy and Gibson (1963) reported an average cadmium content in coal of 0.47 ppm. Berkowitz (1979) cited a maximum concentration of cadmium in coal ash of 50 gm/ton and an average concentration of 5 gm/ton.

United States Coals

Sharkey and others (1975) found that cadmium occurred in 92 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from <0.01 to 0.7 ppm. Others have reported a range in cadmium content from 0.1 to 65 ppm in U.S. coals (Los Alamos Scientific Laboratory, 1976; Wewerka and others, 1976). Swanson and others (1976) found a geometric mean cadmium content of 0.2 ppm in 601 U.S. whole-coal samples. The U.S. National Committee for Gecchemistry (1980) cited a U.S. average cadmium concentration of 1.3 ppm.

Appalachian region. Swanson and others (1976) reported a geometric mean content of 0.3 ppm cadmium in 331 Appalachian region whole-coal samples. Gluskoter and others (1977) reported a geometric mean content of 0.19 ppm cadmium in 23 Appalachian region coals.

Interior region. Swanson and others (1976) reported a geometric mean content of 0.12 ppm cadmium in 194 Interior region whole-coal samples. Gluskoter and others (1977) reported a geometric mean content of 0.59 ppm cadmium in 93 Illinois basin whole-coal samples.

Western region. Swanson and others (1976) reported a geometric mean content of 0.2 ppm cadmium in 93 Western U.S. region coals and a geometric mean content of 0.2 ppm cadmium in 34 Texas coals. Gluskoter and others (1977) reported a geometric mean content of 0.15 ppm cadmium in 29 Western U.S. coals.

Alaska Coals

Northern Alaska province. Conwell and Triplehorn (1976) found an average concentration of 1.5 ppm cadmium in a Kukpuk River coal-ash sample and <1.0 ppm cadmium in a Cape Thompson coal-ash sample.

Cook Inlet-Susitna province. Merritt (1985b) found a mean concentration of 1.9 ppm cadmium in 29 Matanuska Valley coal-ash samples. Merritt and others (1987) reported an average cadmium content of <10 ppm in 31 Kenai field coal-ash samples. Conwell (1977) reported a cadmium content of <1 ppm in seven Beluga field coal-ash samples. Merritt (1987a) reported a range in cadmium content of <1 to 27 ppm and an average content <7 ppm in 45 Susitna lowland coal-ash samples.

Nenana province. Affolter and others (1981) cited a range in cadmium concentration of <0.06 to 0.56 ppm in 20 Healy Quadrangle whole-coal samples and a geometric mean content of 0.07 ppm. Affolter and Stricker (1987) found an average cadmium concentration of 0.010 ppm for two whole-coal samples of Seam No. 3, Usibelli Mine. Belowich (1987) reported an average cadmium content of <1 ppm in 27 Jarvis Creek field whole-coal samples. Merritt (1985a) reported a general factor of enrichment of 5.5X for cadmium concentration in Nenana basin coal-ash samples.

Alaska Peninsula province. Conwell and Triplehorn (1978) reported an average concentration of <1 ppm cadmium in eight Alaska Peninsula coal-ash samples.

PROFILE 10 - CALCIUM

Symbol: Ca Atomic number: 20 Atomic weight: 40.08

	Coal	Ash
Alaska	300-27,000 ppm	N.E.
U.S.	100-38,000 ppm	5,000-15,000 ppm
World	100-40,000 ppm	N.E.

Calcium is a metallic element composing approximately 3 percent of the earth's crust. It is mainly associated with the carbonate and sulfate mineral groups, and occurs naturally as calcite or limestone ($CaCO_3$), gypsum ($CaSO_4 \cdot 2H_2O$), and flourite (CaF_2). Turekian and Wedepohl (1961) reported the following average calcium contents in common sedimentary rocks: shales, 22,100 ppm; sandstones, 39,100 ppm; and carbonates, 302,300 ppm. Calcium is a major inorganic element in the mineral constituents of coal, and calcium oxide forms a significant part of coal ash. Calcium has an important effect on the use of coal in combustion and cokemaking.

World Coals

Abernethy and Gibson (1963) reported an average calcium content in coal of 4,340 ppm. The U.S. National Committee for Geochemistry (1980) reported a worldwide average calcium concentration in coal of 1.0 percent.

United States Coals

Sharkey and others (1975) found that calcium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 800 to 6,100 ppm. Others have cited a range in calcium content from 0.05 to 2.67 percent in U.S. coals (Los Alamos Scientific Laboratory, 1976; Wewerka and others, 1976). Swanson and others (1976) reported a geometric mean calcium content in 601 U.S. coals of 0.5 percent. The U.S. National Committee for Geochemistry (1980) cited an average U.S. calcium concentration in coal of 0.54 percent. Calcium varies from 0.58 to 14 percent in ashes of U.S. coals (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Swanson and others (1976) reported a geometric mean content of 0.093 percent calcium in 331 Appalachian region whole-coal samples. Gluskoter and others (1977) reported a geometric mean content of 0.34 percent calcium in 23 Appalachian whole-coal samples.

Interior region. Swanson and others (1976) reported a geometric mean content of 0.5 percent calcium in 194 Interior region whole-coal samples. Gluskoter and others (1977) reported a geometric mean content of 0.51 percent calcium in 113 Illinois basin whole-coal samples.

Western region. Swanson and others (1976) reported a geometric mean content of 0.92 percent calcium in 93 Western U.S. region coals and a geometric mean content of 0.6 percent calcium in 34 Texas coals. Gluskoter

and others (1977) reported a geometric mean content of 1.5 percent calcium in 29 Western U.S. coals.

Alaska Coals

Affolter and others (1981) reported geometric mean calcium concentrations of 1.3 percent, 0.70 percent, 1.2 percent, and 0.40 percent in whole-coal samples of the Healy (20), Kenai (10), Seldovia (34), and Utukok River (24) Quadrangles, respectively. Compared to 410 Powder River region coal samples, the contents of calcium in coals of the Healy and Seldovia Quadrangles were significantly higher, the content of calcium in Kenai Quadrangle coals was significantly lower. Compared to 295 coal samples of the Rocky Mountain province, the content of calcium in Utukok River Quadrangle coals was not significantly different.

PROFILE 11 - CARBON

Symbol: C Atomic number: 6 Atomic weight: 12.01115

	Coal	Ash
Alaska	350,000-730,000 ppm	---
U.S.	380,000-800,000 ppm	---
World	350,000-850,000 ppm	---

Carbon is a naturally abundant nonmetallic element that occurs in all organic and many inorganic compounds. It belongs to the organic mineral group of elements (Wewerka and others, 1978). Carbon is one of the major elements composing the basic structure of coal, and it generally increases in content with rank.

Gluskoter and others (1977) reported a geometric mean carbon content of 70 percent for 110 Illinois basin whole-coal samples, 72 percent for 22 Appalachian whole-coal samples, and 67 percent for 29 Western U.S. whole-coal samples.

Alaskan coals are similar in carbon composition to other U.S. coals when considered by rank. For example, a high-volatile A bituminous coal from the Matanuska Valley contains about 70 percent carbon, whereas Nenana and Beluga subbituminous coals contain 47 percent carbon (equilibrium bed moisture basis).

PROFILE 12 - CERIUM

Symbol: Ce Atomic number: 58 Atomic weight: 140.12

	Coal	Ash
Alaska	N.E.	10-700 ppm
U.S.	1-50 ppm	N.E.
World	N.E.	N.E.

Cerium is a metallic, rare-earth element that occurs chiefly in the mineral monazite [(Ce, La, Y, Th)PO_4] and used in various metallurgical applications. It is an element generally associated with silicate minerals. Turekian and Wedepohl (1961) reported the following average cerium concentrations in common sedimentary rocks: shales, 59 ppm; sandstones, 92 ppm; and carbonates, 11.5 ppm. Abernethy and Gibson (1963) found an average cerium content in coal of 8.2 ppm. The U.S. National Committee for Geochemistry (1980) cited a worldwide average cerium concentration in coal of 11.5 ppm.

Sharkey and others (1975) found that cerium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 1 to 30 ppm. U.S. coals contain an average cerium content of 7.7 ppm; a typical U.S. subbituminous coal contains 5.5 ppm cerium, and a typical U.S. lignite contains 12.3 ppm cerium (U.S. National Committee for Geochemistry, 1980).

Gluskoter and others (1977) reported a geometric mean cerium content of 23 ppm for 14 Appalachian region whole-coal samples, 12 ppm for 56 Illinois basin whole-coal samples, and 22 ppm cerium for 22 Western U.S. whole-coal samples.

Conwell and Triplehorn (1976) found 700 ppm cerium in an ash sample of a Kukpuk River, northern Alaska coal. Merritt (1985b) reported a mean cerium concentration of 29 ppm in ash samples of 31 Matanuska Valley coals. Affolter and Stricker (1987) cited an average cerium content of 10 ppm for two whole-coal samples of Seam No. 3, Usibelli Mine.

PROFILE 13 - CESIUM

Symbol: Cs Atomic number: 55 Atomic weight: 132.905

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	0.02-10 ppm	N.E.
World	N.E.	N.E.

Cesium is a highly electropositive and alkaline element capable of catalyzing the hydrogenation of some organic compounds. Average cesium concentrations in common sedimentary rocks are 5 ppm in shales, 0.X ppm in sandstones, and 0.X ppm in carbonates (Turekian and Wedepohl, 1961). Abernethy and Gibson (1963) found an average cesium content in coal of 1.1 ppm. U.S. coals contain an average cesium content of 0.4 ppm (U.S. National Committee for Geochemistry, 1980).

Sharkey and others (1975) found that cesium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 0.2 to 9 ppm. Gluskoter and others (1977) reported a geometric mean cesium content of 1.6 ppm in 14 Appalachian region whole-coal samples, 1.2 ppm cesium in 56 Illinois basin whole-coal samples, and 0.16 ppm cesium in 22 Western U.S. whole-coal samples.

Merritt (1985b) found a mean cesium content of 4.0 ppm in ash samples of 25 Matanuska Valley coals.

PROFILE 14 - CHLORINE

Symbol: Cl Atomic number: 17 Atomic weight: 35.453

	Coal	Ash
Alaska	N.E.	10-2,000 ppm
U.S.	100-8,000 ppm	N.E.
World	N.E.	N.E.

Chlorine is a gaseous element, the most abundant halogen. It is capable of combining with nearly all other elements, although it is classified in the organic mineral group of trace elements (Wewerka and others, 1978). It has important effects on the use of coal in combustion and cokemaking.

Chlorine is generally present in coal in concentrations significantly greater than its clarke value (Gluskoter and others, 1977). Turekian and Wedepohl (1961) reported the following average chlorine concentrations in common sedimentary rocks: shales, 180 ppm; sandstones, 10 ppm; and carbonates, 150 ppm.

Abernethy and Gibson (1963) found an average chlorine content of 914 ppm in coal. The U.S. National Committee for Geochemistry (1980) reported an average worldwide concentration of 1,000 ppm chlorine in coal.

Sharkey and others (1975) found that chlorine occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 10 to 1,500 ppm. Los Alamos Scientific Laboratory (1976) cited a range in concentration of 0 to 0.56 percent chlorine in U.S. coals. The U.S. National Committee for Geochemistry (1980) gave an average chlorine concentration of 207 ppm in U.S. coal.

Gluskoter and others (1977) reported a geometric mean chlorine content of 0.10 percent in 23 Appalachian region whole-coal samples, 0.08 percent in 113 Illinois basin whole-coal samples, and 0.02 percent in 29 Western U.S. whole-coal samples.

Conwell and Triplehorn (1976) found an average 0.20 ppm chlorine in two whole-coal samples from Kukpuk River and Cape Thompson, northern Alaska. Conwell (1977) reported a mean chlorine content of 2,000 ppm in seven Beluga field coal-ash samples. Merritt (1985b) reported a mean chlorine concentration of 46 ppm in 18 Matanuska Valley coal-ash samples.

PROFILE 15 - CHROMIUM

Symbol: Cr Atomic number: 24 Atomic weight: 51.996

	Coal	Ash
Alaska	1-100 ppm	80-400 ppm
U.S.	0-700 ppm	0-2,000 ppm
World	N.E.	15-1,500 ppm

Chromium is a metallic element found principally in chromite ($FeCr_2O_4$) and associated with silicate minerals. It is used as a catalyst and to harden steel alloys. Turekian and Wedepohl (1961) reported the following average chromium concentrations in common sedimentary rocks: shales, 90 ppm; sandstones, 35 ppm; and carbonates, 11 ppm. Orheim (1979) cited the following clarke values for chromium: earth's crust, 100 ppm; soil, 200 ppm; plant ash, 9 ppm; and water, 0.00005 ppm.

Chromium generally occurs in coal in lower concentration than its estimated average concentration in the earth's crust (Averitt, 1975). Chromium is associated with both the organic and inorganic fractions of coal; it tends to be more closely allied or concentrated in the heavier specific gravity, inorganic fractions (Ruch and others, 1974; Cavallaro and others, 1978). Chromium is generally retained in high-temperature ash, and over 95 percent is retained in low-temperature ash (Ruch and others, 1974). It can be enriched on the surfaces of fly-ash particles from coal-fired plants (Mraw and others, 1983).

World Coals

Abernethy and Gibson (1963) cited an average chromium content in coal of 18 ppm. The U.S. National Committee for Geochemistry (1980) noted a world-wide average chromium content in coal of 10 ppm.

United States Coals

Sharkey and others (1975) found that chromium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 26 to 400 ppm. Others have cited a range in chromium content from 0 to 610 ppm in U.S. coals (Los Alamos Scientific Laboratory, 1976). Swanson and others (1976) found a geometric mean chromium content of 10.7 ppm in 601 U.S. coals. The U.S. National Committee for Geochemistry (1980) reported an average concentration in coal of 15 ppm.

Chromium concentration in ashes of U.S. coals ranges from <1 to 1,800 ppm and averages 304 ppm. Average chromium contents in ashes of various ranks of coal are as follows: anthracites, 304 ppm; low-volatile bituminous coals, 221 ppm; medium-volatile bituminous coals, 169 ppm; high-volatile bituminous coals, 193 ppm; subbituminous coals and lignites, 54 ppm (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Los Alamos Scientific Laboratory (1976) reported an average concentration of 13 ppm chromium in 73 Appalachian region whole-coal samples. Swanson and others (1976) reported a geometric mean content of 15 ppm chromium in 331 Appalachian region whole-coal samples. Gluskoter and others (1977) reported a geometric mean content of 18 ppm chromium in 23 Appalachian region whole-coal samples.

Interior region. Los Alamos Scientific Laboratory (1976) reported an average concentration of 20 ppm chromium in 53 Interior region whole-coal samples. Swanson and others (1976) reported a geometric mean content of 10 ppm chromium in 194 Interior region whole-coal samples. Gluskoter and others (1977) reported a geometric mean content of 16 ppm chromium in 113 Illinois basin coals.

Western region. Los Alamos Scientific Laboratory (1976) reported an average concentration of 13 ppm chromium in 48 Western and Southwestern Interior region whole-coal samples, and an average content of 7 ppm chromium in 51 Northern Great Plains coals. Swanson and others (1976) reported a geometric mean content of 3 ppm in 93 Western region coals and a geometric mean content of 15 ppm chromium in 34 Texas coals. Gluskoter and others (1977) reported a geometric mean content of 8.1 ppm chromium in 29 Western U.S. whole-coal samples.

Alaska Coals

There exists an abundant amount of data relating to chromium concentrations in Alaskan coals and coal ashes. In general, compared to other U.S. coals, the content of chromium in Alaska coals tends to be higher.

Northern Alaska province. Rao (1968) reported an average concentration of 4.0 ppm chromium in 12 Northern Alaska whole-coal samples; ash samples of the same coals contained an average 43 ppm chromium. Conwell and Triplehorn (1976) found an average content of 500 ppm chromium in a Kukpuk River coal-ash sample and 300 ppm chromium in a Cape Thompson coal-ash sample. Rao (1980) analyzed and reported on chromium concentrations in some 38 Cape Beaufort region whole-coal and coal-ash samples. Although certain of the Cape Beaufort region samples showed a high concentration of chromium, its average concentration was quite low compared to other U.S. coals. In raw coals, chromium ranged from 4 to 79 ppm and had a mean content <15 ppm; in coal-ash samples, chromium ranged from <30 ppm to 157 ppm and had a mean content <54 ppm (Rao, 1980). Rao and Wolff (1981) found 3.5 ppm chromium in a whole-coal sample of a subbituminous B seam from Meade River, northern Alaska; ash of the same sample contained 81 ppm chromium. They reported a whole-coal chromium content of 95 ppm in a high-volatile bituminous seam from Sagwon Bluffs, northern Alaska; ash of the same sample contained 150 ppm chromium. Affolter and others (1981) reported a range in chromium concentration of 1 to 100 ppm for 54 Utukok River Quadrangle whole-coal samples and a geometric mean content of 7 ppm.

Cook Inlet-Susitna province. Rao (1968) reported an average chromium content of 13.8 ppm in 22 Matanuska Valley whole-coal samples and an average content of 80 ppm in ash samples of the same coals. Rao and Wolff (1981)

found a chromium content of 20 ppm in a whole-coal sample of the high-volatile bituminous lower seam, Castle Mountain mine, Matanuska field; an ash sample of the same coal contained 110 ppm chromium. They also reported a chromium content of 28 ppm in a whole-coal sample of a high-volatile bituminous seam from the Premier Mine, Matanuska field; an ash sample of this coal contained 180 ppm chromium. Merritt (1985b) found a mean chromium concentration of 13 ppm in ash samples of 31 Matanuska Valley coals.

Rao (1968) reported an average chromium content of 7.5 ppm in eight Kenai field whole-coal samples; ash samples of the same coals contained an average 73 ppm chromium. Rao and Wolff (1981) found a chromium content of 19 ppm in a whole-coal sample of the subbituminous C-ranked Cabin bed, Kenai field; an ash sample of the coal showed 170 ppm chromium. Affolter and others (1981) reported a range in chromium content from 7 to 50 ppm in 20 Healy Quadrangle whole-coal samples, and a geometric mean chromium content of 20 ppm. In 34 Seldovia Quadrangle samples, they reported a range in chromium content of 2 to 70 ppm on a whole-coal basis and a geometric mean content 15 ppm. Merritt and others (1987) cited a mean chromium concentration of 416 ppm in ash samples of 31 Kenai field coals.

Conwell (1977) reported a range in chromium content from 100 to 300 ppm and a mean content of 214 ppm in seven Beluga field coal-ash samples. Rao and Wolff (1981) reported a chromium content of 24 ppm in a whole-coal sample of the subbituminous C-ranked Waterfall seam, Beluga field; an ash sample of the same coal contained 230 ppm chromium. They also reported a chromium content of 6.7 ppm (whole-coal basis) in a Sunflower Creek lignite, Yentna field; an ash sample of the same coal contained 165 ppm chromium. Based on samples of six coal beds from the Tyonek Formation, Beluga field, Affolter and Stricker (1984) found that the concentration of chromium varied directly with the ash content of the coals. Rao and Smith (1987) found that the average chromium content of ash samples of five coal seams from the Chuitna district, Beluga field, generally increased downsection. The chromium concentrations of the respective seams, as reported, were: Blue Seam (15 samples), 123 ppm; Red 3 Seam (13 samples), 159 ppm; Red 2 Seam (26 samples), 172 ppm; Red 1 Seam (16 samples), 167 ppm; and Purple Seam (5 samples), 198 ppm. Merritt (1987a) found a range in chromium content from <10 to 1,450 ppm and an average content of <213 ppm for ash samples of 45 Susitna lowland coals.

Rao and Wolff (1981) analyzed a lignite seam from Coal Creek, Broad Pass field. A raw coal sample had a chromium content of 75 ppm, and a coal-ash sample had 380 ppm.

Nenana province. Rao (1968) reported an average chromium concentration of 11.1 ppm in 25 Nenana basin whole-coal samples; ash samples of the coals contained an average 81 ppm chromium. Rao and Wolff (1981) analyzed seven samples of five Nenana basin subbituminous C-ranked coals, including the No. 2, No. 4, No. 6 (3 splits), Moose, and Caribou seams. The whole-coal samples contained an average chromium content of 19 ppm and the coal-ash samples contained an average chromium content of 144 ppm. Affolter and others (1981) cited a range of 7 to 70 ppm chromium in 20 Healy Quadrangle whole-coal samples and a geometric mean chromium content of 15 ppm. Affolter

and Stricker (1987) found an average 6.5 ppm chromium in two whole-coal samples of Seam No. 3, Usibelli Mine.

Rao (1968) reported an average chromium concentration of 4.2 ppm in three Jarvis Creek field whole-coal samples; ash samples of the same coals revealed an average chromium content of 41 ppm. Belowich (1987) found an average 17 ppm chromium in 27 Jarvis Creek field whole-coal samples. Rao and Wolff (1981) reported a chromium content of 16 ppm in an Ober Creek, Jarvis Creek field subbituminous C-ranked whole-coal sample; ash of the same coal contained 140 ppm chromium.

Rao and Wolff (1981) also analyzed the main seam, a subbituminous C-ranked coal, from the Little Tonzona River field. A whole-coal sample showed 28 ppm chromium in a whole-coal sample and an ash sample contained 200 ppm chromium.

Alaska Peninsula province. Conwell and Triplehorn (1978) cited an average chromium concentration of 162 ppm in eight Alaska Peninsula coal-ash samples.

Gulf of Alaska province. Rao (1969) reported an average chromium content of 1.6 ppm in five Bering River field whole-coal samples and an average 63 ppm chromium in ash samples of the same coals. Smith and Rao (1987) found an average chromium concentration of 246 ppm in 20 Bering River field coal-ash samples.

Yukon-Koyukuk province. Rao and Wolff (1981) reported the chromium content of whole-coal and ash samples of the high-volatile bituminous ranked main seam from the Tramway Bar field. The former contained 61 ppm chromium and the latter showed 160 ppm chromium.

PROFILE 16 - COBALT

Symbol: Co Atomic number: 27 Atomic weight: 58.9332

	Coal	Ash
Alaska	1-70 ppm	20-300 ppm
U.S.	0-90 ppm	0-600 ppm
World	N.E.	10-1,500 ppm

Cobalt is a metallic element found in linnaeite (Co_3S_4) and with arsenic in minerals. It is typically associated with ores of copper, iron, lead, nickel, and silver. The element cobalt has affinities with both organic and inorganic matter, but is more closely allied with inorganic fractions (Ruch and others, 1974).

Turekian and Wedepohl (1961) reported the following average cobalt concentrations in common sedimentary rocks: shales, 19 ppm; sandstones, 0.3 ppm; and carbonates, 0.1 ppm. Orheim (1979) cited the following clarke values for cobalt: earth's crust, 25 ppm; soil, 10 ppm; plant ash, 9 ppm; and water, 0.0005 ppm.

Cobalt generally occurs in coal in appreciably greater concentrations than its estimated average concentration in the earth's crust. It is generally retained in high-temperature ash, and over 95 percent is retained in low-temperature ash (Ruch and others, 1974).

World Coals

Abernethy and Gibson (1963) reported an average cobalt concentration in coal of 2.9 ppm. Berkowitz (1979) reported a maximum cobalt content in coal ash of 1,500 gm/ton, and an average cobalt content of 300 gm/ton. The U.S. National Committee for Geochemistry (1980) cited a worldwide average cobalt content in coal of 5 ppm.

United States Coals

Sharkey and others (1975) found that cobalt occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 1 to 90 ppm. Swanson and others (1976) reported an average U.S. cobalt content of 4.6 ppm in 601 U.S. coals. The U.S. National Committee for Geochemistry (1980) reported an average cobalt concentration in U.S. coals of 7 ppm. Los Alamos Scientific Laboratory (1976) reported a range in cobalt concentration for U.S. coals of 0 to 43 ppm. They also cited a range in cobalt content in ashes of U.S. coals of 0 to 600 ppm and average cobalt contents in ashes of U.S. coals by rank as follows: anthracite, 81 ppm; low-volatile bituminous, 172 ppm; medium-volatile bituminous, 105 ppm; high-volatile bituminous, 64 ppm; and subbituminous and lignite, 45 ppm.

Appalachian region. Swanson and others (1976) found a geometric mean cobalt content of 5 ppm in 331 Appalachian region whole-coal samples. Los Alamos Scientific Laboratory (1976) reported an average cobalt concentration

of 5.1 ppm in 73 Appalachian region coals. Gluskoter and others (1977) reported a geometric mean cobalt content of 7.6 ppm in 23 Appalachian region whole-coal samples.

Interior region. Swanson and others (1976) found a geometric mean cobalt content of 7 ppm in 194 Interior region whole-coal samples. Los Alamos Scientific Laboratory (1976) reported an average cobalt concentration of 3.8 ppm in 53 Interior region coals. Gluskoter and others (1977) reported a geometric mean cobalt content of 6.0 ppm in 113 Illinois basin whole-coal samples.

Western region. Swanson and others (1976) reported a geometric mean cobalt content of 1.5 ppm in 93 Western region coals and 5 ppm in 34 Texas coals. Los Alamos Scientific Laboratory (1976) found an average cobalt concentration of 4.6 ppm in 48 Western and Southwestern Interior region coals and an average of 2.7 ppm cobalt in 51 Northern Great Plains region coals. Gluskoter and others (1977) cited a geometric mean cobalt concentration of 1.5 ppm in 29 Western U.S. whole-coal samples.

Alaska Coals

Abundant data exists on cobalt concentrations in Alaska coals and coal ashes. Compared to other U.S. coals, the content of cobalt is higher in Alaskan coals.

Northern Alaska province. Rao (1968) reported an average cobalt concentration of <3.6 ppm in 12 Northern Alaska whole-coal samples; ash samples of the same coals revealed an average cobalt content of <35 ppm. Conwell and Triplehorn (1976) reported a cobalt content of 300 ppm in a Kukpuk River coal-ash sample and <10 ppm in a Cape Thompson coal-ash sample. Rao (1980) reported a range in cobalt content from <2 to 51 ppm and a mean content <8 ppm in 38 Cape Beaufort region whole-coal samples. Ash samples of the same coals showed a range in cobalt content from <10 to 417+ ppm and a mean cobalt content of <41 ppm. Rao (1980) concluded that although certain of the Cape Beaufort region samples showed high concentrations of cobalt, its average concentration was low compared to other U.S. coals. Rao and Wolff (1981) analyzed subbituminous B-ranked seams from Wainwright and Meade River, Northern Alaska. A whole-coal sample of the Wainwright seam had 3.7 ppm cobalt; an ash sample of the same coal revealed a cobalt content of 61 ppm. A whole-coal sample of the Meade River seam had 8.8 ppm cobalt; an ash sample of this coal showed a cobalt content of 200 ppm. Affolter and others (1981) reported a range in cobalt content from 1 to 70 ppm in 54 Utukok River whole-coal samples and a geometric mean content of 3 ppm cobalt.

Cook Inlet-Susitna province. Rao (1968) found an average cobalt concentration of 10.5 ppm in 22 Matanuska Valley whole-coal samples and 100 ppm cobalt in ash samples of the same coals. Rao and Wolff (1981) reported cobalt concentrations in two high-volatile bituminous seams from the Matanuska Valley---a seam from the Premier Mine and the lower seam from the Castle Mountain Mine. The former seam showed 40 ppm cobalt on a whole-coal basis and 260 ppm cobalt on an ashed-basis. The latter seam revealed 7.2 ppm cobalt on whole-coal basis and 40 ppm cobalt on an ashed-basis. Merritt

(1985b) reported a mean cobalt content of 9 ppm in 31 Matanuska Valley coal-ash samples.

Rao (1968) reported an average cobalt concentration of 3.9 ppm in eight Kenai field whole-coal samples; ash samples of the same coals had 39 ppm cobalt. Rao and Wolff (1981) found 3.1 ppm cobalt in a whole-coal sample of the subbituminous C-ranked Cabin bed, and 28 ppm cobalt in an ash sample of the same coal. Affolter and others (1981) reported a range in cobalt content from 5 to 10 ppm and a geometric mean content of 7 ppm in 10 Kenai Quadrangle whole-coal samples. They found a range in cobalt content from 2 to 15 ppm and a geometric mean content of 5 ppm in 34 Seldovia Quadrangle whole-coal samples. Merritt and others (1987) reported an average cobalt content of 94 ppm in 31 Kenai field coal-ash samples.

Conwell (1977) reported a range in cobalt content of 30 to 70 ppm in seven Beluga field coal-ash samples and a mean of 47 ppm cobalt. Rao and Wolff (1981) found 9.0 ppm cobalt in the subbituminous C-ranked Waterfall bed, Beluga field on a whole-coal basis; an ash sample of the same coal had 88 ppm cobalt. An average of two whole-coal samples of the Sunflower Creek seam, a Yentna field lignite, showed 2.6 ppm cobalt; ash samples of the coal contained 66 ppm cobalt (Rao and Wolff, 1981). Rao and Smith (1987) analyzed the average cobalt contents of coal-ash samples from five seams of the Chuitna district, Beluga field. Results reported were: Blue Seam (15 samples), 87 ppm; Red 3 Seam (13 samples), 43 ppm; Red 2 Seam (26 samples), 73 ppm; Red 1 Seam (32 samples), 32 ppm; and Purple Seam (5 samples), 42 ppm. Merritt (1987a) cited a range of <10 to 213 ppm cobalt in 45 Susitna lowland coal-ash samples and an average of <38 ppm cobalt.

Rao and Wolff (1981) also analyzed a lignite sample from Coal Creek, Broad Pass field. They reported 14 ppm cobalt in a whole-coal sample and 71 ppm cobalt in a coal-ash sample.

Nenana province. Rao (1968) found an average cobalt concentration of <1.7 ppm cobalt in 25 Nenana basin whole-coal samples; ash samples of the coals contained an average of <16 ppm cobalt. Rao and Wolff (1981) reported an average cobalt content of 7.2 ppm in three whole-coal samples of the Nenana basin; the subbituminous C-ranked seams analyzed were the No. 4, Moose, and Caribou seams. Coal-ash samples of the seams showed an average cobalt content of 60 ppm. Affolter and Stricker (1981) reported a range of from 1.5-10 ppm cobalt and a geometric mean of 3 ppm cobalt in 20 Healy Quadrangle whole-coal samples. Merritt (1985a) cited a general factor of enrichment for cobalt of 2.1X based on Nenana coal-ash samples. Affolter and Stricker (1987) reported an average cobalt content of 1.6 ppm in two whole-coal samples of Seam No. 3, Usibelli Mine.

Rao (1968) found an average cobalt concentration of <1.0 ppm in three Jarvis Creek field whole-coal samples; ash samples of the same coals showed an average cobalt content of <11 ppm. Rao and Wolff (1981) reported that the cobalt content of an Ober Creek, Jarvis Creek field, subbituminous C-ranked coal was 6.8 ppm on a whole-basis and 60 ppm on an ash-basis. Belowich (1987) reported an average cobalt content of 12 ppm in 27 Jarvis Creek field whole-coal samples.

Rao and Wolff (1981) analyzed the subbituminous C-ranked main seam from the Little Tonzona River field. They reported a cobalt content of 10 ppm in a whole-coal sample and 73 ppm in a coal-ash sample.

Alaska Peninsula province. Conwell and Triplehorn (1978) reported an average cobalt concentration of 180 ppm in eight Alaska Peninsula coal-ash samples.

Gulf of Alaska province. Rao (1968) cited an average cobalt content of 1.1 ppm in five Bering River field whole-coal samples. Ash samples of the same coals contained an average cobalt content of 46 ppm. Smith and Rao (1987) reported an average cobalt concentration of 86 ppm in 20 Bering River field coal-ash samples.

Yukon-Koyukuk province. Rao and Wolff (1981) reported cobalt concentrations for the high-volatile bituminous main seam of the Tramway Bar field. A whole-coal sample contained 8.8 ppm cobalt, and a coal-ash sample contained 23 ppm cobalt.

PROFILE 17 - COPPER

Symbol: Cu Atomic number: 29 Atomic weight: 63.54

	Coal	Ash
Alaska	2-90 ppm	40-450 ppm
U.S.	1-200 ppm	10-500 ppm
World	N.E.	10-600 ppm

Copper is a metallic element of wide application. It is intimately associated with pyrite (FeS_2) and chalcopyrite ($CuFeS_2$), and is one of the elements of environmental concern in coal. Anomalously high copper may result from core-hole samples contaminated by drilling fluids and drill pipe. Turekian and Wedepohl (1961) reported the following average copper concentrations in common sedimentary rocks: shales, 45 ppm; sandstones, X ppm; and carbonates, 4 ppm. Orheim (1979) cited the following clarke values for copper: earth's crust, 55 ppm; soil, 20 ppm; plant ash, 180 ppm; and water, 0.003 ppm.

Copper generally occurs in coal in appreciably greater concentration than its estimated average concentration in the earth's crust (Averitt, 1975). Copper has affinity with both organic and inorganic matter, but is more closely allied with the heavier specific gravity, inorganic fractions of coal (Ruch and others, 1974; Cavallaro and others, 1978). On coal combustion, copper is generally retained in high temperature ash and over 95 percent is retained in low-temperature ash.

World Coals

Abernethy and Gibson (1963) reported an average copper content in coal of 8.3 ppm. The U.S. National Committee for Geochemistry reported a worldwide average copper content in coal of 15 ppm.

United States Coals

Sharkey and others (1975) found that copper occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 3 to 180 ppm. Others have cited a range in copper content in U.S. coals from 1.8 to 185 ppm (Los Alamos Scientific Laboratory, 1976; Wewerka and others, 1976). Swanson and others (1976) found a geometric mean copper content in 601 U.S. coals of 14.9 ppm. The U.S. National Committee for Geochemistry (1980) reported a U.S. average copper concentration in coal of 19 ppm. Copper concentration in ashes of U.S. coals ranges from 10 to 100 ppm, and averages as follows in coals of various rank: anthracite, 405 ppm; low-volatile bituminous, 379 ppm; medium-volatile bituminous, 313 ppm; high-volatile bituminous, 293 ppm; and subbituminous and lignite, 655 ppm (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Swanson and others (1976) found a geometric mean copper content of 16 ppm in 331 Appalachian region whole-coal samples. Los Alamos Scientific Laboratory (1976) reported an average copper concentration of 15 ppm in 73 Appalachian region coals. Gluskoter and others (1977) reported a geometric mean copper content of 16 ppm in 23 Appalachian region whole-coal samples.

Interior region. Swanson and others (1976) found a geometric mean copper content of 16.3 ppm in 194 Interior region whole-coal samples. Los Alamos Scientific Laboratory (1976) reported an average copper concentration of 11 ppm in 53 Interior region coals. Gluskoter and others (1977) reported a geometric mean copper content of 13 ppm in 113 Illinois basin whole-coal samples.

Western region. Swanson and others (1976) reported a geometric mean copper content of 7.4 ppm in 93 Western region coals and 20 ppm in 34 Texas coals. Los Alamos Scientific Laboratory (1976) found an average copper concentration of 11 ppm in 48 Western and Southwestern Interior region coals and an average of 15 ppm copper in 51 Northern Great Plains region coals. Gluskoter and others (1977) cited a geometric mean copper concentration of 8.5 ppm in 29 Western U.S. whole-coal samples.

Alaska Coals

Abundant data exist on copper concentrations in Alaska coals and coal ashes. Compared to other U.S. coals, the content of copper in Alaskan coals is higher.

Northern Alaska province. Rao (1968) reported an average copper concentration of 12.2 ppm in 12 Northern Alaska whole-coal samples; ash samples of the same coals revealed an average copper content of 155 ppm. Conwell and Triplehorn (1976) reported a copper content of 312 ppm in a Kukpuk River coal-ash sample and 162 ppm in a Cape Thompson coal-ash sample. Rao (1980) reported a range in copper content from 2.9 to 18 ppm and a mean content of 8.9 ppm in 38 Cape Beaufort region whole-coal samples. Ash samples of the same coals showed a range in copper content from 18 to 98 ppm and a mean copper content of 42 ppm. Rao (1980) concluded that although certain Cape Beaufort region samples showed high concentrations of copper, its average concentration was quite low compared to other U.S. coals. Rao and Wolff (1981) analyzed subbituminous B ranked seams from Wainwright and Meade River, northern Alaska and a high-volatile bituminous seam from Sagwon Bluffs. A whole-coal sample of the Wainwright seam had 2.8 ppm copper; an ash sample of the same coal revealed a copper content of 46 ppm. A whole-coal sample of the Meade River seam had 4.5 ppm copper; an ash sample of this coal showed a copper content of 103 ppm. The Sagwon Bluffs coal had 45 ppm copper, and an ash sample of the coal had 72 ppm copper. Affolter and others (1981) reported a range in copper content from 1 to 32 ppm in 54 Utukok River whole-coal samples and a geometric mean content of 4.8 ppm copper.

Cook Inlet-Susitna province. Rao (1968) found an average copper concentration of 22 ppm in 22 Matanuska Valley whole-coal samples and 140 ppm copper in ash samples of the same coals. Rao and Wolff (1981) reported

copper concentrations in two high-volatile bituminous seams from the Matanuska Valley---a seam from the Premier Mine and the lower seam from the Castle Mountain Mine. The former seam showed 13 ppm copper on a whole-coal basis and 86 ppm copper on an ashed-basis. The latter seam revealed 17 ppm copper on a whole-coal basis and 92 ppm copper on an ashed-basis. Merritt (1985b) reported a mean copper content of 30 ppm in 31 Matanuska Valley coal-ash samples.

Rao (1968) reported an average copper concentration of 10.6 ppm in eight Kenai field whole-coal samples; ash samples of the same coals had 104 ppm copper. Rao and Wolff (1981) found 26 ppm copper in a whole-coal sample of the subbituminous C-ranked Cabin bed, and 235 ppm copper in an ash sample of the same coal. Affolter and others (1981) reported a range in copper content from 7.4 to 35 ppm and a geometric mean content of 17 ppm in 10 Kenai Quadrangle whole-coal samples. They found a range in copper content from 7.1 to 86 ppm and a geometric mean content of 18 ppm in 34 Seldovia Quadrangle whole-coal samples. Merritt and others (1987) reported an average copper content of 204 ppm in 31 Kenai field coal-ash samples.

Conwell (1977) reported a range in copper content of 104 to 239 ppm in seven Beluga field coal-ash samples and a mean of 144 ppm copper. Rao and Wolff (1981) found 17 ppm copper in the subbituminous C-ranked Waterfall bed, Beluga field on a whole-coal basis; an ash sample of the same coal had 164 ppm copper. An average of two whole-coal samples of the Sunflower Creek seam, a Yentna field lignite, showed 9.8 ppm copper; ash samples of the coal contained 240 ppm copper (Rao and Wolff, 1981). Rao and Smith (1987) analyzed the average copper contents of coal-ash samples from five seams of the Chuitna district, Beluga field. Results reported were: Blue Seam (15 samples), 159 ppm; Red 3 Seam (13 samples), 370 ppm; Red 2 Seam (26 samples), 184 ppm; Red 1 Seam (16 samples), 142 ppm; and Purple Seam (5 samples), 150 ppm. Based on samples of six coal beds from the Tyonek Formation, Beluga field, Affolter and Stricker (1984) found that the concentration of copper varied directly with the ash content of the coals. Merritt (1987a) cited a range of 25 to 390 ppm copper and an average of 120 ppm copper in 45 Susitna lowland coal-ash samples.

Rao and Wolff (1981) also analyzed a lignite sample from Coal Creek, Broad Pass field. They reported 31 ppm copper in a whole-coal sample and 157 ppm copper in a coal-ash sample.

Nenana province. Rao (1968) found an average copper concentration of 10.2 ppm in 25 Nenana basin whole-coal samples; ash samples of the coals contained an average of 89 ppm copper. Rao and Wolff (1981) reported an average copper content of 24 ppm in seven samples of five subbituminous seams from the Nenana basin, including No. 2, No. 4, No. 6 (three splits, top, middle, and lower), Moose, and Caribou seams. Coal-ash samples of the seams showed an average copper content of 183 ppm. Affolter and Stricker (1981) reported a range of from 8.2 to 58 ppm copper and a geometric mean of 17 ppm copper in 20 Healy Quadrangle whole-coal samples. Affolter and Stricker (1987) reported an average copper content of 7.0 ppm in two whole-coal samples of Seam No. 3, Usibelli Mine.

Rao (1968) found an average copper concentration of 5.2 ppm in three Jarvis Creek field whole-coal samples; ash samples of the same coals showed an average copper content of 52 ppm. Rao and Wolff (1981) reported that the copper content of an Ober Creek, Jarvis Creek field, subbituminous C-ranked coal was 21 ppm on a whole-basis and 180 ppm on an ash-basis. Belowich (1987) reported an average copper content of 51 ppm in 27 Jarvis Creek field whole-coal samples.

Rao and Wolff (1981) analyzed the subbituminous C-ranked main seam from the Little Tonzona River field. They reported a copper content of 60 ppm in a whole-coal sample and 434 ppm in a coal-ash sample.

Alaska Peninsula province. Conwell and Triplehorn (1978) reported an average copper concentration of 80 ppm in eight Alaska Peninsula coal-ash samples.

Gulf of Alaska province. Rao (1968) cited an average copper content of 6.0 ppm in five Bering River field whole-coal samples. Ash samples of the same coals contained an average copper content of 260 ppm. Smith and Rao (1987) reported an average copper concentration of 166 ppm in 20 Bering River field coal-ash samples.

Yukon-Koyukuk province. Rao and Wolff (1981) reported copper concentrations for the high-volatile bituminous main seam of the Tramway Bar field. A whole-coal sample contained 29 ppm copper, and a coal-ash sample contained 76 ppm copper.

PROFILE 18 - DYSPROSIUM

Symbol: Dy Atomic number: 66 Atomic weight: 162.50

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	<0.1-5 ppm	N.E.
World	N.E.	N.E.

Dysprosium is a rare-earth metallic element found in association with silicate minerals. Turekian and Wedepohl (1961) reported the following average dysprosium concentrations in common sedimentary rocks: shales, 4.6 ppm; sandstones, 7.2 ppm; and carbonates, 0.9 ppm.

Sharkey and others (1975) found that dysprosium occurred in 85 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from <0.1 to 5 ppm. The U.S. National Committee for Geochemistry (1980) reported an average dysprosium concentration in U.S. coals of 2.2 ppm; for U.S. subbituminous coals, they found an average 2.7 ppm dysprosium, and for U.S. lignites, they found an average 1.4 ppm dysprosium.

Gluskoter and others (1977) reported a geometric mean dysprosium content of 2.0 ppm in 14 Appalachian whole-coal samples, 1.0 ppm dysprosium in 56 Illinois basin whole-coal samples, and 0.57 ppm dysprosium in 22 Western U.S. whole-coal samples.

There is no available data for dysprosium concentrations in Alaska coal.

PROFILE 19 - ERBIUM

Symbol: Er Atomic number: 68 Atomic weight: 167.26

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	<0.1-0.5 ppm	N.E.
World	0-1 ppm	N.E.

Erbium is one of the rare-earth elements. Turekian and Wedepohl (1961) reported the following average erbium concentrations in common sedimentary rocks: shales, 2.5 ppm; sandstones, 4.0 ppm; and carbonates, 0.5 ppm. The average worldwide erbium content in coal is 0.6 ppm (U.S. National Committee for Geochemistry, 1980). Sharkey and others (1975) found that erbium occurred in 77 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from <0.1 to 0.4 ppm. The average U.S. erbium content is 0.34 ppm; for U.S. subbituminous coals, it is 0.46 ppm, and for U.S. lignites, it is 0.16 ppm (U.S. National Committee for Geochemistry, 1980).

There is no available data on erbium concentrations in Alaska coals.

PROFILE 20 - EUROPIUM

Symbol: Eu Atomic number: 63 Atomic weight: 151.96

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	<0.1-1 ppm	N.E.
World	0-1 ppm	N.E.

Europium is a rare-earth element associated with silicate minerals. Turekian and Wedepohl (1961) reported the following average europium concentrations in common sedimentary rocks: shales, 1.0 ppm; sandstones, 1.6 ppm; and carbonates, 0.2 ppm. Abernethy and Gibson (1963) found an average europium content in coal of 0.1 ppm. The U.S. National Committee for Geochemistry (1980) reported an average worldwide concentration of 0.7 ppm europium in coal.

Sharkey and others (1975) found that europium occurred in 100 percent of 13 U.S. raw coals and that it ranged in concentration from <0.1 to 0.4 ppm. U.S. coals contain an average europium content of 0.45 ppm; a typical U.S. subbituminous coal contains 0.61 ppm europium, and a typical U.S. lignite contains 0.13 ppm europium (U.S. National Committee for Geochemistry, 1980).

Gluskoter and others (1977) reported a geometric mean europium content of 0.47 ppm for 14 Appalachian region whole-coal samples, 0.25 ppm europium for 56 Illinois basin whole-coal samples, and 0.16 ppm europium for 22 Western U.S. whole-coal samples.

Merritt (1985b) reported a mean europium concentration of 0.70 ppm in ash samples of 24 Matanuska Valley coals.

PROFILE 21 - FLUORINE

Symbol: F Atomic number: 9 Atomic weight: 18.9984

	Coal	Ash
Alaska	20-350 ppm	N.E.
U.S.	1-1,900 ppm	N.E.
World	N.E.	N.E.

Fluorine is a gaseous halogen element, the most electronegative and highly reactive of the elements. It is found in the minerals apatite, $Ca_5 (PO_4)_3 (F, CO_3)$ and fluorapatite, $Ca_5 (PO_4)_3 (F,OH)$. Turekian and Wedepohl (1961) reported the following average fluorine concentrations in common sedimentary rocks: shales, 740 ppm; sandstones, 270 ppm; and carbonates, 330 ppm. Orheim (1979) reported a clarke of 625 ppm fluorine in the earth's crust and a clarke of 1.3 ppm fluorine in water. Fluorine tends to be concentrated in the heavier specific gravity fraction of coal (Cavallaro and others, 1978). Fluorine is presumed lost in low-temperature ash (Ruch and others, 1974).

United States Coals

Sharkey and others (1975) found that fluorine occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 1 to 110 ppm. Los Alamos Scientific Laboratory (1976) cited a range in fluorine content in U.S. coals of from 10 to 295 ppm. Swanson and others (1976) cited an average fluorine content in 601 U.S. coals of 61.5 ppm. Zubovic and others (1979) indicated a range in fluorine content in U.S. coals of 0.45 to 1,900 ppm, a geometric mean of 64 ppm, and an arithmetic mean of 86 ppm. The U.S. National Committee for Geochemistry (1980) reported an average fluorine concentration in U.S. coals of 74 ppm.

Appalachian region. Swanson and others (1976) found a geometric mean fluorine content of 60 ppm in 331 Appalachian region whole-coal samples. Gluskoter and others (1977) reported a geometric mean fluorine content of 84 ppm in 23 Appalachian region coals.

Interior region. Swanson and others (1976) found a geometric mean fluorine content of 58 ppm in 194 Interior region whole-coal samples. Gluskoter and others (1977) reported a geometric mean fluorine content of 63 ppm in 113 Illinois basin whole-coal samples.

Western region. Swanson and others (1976) found a geometric mean fluorine content of 37 ppm in 93 Western U.S. coals and 91 ppm in 34 Texas coals. Gluskoter and others (1977) reported a geometric mean fluorine content of 57 ppm in 29 Western U.S. whole-coal samples.

Alaska Coals

Northern Alaska province. Conwell and Triplehorn (1976) found a fluorine concentration of 40 ppm in a Kukpuk River whole-coal sample and 120 ppm in a Cape Thompson whole-coal sample. Affolter and others (1981)

cited a range in fluorine content of 20 to 310 ppm in 54 Utukok River Quadrangle whole-coal samples and a geometric mean fluorine content of 48 ppm.

Cook Inlet-Susitna province. Merritt (1985b) reported a mean fluorine content of 374 ppm in 24 Matanuska Valley coal-ash samples. Conwell (1977) cited a range of 20 to 145 ppm fluorine and a mean content of 67 ppm fluorine in seven Beluga field whole-coal samples. Based on samples of six coal beds from the Tyonek Formation, Beluga field, Affolter and Stricker (1984) found that the concentration of fluorine varied directly with the ash content of the coals.

Affolter and others (1981) reported a range of <20 to 75 ppm fluorine and a geometric mean of 31 ppm fluorine in 10 Kenai Quadrangle whole-coal samples. They also found a range of 20 to 290 ppm fluorine and a geometric mean of 55 ppm fluorine in 34 Seldovia Quadrangle whole-coal samples.

Nenana province. Affolter and others (1981) reported a range of 35 to 340 ppm fluorine and a geometric mean of 82 ppm fluorine in 20 Healy Quadrangle whole-coal samples. Affolter and Stricker (1987) found an average fluorine content of 88 ppm in two whole-coal samples of Seam No. 3, Usibelli Mine.

Alaska Peninsula province. Conwell and Triplehorn (1978) reported an average concentration of 114 ppm fluorine in eight Alaska Peninsula whole-coal samples.

PROFILE 22 - GADOLINIUM

Symbol: Gd Atomic number: 64 Atomic weight: 157.25

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	<0.1-3 ppm	N.E.
World	0-5 ppm	N.E.

Gadolinium is a metallic rare-earth element. Turekian and Wedepohl (1961) reported the following average gadolinium concentrations in common sedimentary rocks: shales, 6.4 ppm; sandstones, 10 ppm; and carbonates, 1.3 ppm. The average worldwide gadolinium content in coal is 1.6 ppm (U.S. National Committee for Geochemistry, 1980).

Sharkey and others (1975) found that gadolinium occurred in 85 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from <0.1 to 3 ppm. The average U.S. gadolinium content in coal is 0.17 ppm; for U.S. subbituminous coals, it averages 0.13 ppm, and for U.S. lignites, it averages 0.21 ppm (U.S. National Committee for Geochemistry, 1980).

Merritt (1985b) reported a mean gadolinium concentration of <3 ppm in ash samples of six Matanuska Valley coals.

PROFILE 23 - GALLIUM

Symbol: Ga Atomic number: 31 Atomic weight: 69.72

	Coal	Ash
Alaska	0.3-25 ppm	10-100 ppm
U.S.	0-70 ppm	0-600 ppm
World	0-100 ppm	0-400 ppm

Gallium is a rare metallic element that forms small highly charged ions (high ionic potential). It tends to be concentrated near the source areas of a coal basin (Zubovic and others, 1966a,b). Turekian and Wedepohl (1961) reported the following gallium concentrations in common sedimentary rocks: shales, 19 ppm; sandstones, 12 ppm; and carbonates, 4 ppm. Orheim (1979) cited the following clarke values for gallium: earth's crust, 15 ppm; soil, 20 ppm; plant ash, 1 ppm; and water 0.00009 ppm.

Gallium generally occurs in coal in appreciably greater concentration that its estimated average concentration in the earth's crust (Averitt, 1975). It is an element that is associated with both the organic and inorganic fractions of coal, but it is more closely allied with the organic fractions. On coal combustion, over 95 percent of gallium's content is retained in low-temperature ash (Ruch and others, 1974).

World Coals

Abernethy and Gibson (1963) cited an average gallium concentration in coal of 4.5 ppm. The U.S. National Committee for Geochemistry (1980) indicated a worldwide average gallium concentration in coal of 7 ppm. Berkowitz (1979) reported a maximum gallium content in coal ash of 400 gm/ton and an average gallium content of 100 gm/ton.

United States Coals

Sharkey and others (1975) found that gallium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 0.3 to 10 ppm. Los Alamos Scientific Laboratory (1976) reported a range in gallium content of U.S. coals of 0 to 61 ppm. Swanson and others (1976) found a geometric mean gallium content in 601 U.S. coals of 4.7 ppm. The U.S. National Committee for Geochemistry (1980) reported a U.S. average gallium concentration in coal of 7 ppm. Gallium content in ashes of U.S. coals ranges from 0 to 540 ppm, and shows the following averages in coals of various rank: anthracite, 42 ppm; low-volatile bituminous, 41 ppm; high-volatile bituminous, 40 ppm; and subbituminous and lignite, 23 ppm (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Swanson and others (1976) found a geometric mean gallium content of 7 ppm in 331 Appalachian region whole-coal samples. Los Alamos Scientific Laboratory (1976) reported an average gallium concentration of 4.9 ppm in 73 Appalachian region coals. Gluskoter and others (1977) reported a geometric mean gallium content of 5.2 ppm in 23 Appalachian whole-coal samples.

Interior region. Swanson and others (1976) found a geometric mean gallium content of 2 ppm in 194 Interior region whole-coal samples. Los Alamos Scientific Laboratory (1976) reported an average gallium concentration of 4.1 ppm in 53 Interior region coals. Gluskoter and others (1977) reported a geometric mean gallium content of 3.0 ppm in 113 Illinois basin whole-coal samples.

Western region. Swanson and others (1976) found a geometric mean gallium content of 3 ppm in 93 Western region coals and 7 ppm in 34 Texas coals. Los Alamos Scientific Laboratory (1976) found an average gallium concentration of 2.0 ppm in 48 Western and Southwestern Interior region coals and an average of 5.5 ppm gallium in 51 Northern Great Plains region coals. Gluskoter and others (1977) cited a geometric mean gallium concentration of 2.1 ppm in 29 Western U.S. whole-coal samples.

Alaska Coals

Abundant data exist on gallium concentrations in Alaska coals and coal ashes. Compared to other U.S. coals, the content of gallium is higher in Alaska coals.

Northern Alaska province. Rao (1968) reported an average gallium concentration of 3.9 ppm in 12 Northern Alaska whole-coal samples; ash samples of the same coals revealed an average gallium content of 31 ppm. Conwell and Triplehorn (1976) reported a gallium content of 150 ppm in a Kukpuk River coal-ash sample and 100 ppm in a Cape Thompson coal-ash sample. Rao (1980) reported a range in gallium content from 1.2 to 11.4 ppm and a mean content of 6.1 ppm in 38 Cape Beaufort region whole-coal samples. Ash samples of the same coals showed a range in gallium content from 16 to 53 ppm and a mean gallium content of 31 ppm. Rao (1980) concluded that the concentration of gallium in the Cape Beaufort region samples was quite low compared to other U.S. coals. Rao and Wolff (1981) analyzed subbituminous B-ranked seams from Wainwright and Meade River, northern Alaska and a high-volatile bituminous seam from Sagwon Bluffs. A whole-coal sample of the Wainwright seam had 0.84 ppm gallium; an ash sample of the same coal revealed a gallium content of 14 ppm. A whole-coal sample of the Meade River seam had 4.4 ppm gallium; an ash sample of this coal showed a gallium content of 100 ppm. The Sagwon Bluffs coal had 20 ppm gallium, and an ash sample of the coal had 32 ppm gallium. Affolter and others (1981) reported a range in gallium content from 0.3 to 20 ppm in 54 Utukok River Quadrangle whole-coal samples and a geometric mean content of 3 ppm.

Cook Inlet-Susitna province. Rao (1968) found an average gallium concentration of 7.0 ppm in 22 Matanuska Valley whole-coal samples and 45 ppm gallium in ash samples of the same coals. Rao and Wolff (1981) reported gallium concentrations in two high-volatile bituminous seams from the Matanuska Valley——a seam from the Premier Mine and the lower seam from the Castle Mountain Mine. The former seam showed 9.7 ppm gallium on a whole-coal basis and 63 ppm gallium on an ashed-basis. The latter seam revealed 9.4 ppm gallium on a whole-coal basis and 52 ppm gallium on an ashed-basis. Merritt (1985b) reported a mean gallium content of 18 ppm in 31 Matanuska Valley coal-ash samples.

Rao (1968) reported an average gallium concentration of 2.1 ppm in eight Kenai field whole-coal samples; ash samples of the same coals had 19 ppm gallium. Rao and Wolff (1981) found 3.0 ppm gallium in a whole-coal sample of the subbituminous C-ranked Cabin bed, and 27 ppm gallium in an ash sample of the same coal. Affolter and others (1981) reported a range in gallium content from 1.5 to 10 ppm and a geometric mean content of 3 ppm in 10 Kenai Quadrangle whole-coal samples. They found a range in gallium content from 1 to 15 ppm and a geometric mean content of 3 ppm in 34 Seldovia Quadrangle whole-coal samples.

Conwell (1977) reported a range in gallium content of 30 to 70 ppm in seven Beluga field coal-ash samples and a mean of 61 ppm gallium. Rao and Wolff (1981) found 5.3 ppm gallium in the subbituminous C-ranked Waterfall bed, Beluga field on a whole-coal basis; an ash sample of the same coal had 52 ppm gallium. An average of two whole-coal samples of the Sunflower Creek seam, a Yentna field lignite, showed 1.6 ppm gallium; ash samples of the coal contained 39 ppm gallium (Rao and Wolff, 1981). Based on samples of six coal beds from the Tyonek Formation, Beluga field, Affolter and Stricker (1984) found that the concentration of gallium varied directly with the ash content of the coals.

Rao and Wolff (1981) also analyzed a lignite sample from Coal Creek, Broad Pass field. They reported 11 ppm gallium in a whole-coal sample and 57 ppm gallium in a coal-ash sample.

Nenana province. Rao (1968) found an average gallium concentration of 4.5 ppm in 25 Nenana basin whole-coal samples; ash sample of the coals contained an average of 36 ppm gallium. Rao and Wolff (1981) reported an average gallium content of 4.1 ppm in seven samples of five subbituminous C seams from the Nenana basin, including No. 2, No. 4, No. 6 (three splits, top, middle, and lower), Moose and Caribou seams. Coal-ash samples of the seams showed an average gallium content of 30 ppm. Affolter and Stricker (1981) reported a range of from 1.5 to 10 ppm gallium and a geometric mean of 3 ppm gallium in 20 Healy Quadrangle whole-coal samples. Affolter and Stricker (1987) reported an average gallium content of 0.44 ppm in two whole-coal samples of Seam No. 3, Usibelli Mine. Merritt (1985a) reported a general factor of enrichment of 1.8X for gallium based on its occurrence in Nenana basin coal-ash samples.

Rao (1968) found an average gallium concentration of 2.9 ppm in three Jarvis Creek field whole-coal samples; ash samples of the same coals showed an average gallium content of 29 ppm. Rao and Wolff (1981) reported that the gallium content of an Ober Creek, Jarvis Creek field, subituminous C-ranked coal was 2.5 ppm on a whole-basis and 22 ppm on an ash-basis.

Rao and Wolff (1981) also analyzed the subbituminous C-ranked main seam from the Little Tonzona River field. They reported a gallium content of 3 ppm in a whole-coal sample and 22 ppm in a coal-ash sample.

Alaska Peninsula province. Conwell and Triplehorn (1978) reported an average gallium concentration of 28 ppm in eight Alaska Peninsula coal-ash samples.

Gulf of Alaska province. Rao (1968) cited an average gallium content of 1.2 ppm in five Bering River field whole-coal samples. Ash samples of the same coals contained an average gallium content of 48 ppm.

Yukon-Koyukuk province. Rao and Wolff (1981) reported gallium concentrations for the high-volatile bituminous main seam of the Tramway Bar field. A whole-coal sample contained 18 ppm gallium, and a coal-ash sample contained 46 ppm gallium.

PROFILE 24 - GERMANIUM

Symbol: Ge Atomic number: 32 Atomic weight: 72.59

	Coal	Ash
Alaska	0-10 ppm	0-100 ppm
U.S.	0-850 ppm	0-1,500 ppm
World	0-1,800 ppm	0-11,000 ppm

Germanium is a metalloid element that forms small highly charged ions (high ionic potential). It is used as a catalyst and alloying agent. Turekian and Wedepohl (1961) reported the following average germanium concentrations in common sedimentary rocks: shales, 1.6 ppm; sandstones, 0.8 ppm; and carbonates, 0.2 ppm. Orheim (1979) cited the following clarke values for gallium: earth's crust, 1.5 ppm; soil, 5 ppm; plant ash, 5 ppm; and water, 0.00007 ppm.

Germanium occurs in coal in vastly greater concentration than its estimated average concentration in the earth's crust (Averitt, 1971; 1975). It tends to be concentrated near the source areas of a coal basin (Zubovic and others, 1966a,b) and more often in the top and bottom layers of a coal bed or immediately above a thick parting. Germanium has been found to be more abundant in bright coal bands than in dull bands (Averitt, 1961).

Much consideration and research has been directed to recovering commercial quantities of germanium from coal (Stach and others, 1982). Germanium is one of the elements showing greatest organic affinity; it is concentrated in clean-coal fractions. Germanium is retained in high-temperature ash (Ruch and others, 1974).

World Coals

Berkowitz (1979) reported a maximum germanium concentration in coal ash of 11,000 gm/ton and an average content of 500 gm/ton. The U.S. National Committee for Geochemistry (1980) indicated a worldwide average germanium concentration in coal of 5 ppm.

U.S. Coals

Sharkey and others (1975) found that germanium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 0.03 to 1 ppm. The U.S. National Committee of Geochemistry (1980) reported a U.S. average germanium content in coal of 0.71 ppm. Los Alamos Scientific Laboratory (1976) reported a range in germanium content of U.S. coals of 0 to 819 ppm, and 0 to 1,500 ppm in ashes of U.S. coals. They found that germanium showed an average concentration of <20 ppm in the ashes of both U.S. anthracites and low-volatile bituminous coals.

Appalachian region. Los Alamos Scientific Laboratory (1976) reported an average germanium concentration of 5.8 ppm in 73 Appalachian region whole-coal samples. Gluskoter and others (1977) reported a geometric mean germanium content of 0.87 ppm in 23 Appalachian region coals.

Interior region. Los Alamos Scientific Laboratory (1976) reported an average germanium concentration of 13 ppm in 53 Interior region whole-coal samples. Gluskoter and others (1977) reported a geometric mean germanium content of 4.8 ppm in 113 Illinois basin coals.

Western region. Los Alamos Scientific Laboratory (1976) found an average germanium concentration of 5.9 ppm in 48 Western and Southwestern Interior region coals and an average of 1.6 ppm germanium in 51 Northern Great Plains region whole-coal samples. Gluskoter and others (1977) cited a geometric mean germanium concentration of 0.50 ppm in 29 Western U.S. coals.

Alaska Coals

There exists very little data on germanium concentrations in Alaska coals and coal ashes.

Northern Alaska province. Conwell and Triplehorn (1976) reported a germanium content of 30 ppm in a Kukpuk River coal-ash sample and 70 ppm in a Cape Thompson coal-ash sample. Rao (1980) found the content of germanium in Cape Beaufort region samples to be quite low compared to other U.S. coals.

Cook Inlet-Susitna province. Merritt (1985b) reported a mean germanium content of 1.4 ppm in 29 Matanuska Valley coal-ash samples. Rao (1968) reported an average germanium concentration of 1.2 ppm in eight Kenai field whole-coal samples; ash samples of the same coals had 12.5 ppm germanium.

Nenana province. Rao (1968) found an average germanium concentration of <1.2 ppm in 25 Nenana basin whole-coal samples; ash samples of the coals contained an average of <10.6 ppm germanium. He also reported an average germanium concentration of 2.1 ppm in three Jarvis Creek field whole-coal samples; ash samples of the same coals showed an average germanium content of 20.1 ppm.

PROFILE 25 - GOLD

Symbol: Au Atomic number: 19 Atomic weight: 196.967

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	<0.1 ppm	N.E.
World	N.E.	<0.1 ppm

Gold is a highly malleable and ductile element that occurs in veins and alluvial deposits. It is a precious metal that can be recovered by panning, sluicing, or mining. Turekian and Wedepohl (1961) reported the following average gold concentrations in common sedimentary rocks: shales, 0.00X ppm; sandstones, 0.00X ppm; and carbonates 0.00X ppm. Orheim (1979) reported the following clarke values for gold: earth's crust, 0.004 ppm; soils, 0.002 ppm, plant ash, 0.005 ppm; and water, 0.000004 ppm. Averitt (1975) stated that gold can be concentrated locally in some coal beds, although there is little evidence available to support this claim. Gold is generally reported to be below the detection limit in coals. Berkowitz (1979) cited a maximum concentration of gold in coal ash of 0.1 gm/ton. Sharkey and others (1975) found that the concentration of gold in 13 U.S. raw coal samples was <0.1 ppm.

Gold was reported to be below the detection limit in two coal-ash samples from northern Alaska---Kukpuk River and Cape Thompson---analyzed by Conwell and Triplehorn (1976).

PROFILE 26 - HAFNIUM

Symbol: Hf Atomic number: 72 Atomic weight: 178.49

	Coal	Ash
Alaska	N.E.	<5 ppm
U.S.	0.1-5 ppm	N.E.
World	N.E.	N.E.

Hafnium is a metallic element generally associated with silicate minerals, and that can be separated from ores of zirconium. Turekian and Wedepohl (1961) reported the following average hafnium concentrations in common sedimentary rocks: shales, 2.8 ppm; sandstones, 3.9 ppm; and carbonates, 0.3 ppm. Abernethy and Gibson (1963) reported an average hafnium concentration in coal of 0.4 ppm.

Sharkey and others (1975) found that hafnium occurred in 46 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from <0.3 to 4 ppm. The U.S. average hafnium content in coal is 0.60 ppm (U.S. National Committee for Geochemistry, 1980). Gluskoter and others (1977) reported a geometric mean hafnium content of 1.1 ppm in 14 Appalachian region whole-coal samples, 0.49 ppm hafnium in 56 Illinois basin whole-coal samples, and 0.70 ppm hafnium in 22 Western U.S. whole-coal samples. Wewerka and others (1979) cited a range in hafnium concentration in ashes of Illinois basin coals of 1.3 to 2.9 ppm and a mean hafnium concentration of 1.8 ppm.

Merritt (1985b) reported a mean hafnium content of <3 ppm in ash samples of three Matanuska Valley coals.

PROFILE 27 - HOLMIUM

Symbol: Ho Atomic number: 67 Atomic weight: 164.930

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	<0.1-0.5 ppm	N.E.
World	0-1 ppm	N.E.

Holmium is a stable rare-earth element. Turekian and Wedepohl (1961) reported the following average holmium concentrations in common sedimentary rocks: shales, 1.2 ppm; sandstones, 2.0 ppm; and carbonates, 0.3 ppm.

Sharkey and others (1975) found that holmium occurred in 77 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from <0.1 to 0.4 ppm. The average worldwide holmium content in coal is 0.3 ppm. The average U.S. holmium content in coal is 0.11 ppm; for U.S. subbituminous coals, it is 0.13 ppm, and for U.S. lignites it is 0.06 ppm (U.S. National Committee for Geochemistry, 1980).

There is no available data on holmium concentrations in Alaska coals.

PROFILE 28 - HYDROGEN

Symbol: H Atomic number: 1 Atomic weight: 1.00797

	Coal	Ash
Alaska	40,000-70,000 ppm	- -
U.S.	38,000-60,000 ppm	- -
World	15,000-75,000 ppm	- -

Hydrogen is a gaseous element, the lightest of all gases, and the most abundant element in the universe. It belongs to the organic mineral group of elements (Wewerka and others, 1978). Among hydrogen's many uses are in methanol production, petroleum refining, and hydrogenation of organic materials.

Gluskoter and others (1977) reported a geometric mean hydrogen content of 4.9 percent for 22 Appalachian region whole-coal samples, 5.0 percent for 110 Illinois basin whole-coal samples, and 4.6 percent for 29 Western U.S. whole-coal samples.

Alaskan coals are similar in hydrogen composition to other U.S. coals when considered by rank. For example, a high-volatile A bituminous coal from the Matanuska Valley contains about 4.7 percent hydrogen, whereas Nenana and Beluga subbituminous coals contain about 6.2 percent hydrogen (equilibrium bed moisture basis).

PROFILE 29 - INDIUM

Symbol: In Atomic number: 49 Atomic weight: 114.82

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	0.01-0.7 ppm	N.E.
World	N.E.	N.E.

Indium is a metallic element found principally in ores of tin and zinc. Turekian and Wedepohl (1961) reported the following average indium concentrations in common sedimentary rocks: shales, 0.1 ppm; sandstones, 0.0X ppm; and carbonates, 0.0X ppm. Orheim (1979) reported a clarke value for indium in the earth's crust of 0.1 ppm.

Indium is one of the elements of chief environmental concern in coal. Berkowitz (1979) cited a maximum concentration of indium in coal ash of 2 gm/ton.

Gluskoter and others (1977) reported a geometric mean indium content of 0.22 ppm for 14 Appalachian region whole-coal samples, 0.13 ppm for 56 Illinois basin whole-coal samples, and 0.07 ppm for 22 Western U.S. whole-coal samples.

There is no available data on indium concentrations in Alaska coals.

PROFILE 30 - IODINE

Symbol: I Atomic number: 53 Atomic weight: 126.9044

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	<0.1-15 ppm	N.E.
World	N.E.	N.E.

Iodine is a poisonous halogen element having radioactive isotopes, especially I 131. Turekian and Wedepohl (1961) reported the following average iodine concentrations in common sedimentary rocks: shales, 2.2 ppm; sandstones, 1.7 ppm; and carbonates, 1.2 ppm. Orheim (1979) reported the following clarke values for iodine: earth's crust, 0.5 ppm, and water, 0.06 ppm.

Sharkey and others (1979) found that iodine occurred in 95 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from <0.1 to 4 ppm. The U.S. average iodine content in coal is 1.10 ppm (U.S. National Committee for Geochemistry, 1980). Gluskoter and others (1977) reported a geometric mean iodine content of 1.4 ppm in 14 Appalachian region whole-coal samples, 1.2 ppm iodine in 56 Illinois basin whole-coal samples, and 0.46 ppm iodine in 22 Western U.S. whole-coal samples.

Merritt (1985b) reported a mean iodine content of 3.7 ppm in ash samples of 30 Matanuska Valley coals.

PROFILE 31 - IRIDIUM

Symbol: Ir Atomic number: 77 Atomic weight: 192.2

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	<0.2 ppm	N.E.
World	N.E.	N.E.

Iridium is a metallic element found in platinum ores. Sharkey and others (1975) found that iridium content was <0.2 ppm in 13 U.S. raw coals analyzed. Somerville and Elder (1977) reported that iridium content was below the 0.1 ppm detection limit in North Dakota lignite samples. There is no available data on iridium concentrations in Alaska coals.

PROFILE 32 - IRON

Symbol: Fe Atomic number: 26 Atomic weight: 55.847

	Coal	Ash
Alaska	1,000-24,000 ppm	N.E.
U.S.	1,000-50,000 ppm	20,000-250,000 ppm
World	N.E.	N.E.

Iron is a metallic element used as an alloy in a wide variety of important structural materials. It is contained in sulfide and carbonate minerals, including pyrite (FeS_2), marcasite (FeS_2), hematite (Fe_2O_3), siderite ($FeCO_3$), limonite [$FeO(OH)\cdot nH_2O$], magnetite (Fe_3O_4), and taconite. The latter is a sedimentary rock and low-grade iron ore consisting of magnetite, hematite, and quartz. Iron has an important effect on the use of coal in combustion and cokemaking.

Turekian and Wedepohl (1961) reported the following average iron concentrations in common sedimentary rocks: shales, 47,200 ppm; sandstones, 9,800 ppm; and carbonates, 3,800 ppm. Orheim (1979) cited the following clarke values for iron: earth's crust, 64,500 ppm; soil, 30,000 ppm; plant ash, 6,700 ppm; and water 0.01 ppm.

World Coals

Iron is an important inorganic element of coal. Abernethy and Gibson (1963) reported an average iron concentration in coal of 10,850 ppm. The U.S. National Committee for Geochemistry reported a mean worldwide iron content in coal of 1.0 percent.

United States Coals

Sharkey and others (1975) found that iron occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 1,400 to 12,000 ppm. Others have reported that iron content in U.S. coals ranges from 0.32 to 4.32 percent (Los Alamos Scientific Laboratory, 1976; Wewerka and others, 1976). Swanson and others (1976) reported an average iron content of 1.3 percent in 601 U.S. coals, and the U.S. National Committee for Geochemistry (1980) cited an average iron concentration in U.S. coals of 1.6 percent.

Iron oxide is one of the major constituents of coal ash. In ashes of U.S. coals, iron ranges in content from 2.09 to 24.4 percent (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Swanson and others (1976) found a geometric mean of 1.0 percent iron in 331 Appalachian region whole-coal samples. Gluskoter and others (1977) reported a geometric mean iron content of 1.3 percent in 23 Appalachian region coals.

Interior region. Swanson and others (1976) found a geometric mean iron content of 2.3 percent in 194 Interior region whole-coal samples. Gluskoter and others (1977) reported a geometric mean-iron content of 1.9 percent in 113 Illinois basin coals.

Western region. Swanson and others (1976) found a geometric mean iron content of 0.45 percent in 93 Western region whole-coal samples, and 1.6 percent in 34 Texas coals. Gluskoter and others (1977) reported a geometric mean iron content of 0.49 percent in 29 Western U.S. coals.

Alaska Coals

Affolter and others (1981) reported geometric mean iron concentrations of 0.32 percent, 0.41 percent, 0.54 percent, and 0.32 percent in whole-coal samples of the Healy (20), Kenai (10), Seldovia (34), and Utukok River (54) Quadrangles, respectively. Compared to 410 Powder River region and 295 Rocky Mountain province coal samples, the contents of iron in these Alaskan coals is not significantly different.

PROFILE 33 - LANTHANUM

Symbol: La Atomic number: 57 Atomic weight: 138.91

	Coal	Ash
Alaska	5-30 ppm	20-500 ppm
U.S.	0-100 ppm	0-900 ppm
World	0-100 ppm	N.E.

Lanthanum is a metallic rare-earth element that is obtained chiefly from monazite [(Ce, La, Y, Th) PO_4]. It is commonly found in association with silicate minerals. Turekian and Wedepohl (1961) reported the following average lanthanum concentrations in common sedimentary rocks: shales, 92 ppm; sandstones, 30 ppm; and carbonates, X ppm.

World Coals

Lanthanum generally occurs in coal in appreciably greater concentration than its estimated average concentration in the earth's crust (Averitt, 1975). Abernethy and Gibson (1963) reported a general average lanthanum concentration in coal of 3.8 ppm. The U.S. National Committee for Geochemistry (1980) cited a worldwide average lanthanum concentration in coal of 10 ppm.

United States Coal

Sharkey and others (1975) found that lanthanum occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 0.3 to 29 ppm. Others have cited a range in lanthanum content in U.S. coals from 0 to 98 ppm (Los Alamos Scientific Laboratory, 1976), and an average concentration of 6.1 ppm (U.S. National Committee for Geochemistry, 1980). In ashes of U.S. coals, lanthanum exhibits a range from 0 to 820 ppm and average concentrations, by rank, as follows: anthracites, 142 ppm; low-volatile bituminous, 110 ppm; medium-volatile bituminous, 83 ppm; high-volatile bituminous, 111 ppm; and subbituminous and lignite, 62 ppm (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Los Alamos Scientific Laboratory (1976) reported an average lanthanum concentration of 9.4 ppm in 73 Appalachian region whole-coal samples. Gluskoter and others (1977) reported a geometric mean lanthanum content of 14 ppm in 14 Appalachian region coals.

Interior region. Los Alamos Scientific Laboratory (1976) reported an average lanthanum concentration of 5.1 ppm in 53 Interior region whole-coal samples. Gluskoter and others (1977) reported a geometric mean lanthanum concentration of 6.4 ppm in 56 Illinois basin coals.

Western region. Los Alamos Scientific Laboratory (1976) reported an average lanthanum concentration of 6.5 ppm in 48 Western and Southwestern Interior region coals, and an average of 9.5 ppm lanthanum in 51 Northern Great Plains region coals. Gluskoter and others (1977) reported a geometric mean lanthanum concentration of 4.5 ppm in 22 Western U.S. coals.

Alaska Coals

Northern Alaska province. Conwell and Triplehorn (1976) found a lanthanum content of 500 ppm in a Kukpuk River coal-ash sample, and 100 ppm in a Cape Thompson coal-ash sample.

Cook Inlet-Susitna province. Merritt (1985b) reported a mean lanthanum content of 26 ppm in 31 Matanuska Valley coal-ash samples. Affolter and others (1981) reported a range in lanthanum content of 5 to 30 ppm in 34 Seldovia Quadrangle whole-coal samples, and a geometric mean lanthanum content of 3 ppm. Conwell (1977) cited a mean lanthanum concentration <100 ppm in seven Beluga field coal-ash samples. Based on samples of six coal beds from the Tyonek Formation, Beluga field, Affolter and Stricker (1984) found that the concentration of lanthanum varied directly with the ash content of the coals.

Nenana province. Affolter and others (1981) cited a range in lanthanum content from 10 to 20 ppm and a geometric mean of 7 ppm lanthanum in 20 Healy Quadrangle whole-coal samples. Affolter and Stricker (1987) found an average of 1.8 ppm lanthanum in two whole-coal samples of Seam No. 3, Usibelli Mine.

Alaska Peninsula province. Conwell and Triplehorn (1978) reported an average lanthanum concentration of <100 ppm in eight Alaska Peninsula coal-ash samples.

PROFILE 34 - LEAD

Symbol: Pb Atomic number: 82 Atomic weight: 207.19

	Coal	Ash
Alaska	1-35 ppm	20-350 ppm
U.S.	1-220 ppm	10-1,500 ppm
World	0-300 ppm	10-1,000 ppm

Lead is a dense metallic element that is associated with the mineral galena (PbS). Turekian and Wedepohl (1961) reported the following average lead concentrations in common sedimentary rocks: shales, 20 ppm; sandstones, 7 ppm; and carbonates, 9 ppm. Orheim (1979) cited the following clarke values for lead: earth's crust, 12.5 ppm; soil, 10 ppm; plant ash, 70 ppm; and water, 0.00003 ppm. Lead occurs in coal in appreciably greater concentration than its estimated average concentration in the earth's crust (Averitt, 1961; 1975). Lead shows a limited enrichment factor of 1.28X in coal (U.S. National Committee for Geochemistry, 1980).

Lead is generally inorganically combined in coal; it is one of the elements showing least organic affinity (Ruch and others, 1974). It tends to be concentrated in the heavier specific gravity or mineral matter fraction of coal (Cavallaro and others, 1978).

Lead is one of the elements of chief environmental concern in coal; it is generally toxic to plant and animal life at relatively low concentrations (Ruch and others, 1974). It is commonly enriched on the surfaces of fly-ash particles released from coal-combustion sources (Mraw and others, 1983). Lead is generally retained in high-temperature ash, and over 95 percent is retained in low-temperature ash (Ruch and others, 1974). Anomalously high lead in core-hole coal samples can result from contaminated drilling fluids and drill pipe.

World Coals

Abernethy and Gibson (1963) reported an average lead content in coal of 4.9 ppm. The U.S. National Committee for Geochemistry (1980) cited a worldwide average lead concentration in coal of 25 ppm. Berkowitz (1979) cited a maximum concentration of lead in coal ash of 1,000 gm/ton and an average concentration of 100 gm/ton.

United States Coals

Sharkey and others (1975) found that lead occurred in 100 percent of 13 U.S. coals analyzed, and that it ranged in concentration from 1 to 36 ppm. Others have reported a range in lead concentration in U.S. coals from 4 to 218 ppm (Los Alamos Scientific Laboratory, 1976; Wewerka and others, 1976). Swanson and others (1976) reported an average lead content of 9.2 ppm in 601 U.S. coals, and the U.S. National Committee for Geochemistry (1980) reported an average lead content of 16 ppm in U.S. coals. In ashes of U.S. coals, lead ranges in content from 10 to 1,420 ppm, and occurs in the following

average concentrations in the ashes of coals of various rank: anthracites, 81 ppm; low-volatile bituminous, 89 ppm; medium-volatile bituminous, 96 ppm; high-volatile bituminous, 183 ppm; and subbituminous and lignite, 60 ppm (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Swanson and others (1976) reported a geometric mean content of 10.9 ppm lead in 331 Appalachian region whole-coal samples. Gluskoter and others (1977) reported a geometric mean content of 4.7 ppm lead in 23 Appalachian region coals.

Interior region. Swanson and others (1976) reported a geometric mean lead content of 19 ppm in 194 Interior region whole-coal samples. Gluskoter and others (1977) reported a geometric mean content of 15 ppm lead in 113 Illinois basin whole-coal samples.

Western region. Swanson and others (1976) reported a geometric mean lead content of 4.3 ppm in 93 Western region whole-coal samples and a geometric mean of 2.8 ppm lead in 34 Texas coals. Gluskoter and others (1977) reported a geometric mean content of 2.6 ppm lead in 29 Western U.S. coals.

Alaska Coals

There exists an abundant amount of data relating to lead concentrations in Alaska coals and coal ashes.

Northern Alaska province. Rao (1968) reported an average concentration of 13.9 ppm lead in 12 Northern Alaska whole-coal samples; ash samples of the same coals contained an average of 153 ppm lead. Conwell and Triplehorn (1976) found an average content of 430 ppm lead in a Kukpuk River coal-ash sample and 330 ppm lead in a Cape Thompson coal-ash sample. Rao (1980) analyzed and reported on lead concentrations in some 38 Cape Beaufort region whole-coal and coal-ash samples. Although certain of the Cape Beaufort region coals showed high concentrations of lead, the average concentration was quite low compared to other U.S. coals. In raw coals, lead ranged from <2 to 41 ppm and had a mean content <12 ppm; in coal-ash samples, lead ranged from <20 to 253 ppm and had a mean content <56 ppm (Rao, 1980). Rao and Wolff (1981) found 7.9 ppm lead in a whole-coal sample of a subbituminous B seam from Meade River, northern Alaska; ash of the same coal contained 180 ppm lead. They reported a whole-coal lead content of 13 ppm in a high-volatile bituminous seam from Sagwon Bluffs, northern Alaska; ash of the same coal contained 21 ppm lead. Affolter and others (1981) reported a range in lead concentration of 1 to 21 ppm for 54 Utukok River Quadrangle whole-coal samples and a geometric mean content of 1.7 ppm.

Cook Inlet-Susitna province. Rao (1968) reported an average lead content of 13.6 ppm in 22 Matanuska Valley whole-coal samples and an average lead content of 102 ppm in ash samples of the same coals. Rao and Wolff (1981) found a lead content of 4.5 ppm in a whole-coal sample of the high-volatile bituminous lower seam, Castle Mountain mine, Matanuska field; an ash sample of the same coal contained 25 ppm lead. They also reported a lead content of 4.3 ppm in a whole-coal sample of a high-volatile bituminous seam

from the Premier mine, Matanuska field; an ash sample of this coal contained 28 ppm lead. Merritt (1985b) found a mean lead concentration of 10 ppm in 31 Matanuska Valley coal-ash samples.

Rao (1968) reported an average lead content of 8.7 ppm in eight Kenai field whole-coal samples; ash samples of the same coals contained an average 89 ppm lead. Rao and Wolff (1981) found a lead content of 4.7 ppm in a whole-coal sample of the subbituminous C-ranked Cabin bed, Kenai field; an ash sample of the coal showed 42 ppm lead. Affolter and others (1981) reported a range in lead content from <1.5 to 11 ppm in 34 Seldovia Quadrangle whole-coal samples, and a geometric mean lead content of 2.0 ppm. Merritt and others (1987) cited a mean lead concentration of <61 ppm in ash samples of 31 Kenai field coals.

Conwell (1977) reported a range in lead content from 25 to 60 ppm and a mean content of 38 ppm in seven Beluga field coal-ash samples. Rao and Wolff (1981) reported a lead content of 11 ppm in a whole-coal sample of the subbituminous C-ranked Waterfall seam, Beluga field; an ash sample of the same coal contained 110 ppm lead. They also reported a lead content of 2.4 ppm (whole-coal basis) in a Sunflower Creek lignite from the Yentna field; an ash sample of the same coal contained 62 ppm lead. Merritt (1987a) found a range in lead content from 8 to 69 ppm and an average content of 22 ppm for ash samples of 65 Susitna lowland coals.

Rao and Wolff (1981) analyzed a lignite seam from Coal Creek, Broad Pass field. A raw coal sample had a lead content of 19 ppm, and a coal-ash sample had 99 ppm.

Nenana province. Rao (1968) reported an average lead concentration of 12.1 ppm in 25 Nenana basin whole-coal samples; ash samples of the coals contained an average 117 ppm lead. Rao and Wolff (1981) analyzed five samples of four Nenana basin subbituminous C-ranked coals, including the No. 4, No. 6 (two splits, top, and lower), Moose, and Caribou seams. The whole-coal samples contained an average lead content of 14 ppm and the coal-ash samples contained an average lead content of 123 ppm. Affolter and others (1981) cited a range of <2 to 15 ppm lead in 20 Healy Quadrangle whole-coal samples and a geometric mean lead content of 4.5 ppm. Affolter and Stricker (1987) found an average 1.8 ppm lead in two whole-coal samples of Seam No. 3, Usibelli Mine. Merritt (1985a) reported a general factor of enrichment for lead of 6.2X based on Nenana basin coal-ash samples.

Rao (1968) reported an average lead concentration of 5.4 ppm in three Jarvis Creek field whole-coal samples; ash samples of the same coals revealed an average lead content of 52 ppm.

Rao and Wolff (1981) also analyzed the subbituminous C-ranked main seam of the Little Tonzona River field, western Nenana province. A whole-coal sample contained 7.8 ppm lead, and a coal-ash sample contained 57 ppm lead.

Alaska Peninsula province. Conwell and Triplehorn (1978) cited an average lead concentration of <32 ppm in eight Alaska Peninsula coal-ash samples.

Gulf of Alaska province. Rao (1968) reported an average lead content of 6.6 ppm in five Bering River field whole-coal samples and an average 268 ppm lead in ash samples of the same coals.

Yukon-Koyukuk province. Rao and Wolff (1981) cited a whole-coal lead concentration of 23 ppm and a coal-ash lead concentration of 59 ppm in a high-volatile bituminous seam of the Tramway Bar field.

PROFILE 35 - LITHIUM

Symbol: Li Atomic number: 3 Atomic weight: 6.939

	Coal	Ash
Alaska	0.5-90 ppm	20-800 ppm
U.S.	0.1-350 ppm	<20-3,200 ppm
World	N.E.	N.E.

Lithium is a highly-reactive metallic element that is generally found in association with silicate minerals. Turekian and Wedepohl (1961) reported the following average lithium concentrations in common sedimentary rocks: shales, 66 ppm; sandstones, 15 ppm; and carbonates, 5 ppm. Orheim (1979) cited the following clarke values for lithium: earth's crust, 20 ppm; soil, 30 ppm; plant ash, 2 ppm; and water 0.003 ppm. Lithium generally occurs in coal in appreciably greater concentration than its estimated average concentration in the earth's crust (Averitt, 1975).

World Coals

The U.S. National Committee for Geochemistry (1980) cited a worldwide average lithium content in coal of 65 ppm. Barkowitz (1979) reported a maximum lithium concentration in coal ash of 500 gm/ton.

United States Coals

Sharkey and others (1975) found that lithium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 4 to 163 ppm. Swanson and others (1976) reported an average lithium content of 11 ppm in 601 U.S. coals, and the following average concentrations by rank: anthracite, 33 ppm; bituminous, 23 ppm; subbituminous, 7 ppm; and lignite, 19 ppm. Medlin and others (1979) found a range in lithium concentration in U.S. coals of 0.17 to 350 ppm, a geometric mean of 8.3 ppm lithium, and an arithmetic mean of 15 ppm lithium. The U.S. National Committee for Geochemistry (1980) cited an average lithium concentration in U.S. coals of 20 ppm. Los Alamos Scientific Laboratory (1976) reported a range in lithium content of <20 to 3,100 ppm in ashes of U.S. coals.

Swanson and others (1976) also reported the following geometric mean lithium concentrations in whole-coal samples of different regions of the United States: Appalachian region (331 samples), 18.8 ppm; Interior region (194 samples), 7 ppm; Western region (93 samples), 4.3 ppm; and Texas (34 samples), 14 ppm.

Alaska Coals

Compared to other U.S. coals, the content of lithium in Alaskan coals is similar.

Northern Alaska province. Conwell and Triplehorn (1976) reported a lithium content of 683 ppm in a Kukpuk River coal-ash sample and 744 ppm in a Cape Thompson coal-ash sample. Affolter and others (1981) found a range in lithium content in 54 Utukok River Quadrangle whole-coal samples of 0.5 to 84 ppm and a geometric mean lithium content of 9.5 ppm.

Cook Inlet-Susitna province. Merritt (1985b) cited a mean lithium concentration of 168 ppm in 30 Matanuska Valley coal-ash samples. Affolter and others (1981) reported a range in lithium content of <1 to 13 ppm and a geometric mean content of 4 ppm in 10 Kenai Quadrangle whole-coal samples. They reported a range in lithium content of 0.6 to 26 ppm and a geometric mean content of 3.6 ppm in 34 Seldovia Quadrangle whole-coal samples. Conwell (1977) found a range of 27 to 89 ppm lithium and a mean of 60 ppm lithium in seven Beluga field coal-ash samples. Based on samples of six coal beds from the Tyonek Formation, Beluga field, Affolter and Stricker (1984) found that the concentration of lithium varied directly with the ash content of the coals.

Nenana province. Affolter and others (1981) reported a range in lithium content of 1.3 to 32 ppm and a geometric mean of 3.7 ppm lithium in 20 Healy Quadrangle whole-coal samples. Affolter and Stricker (1987) reported an average of 0.6 ppm lithium in two whole-coal samples of Seam No. 3, Usibelli Mine.

Alaska Peninsula province. Conwell and Triplehorn (1978) reported an average lithium content of 127 ppm in eight Alaska Peninsula coal-ash samples.

PROFILE 36 - LUTETIUM

Symbol: Lu Atomic number: 71 Atomic weight: 174.97

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	0.01-0.5 ppm	N.E.
World	N.E.	N.E.

Lutetium is a rare-earth element associated with silicate minerals. Turekian and Wedepohl (1961) reported the following average lutetium concentrations in common sedimentary rocks: shales, 0.7 ppm; sandstones, 1.2 ppm; and carbonates, 0.2 ppm. The average worldwide lutetium content in coal is 0.07 ppm (U.S. National Committee for Geochemistry, 1980).

Sharkey and others (1975) found that lutetium occurred in 38 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from <0.1 to 0.3 ppm. The average U.S. lutetium content in coal is 0.08 ppm; for U.S. subbituminous coals, it averages 0.09 ppm, and for U.S. lignites, it averages 0.05 ppm (U.S. National Committee for Geochemistry, 1980). Gluskoter and others (1977) reported a geometric mean lutetium content of 0.18 ppm in 14 Appalachian region whole-coal samples, 0.08 ppm in 56 Illinois basin whole-coal samples, and 0.05 ppm in 22 Western U.S. whole-coal samples.

There is no available data on lutetium concentrations in Alaska coals.

PROFILE 37 - MAGNESIUM

Symbol: Mg Atomic number: 12 Atomic weight: 24.312

	Coal	Ash
Alaska	200-6,000 ppm	N.E.
U.S.	100-4,000 ppm	0-25,000 ppm
World	N.E.	N.E.

Magnesium is a metallic element contained mainly in the carbonate mineral group but found in association with silicate minerals. Turekian and Wedepohl (1961) reported the following average magnesium concentrations in common sedimentary rocks: shales, 15,000 ppm; sandstones, 7,000 ppm; and carbonates, 47,000 ppm. Orheim (1979) cited the following clarke values for magnesium: earth's crust, 21,000 ppm; plant ash, 700 ppm; and water, 1,000 ppm.

Magnesium is a major inorganic constituent of coal. Magnesium oxide is one of the chief components of coal ash.

World Coals

Abernethy and Gibson (1963) cited an average magnesium concentration in coal of 1,210 ppm. The U.S. National Committee for Geochemistry (1980) reported a worldwide average magnesium content of 0.02 percent.

United States Coals

Sharkey and others (1975) found that magnesium occurred in 100 percent of 13 U.S. raw coals, and that it ranged in concentration from 500 to 3,500 ppm. Others have reported a range in magnesium content in U.S. coals from 0.1 to 0.25 percent (Los Alamos Scientific Laboratory, 1976; Wewerka and others, 1976). Swanson and others (1976) cited an average magnesium content of 0.1 percent in 601 U.S. coals. The U.S. National Committee for Geochemistry (1980) reported an average magnesium content in U.S. coals of 0.12 percent. Magnesium ranges from 0 to 2.4 percent in ashes of U.S. coals (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Swanson and others (1976) reported a geometric mean of 0.052 percent in 331 Appalachian region whole coal samples, and Gluskoter and others (1977) found a geometric mean of 0.05 percent in 23 Appalachian coals.

Interior region. Swanson and others (1976) reported a geometric mean magnesium content of 0.063 percent in 194 Interior whole-coal samples. Gluskoter and others (1977) found a geometric mean of 0.05 percent in 113 Illinois basin coals.

Western region. Swanson and others (1976) reported a geometric mean magnesium content of 0.245 percent in 93 Western region whole-coal samples

and 0.17 percent in 34 Texas coals. Gluskoter and others (1977) found a geometric mean magnesium content of 0.12 percent in 29 Western U.S. coals.

Alaska Coals

Affolter and others (1981) reported geometric mean magnesium concentrations of 0.21 percent, 0.37 percent, 0.13 percent, and 0.14 percent in whole-coal samples of Healy (20), Kenai (10), Seldovia (34), and Utukok River (24) Quadrangles, respectively. Compared to 410 Powder River region coal samples, the magnesium content of Healy Quadrangle coals is not significantly different, the magnesium content of Kenai Quadrangle coals is significantly higher, and the magnesium content of Seldovia Quadrangle coals is significantly lower. Compared with 295 Rocky Mountain province coal samples, the magnesium content of Utukok River Quadrangle coals is significantly higher.

PROFILE 38 - MANGANESE

Symbol: Mn Atomic number: 25 Atomic weight: 54.9380

	Coal	Ash
Alaska	1-290 ppm	30-7,500 ppm
U.S.	5-250 ppm	30-4,500 ppm
World	0-300 ppm	10-6,000 ppm

Manganese is a metallic element found worldwide in the following minerals: pyrolusite (MnO_2), braunite (Mn_2O_3), hausmannite (Mn_3O_4), manganite [MnO(OH)], siderite [$(Fe, Mn)CO_3$], and calcite [$(Ca, Mn)CO_3$]. Turekian and Wedepohl (1961) reported the following average manganese concentrations in common sedimentary rocks: shales, 850 ppm; sandstones, X0 ppm; and carbonates, 1,100 ppm. Orheim (1979) cited the following clarke values for manganese: earth's crust, 1,000 ppm; soil, 850 ppm, plant ash, 4,800 ppm; and water, 0.002 ppm.

Manganese generally occurs in coal in lower concentration than its estimated average concentration in the earth's crust (Averitt, 1975). It is one of the elements of environmental concern in coal. It is typically inorganically combined in coal and concentrated in its mineral matter; thus, it is one of the elements showing least organic affinity. It is generally retained in high-temperature ash and over 95 percent in retained in low-temperature ash (Ruch and others, 1974).

World Coals

Abernethy and Gibson (1963) cited an average manganese content in coal of 33.8 ppm. The U.S. National Committee for Geochemistry (1980) reported an average worldwide manganese content of 0.005 percent.

United States Coals

Sharkey and others (1975) found that manganese occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 5 to 240 ppm. Others have cited a range in manganese content in U.S. coals from 6 to 181 ppm (Los Alamos Scientific Laboratory, 1976; Wewerka and others, 1976). Swanson and others (1976) reported an average manganese concentration in 601 U.S. coals of 89.2 ppm. The U.S. National Committee for Geochemistry (1980) reported an average U.S. manganese content in coal of 0.01 percent. Los Alamos Scientific Laboratory (1976) reported a range in manganese content of 30 to 1,800 ppm in ashes of U.S. coals and the following average concentrations by rank in ashes of U.S. coals: anthracites, 270 ppm; low-volatile bituminous, 280 ppm; medium-volatile bituminous, 1,432 ppm; high-volatile bituminous, 120 ppm, and subbituminous and lignite, 688 ppm (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Swanson and others (1976) reported a geometric mean manganese content of 200 ppm in 331 Appalachian region whole-coal samples. Gluskoter and others (1977) cited a geometric mean manganese content of 12 ppm in 23 Appalachian coals.

Interior region. Swanson and others (1976) reported a geometric mean manganese content of 72 ppm in 194 Interior region whole-coal samples. Gluskoter and others (1977) cited a geometric mean manganese content of 40 ppm in 113 Illinois basin coals.

Western region. Swanson and others (1976) reported a geometric mean manganese content of 34 ppm in 93 Western region whole-coal samples and 51 ppm in 34 Texas coals. Gluskoter and others (1977) cited a geometric mean manganese content of 28 ppm in 29 Western U.S. coals.

Alaska Coals

Northern Alaska province. Conwell and Triplehorn (1976) found a manganese content of 590 ppm in a Kukpuk River, Northern Alaska coal-ash sample and 40 ppm in a Cape Thompson, Northern Alaska coal-ash sample. Affolter and others (1981) reported a range in manganese content of <1.8 to 170 ppm and a geometric mean manganese content of 16 ppm in 54 Utukok River Quadrangle whole-coal samples.

Cook Inlet-Susitna province. Merritt (1985b) reported a mean manganese content of 36 ppm in 31 Matanuska Valley coal-ash samples. Affolter and others (1981) reported a range in manganese from 50 to 290 ppm and a geometric mean of 120 ppm in 10 Kenai Quadrangle whole-coal samples. They also found a range in manganese of 40 to 240 ppm and a geometric mean of 90 ppm in 34 Seldovia Quadrangle whole-coal samples. Conwell (1977) cited a range in manganese concentration of 225 to 485 ppm and a mean of 370 ppm in seven Beluga field coal-ash samples. Merritt (1987a) reported a range of 72 to 7,430 ppm manganese and an average of 1,203 ppm manganese in 45 Susitna lowland coal-ash samples.

Nenana province. Affolter and others (1981) found a range in manganese content of 6.1 to 220 ppm and a geometric mean of 46 ppm in 20 Healy Quadrangle whole-coal samples. Affolter and Stricker (1987) cited an average manganese content of 62 ppm in two whole-coal samples of Seam No. 3, Usibelli Mine.

Alaska Peninsula province. Conwell and Triplehorn (1978) reported an average manganese concentration of 339 ppm in eight Alaska Peninsula coal-ash samples.

PROFILE 39 - MERCURY

Symbol: Hg Atomic number: 80 Atomic weight: 200.59

	Coal	Ash
Alaska	0.01-0.4 ppm	N.E.
U.S.	0.01-10 ppm	<50-300 ppm
World	N.E.	N.E.

Mercury, commonly referred to as 'quicksilver,' is a poisonous metallic element that is liquid at room temperature. It is often found in association with the mineral pyrite (FeS_2). Turekian and Wedepohl (1961) reported the following average mercury concentrations in common sedimentary rocks: shales, 0.4 ppm; sandstones, 0.03 ppm; and carbonates, 0.04 ppm. Orheim (1979) cited these clarke values for mercury: earth's crust, 0.08 ppm; soil, 0.01 ppm; plant ash, 0.01 ppm; and water, 0.00003 ppm.

Mercury generally occurs in coal in appreciably greater concentration than its estimated average concentration in the earth's crust (Averitt, 1975). It shows a limited enrichment factor of 2.25X in coal (U.S. National Committee for Geochemistry, 1980). Mercury is generally inorganically combined in coal and is one of the elements showing least organic affinity (Ruch and others, 1974). It tends to be concentrated in the mineral matter or heavier specific gravity faction of coal (Cavallaro and others, 1978).

Mercury is potentially the most toxic substance in coal and coal ash (Berkowitz, 1979). It is one of the elements of chief environmental concern in coal, and is toxic to plant and animal life at relatively low concentrations. Mercury may be released from coal-combustion sources, and up to 95 percent is lost in low-temperature ash (Ruch and others, 1974).

World Coals

Abernethy and Gibson (1963) cited an average mercury concentration in coal of 0.122 ppm. The U.S. National Committee for Geochemistry (1980) reported a worldwide average mercury concentration in coal of 0.012 ppm.

United States Coals

Sharkey and others (1975) found that mercury occurred in 38 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from <0.3 to 0.5 ppm. Others have reported a range in mercury content in U.S. coals from 0.01 to 1.6 ppm (Los Alamos Scientific Laboratory, 1976; Wewerka and others, 1976). Swanson and others (1976) reported an average mercury concentration in 601 U.S. coals of 0.1 ppm. The U.S. National Committee for Geochemistry (1980) cited a U.S. average mercury content in coal of 0.18 ppm. Mercury ranges from <70-259 ppm in ashes of U.S. coals (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Swanson and others (1976) reported a geometric mean mercury content of 0.14 ppm in 331 Appalachian whole-coal samples. Gluskoter and others (1977) found a geometric mean mercury content of 0.17 ppm in 23 Appalachian coals.

Interior region. Swanson and others (1976) reported a geometric mean mercury content of 0.10 ppm in 194 Interior region whole-coal samples. Gluskoter and others (1977) found a geometric mean mercury content of 0.16 ppm in 113 Illinois basin coals.

Western region. Swanson and others (1976) reported a geometric mean mercury content of 0.06 ppm in 93 Western region coals and 0.13 ppm in 34 Texas coals. Gluskoter and others (1977) found a geometric mean mercury content of 0.07 ppm in 29 Western U.S. coals.

Alaska Coals

Compared to other U.S. coals, the content of mercury in Alaskan coals is similar or lower.

Northern Alaska province. Conwell and Triplehorn (1976) determined that a Kukpuk River coal contained 0.01 ppm mercury and a Cape Thompson coal contained 0.27 ppm mercury. Affolter and others (1981) reported a range in mercury concentration of 0.02 to 0.40 ppm and a geometric mean of 0.04 ppm in 54 Utukok River Quadrangle whole-coal samples.

Cook Inlet-Susitna province. Affolter and others (1981) reported mercury concentrations in 10 Kenai Quadrangle and 34 Seldovia Quadrangle whole-coal samples. They cited a range in mercury content in the Kenai Quadrangle coals from 0.01 to 0.12 ppm and a geometric mean of 0.05 ppm. The range in the Seldovia Quadrangle coals was 0.03 to 0.40 ppm mercury and a geometric mean of 0.08 ppm mercury.

Conwell (1977) reported a range in mercury concentration of 0.02 to 0.07 ppm and a mean of 0.04 ppm in seven Beluga field whole-coal samples. Merritt (1987a) cited a range of 20 to 490 ppb mercury and an average of 106 ppb mercury in 66 Susitna lowland coal-ash samples.

Nenana province. Affolter and Stricker (1981) reported a range of 0.02 to 0.30 ppm mercury and a geometric mean of 0.06 ppm mercury in 20 Healy Quadrangle whole-coal samples. Affolter and Stricker (1987) found an average of 0.10 ppm mercury in two whole-coal samples of Seam No. 3, Usibelli Mine.

Alaska Peninsula province. Conwell and Triplehorn (1978) reported an average mercury concentration of 0.06 ppm in eight Alaska Peninsula whole-coal samples.

PROFILE 40 - MOLYBDENUM

Symbol: Mo Atomic number: 42 Atomic weight: 95.94

	Coal	Ash
Alaska	0.01-15 ppm	10-100 ppm
U.S.	0-75 ppm	0-3,000 ppm
World	0-100 ppm	10-500 ppm

Molybdenum is a metallic element that is generally associated with the sulfide mineral group, especially molybdenite (MoS_2). Turekian and Wedepohl (1961) reported the following average molybdenum concentrations in common sedimentary rocks: shales, 2.6 ppm; sandstones, 0.2 ppm; and carbonates, 0.4 ppm. Orheim (1979) cited these clarke values for molybdenum: earth's crust, 1.7 ppm; soil, 2.5 ppm; plant ash, 13 ppm; and water, 0.01 ppm.

Molybdenum occurs in coal in appreciably greater concentration than its estimated average concentration in the earth's crust (Averitt, 1961). It shows a limited enrichment factor of 2.0X in coal. Molybdenum is generally inorganically combined in coal and is one of the elements showing least organic affinity; it is concentrated in the mineral matter of coal (Ruch and others, 1974). In certain conversion processes, molybdenum in coal can act as a catalyst (Rao, 1976). About 33 percent of molybdenum is lost in high-temperature ash (Ruch and others, 1974).

World Coals

The U.S. National Committee for Geochemistry (1980) cited a worldwide average molybdenum concentration in coal of 5 ppm. Berkowitz (1979) determined a maximum molybdenum concentration in coal ash of 500 gm/ton and an average molybdenum content of 200 gm/ton.

United States Coals

Sharkey and others (1975) found that molybdenum occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 1 to 5 ppm. Los Alamos Scientific Laboratory (1976) reported a range in molybdenum content in U.S. coals of 0 to 73 ppm, and a range in ashes of U.S. coals of 0 to 2,900 ppm. Swanson and others (1976) cited an average molybdenum concentration of 1.5 ppm in 601 U.S. coals, and the U.S. National Committee for Geochemistry (1980) cited an average molybdenum content of 3 ppm in U.S. coals.

Appalachian region. Swanson and others (1976) reported a geometric mean molybdenum content of 2 ppm in 331 Eastern U.S. coals. Los Alamos Scientific Laboratory (1976) reported an average molybdenum concentration of 3.5 ppm in 73 Appalachian region whole-coal samples. Gluskoter and others (1977) found a geometric mean molybdenum content of 1.8 ppm in 23 Appalachian coals.

Interior region. Swanson and others (1976) reported a geometric mean molybdenum content of 2 ppm in 194 Interior region coals. Los Alamos Scientific Laboratory (1976) cited an average molybdenum concentration of 4.3 ppm in 53 Eastern Interior region coals. Gluskoter and others (1977) found a geometric mean molybdenum content of 6.2 ppm in 111 Illinois basin whole-coal samples.

Western region. Swanson and others (1976) reported a geometric mean molybdenum content of 1.5 ppm in 93 Western region coals and 0.7 ppm molybdenum in 34 Texas coals. Los Alamos Scientific Laboratory (1976) cited an average molybdenum content of 3.1 ppm in 48 Western and Southwestern Interior region coals and 1.7 ppm in 51 Northern Great Plains region coals. Gluskoter and others (1977) found a geometric mean molybdenum content of 0.59 ppm in 29 Western U.S. whole-coal samples.

Alaska Coals

Compared to other U.S. coals, the content of molybdenum in Alaskan coals is low.

Northern Alaska province. Conwell and Triplehorn (1976) found 70 ppm molybdenum in a Kukpuk River coal-ash sample and 100 ppm molybdenum in a Cape Thompson coal-ash sample. Rao (1980) found a range in molybdenum content of 0.3 to 23 ppm and a mean of 1.2 ppm in 38 Cape Beaufort region whole-coal samples. He reported a range in molybdenum content of 2.0 to 10 ppm and a mean of 5.9 ppm in ash samples of the same coals. Rao (1980) concluded that the concentration of molybdenum in Cape Beaufort region coals was quite low compared to other U.S. coals. Rao and Wolff (1981) cited a molybdenum content of 0.92 ppm in a whole-coal sample of a Meade River subbituminous B seam, and 21 ppm molybdenum in an ash sample of the same coal. Affolter and others (1981) reported a range in molybdenum content of 0.2 to 1.5 ppm and a geometric mean of 0.07 ppm in 54 Utukok River Quadrangle whole-coal samples.

Cook Inlet-Susitna province. Merritt (1985b) reported a mean molybdenum content of 6.2 ppm in 29 Matanuska Valley coal-ash samples. Rao and Wolff (1981) found a molybdenum content of 1 to 6 ppm in a whole-coal sample of the subbituminous C-ranked Cabin bed, Kenai field; an ash sample of the same coal contained 14 ppm molybdenum. Affolter and others (1981) reported a range in molybdenum content of 1.5 to 5 ppm and a geometric mean of 3 ppm in 10 Kenai Quadrangle whole-coal samples. They also reported a range in molybdenum content of <0.5 to 15 ppm and a geometric mean of 1.5 ppm in 34 Seldovia Quadrangle whole-coal samples. Conwell (1977) found a range in molybdenum content of 15 to 150 ppm and a mean of 44 ppm in seven Beluga field coal-ash samples. Rao and Wolff (1981) reported molybdenum concentrations in a lignitic coal of the upper bench, Sunflower Creek seam, Yentna field; a whole-coal sample contained 0.34 ppm molybdenum and a coal-ash sample contained 10 ppm molybdenum. Merritt (1987) found a range in molybdenum content of 2 to 175 ppm and an average of 19 ppm in 65 Susitna lowland coal-ash samples.

Nenana province. Rao and Wolff (1981) reported a molybdenum content of 2.5 ppm in a whole-coal sample of the subbituminous C-ranked No. 4 seam from the Nenana basin; an ash sample of the same coal contained 17 ppm molybdenum. Affolter and others (1981) reported a range in molybdenum content of 0.7 to 3 ppm and a geometric mean of 1.5 ppm in 20 Healy Quadrangle whole-coal samples. Merritt (1985a) noted a general factor of enrichment for molybdenum of 17X based on Nenana basin coal-ash samples. Affolter and Stricker (1987) found an average molybdenum content of 0.9 ppm in two whole-coal samples of seam No. 3, Usibelli Mine.

Rao and Wolff (1981) reported molybdenum contents of 11 ppm and 94 ppm in whole-coal and coal-ash samples, respectively, of a subbituminous C-ranked seam from Oher Creek, Jarvis Creek field. They also cited molybdenum contents for the subbituminous C-ranked main seam from the Little Tonzona River field, western Nenana province; a whole-coal sample contained 11 ppm molybdenum and a coal-ash sample contained 79 ppm molybdenum.

Alaska Peninsula province. Conwell and Triplehorn (1978) reported an average molybdenum concentration of 56 ppm in eight Alaska Peninsula coal-ash samples.

PROFILE 41 - NEODYMIUM

Symbol: Nd Atomic number: 60 Atomic weight: 144.24

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	3-40 ppm	N.E.
World	0-50 ppm	N.E.

Neodymium is a metallic rare-earth element. Turekian and Wedepohl (1961) reported the following average neodymium concentrations in common sedimentary rocks: shales, 24 ppm; sandstones, 37 ppm, and carbonates, 4.7 ppm. The average worldwide neodymium content in coal is 4.7 ppm (U.S. National Committee for Geochemistry, 1980).

Sharkey and others (1975) found that neodymium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 4 to 36 ppm. The U.S. National Committee for Geochemistry (1980) found that the average U.S. neodymium content in coal is 37 ppm; in addition, for U.S. subbituminous coals, it averages 50 ppm, and for U.S. lignites, it averages 11 ppm.

Merritt (1985b) reported a mean neodymium concentration of 6 ppm in ash samples of 29 Matanuska Valley coals.

PROFILE 42 - NICKEL

Symbol: Ni Atomic number: 28 Atomic weight: 58.71

	Coal	Ash
Alaska	3-60 ppm	50-300 ppm
U.S.	0.5-110 ppm	0-1,200 ppm
World	0-100 ppm	10-3,000 ppm

Nickel is a hard and ductile ferromagnetic metallic element. It is found in millerite (NiS) and in intimate association with pyrite (FeS_2). Turekian and Wedepohl (1961) reported the following nickel concentrations in common sedimentary rocks: shales, 68 ppm; sandstones, 2 ppm; and carbonates, 20 ppm. Orheim (1979) cited these clarke values for nickel: earth's crust, 75 ppm; soil, 40 ppm; plant ash, 65 ppm; and water, 0.002 ppm.

Nickel generally occurs in coal in appreciably greater concentration that its estimated average concentration in the earth's crust (Averitt, 1975). It is one of the elements associated with both organic and inorganic matter, but is more closely allied with the inorganic, heavier specific gravity fractions of coal (Ruch and others, 1974; Cavallaro and others, 1978).

Nickel is one of the elements of environmental concern in coal. It can be enriched on the surfaces of fly-ash particles released from coal-fired plants (Mraw and others, 1983). Nickel is generally retained in high-temperature ash, and over 95 percent is retained in low-temperature ash (Ruch and others, 1974).

World Coals

Abernethy and Gibson (1963) cited an average nickel concentration in coal of 16 ppm. The U.S. National Committee for Geochemistry (1980) reported a worldwide average nickel content in coal of 15 ppm. Berkowitz (1979) reported a maximum nickel concentration in coal ash of 8,000 gm/ton and an average nickel concentration of 700 gm/ton.

United States Coals

Sharkey and others (1975) found that nickel occurred in 100 percent of 13 U.S. raw coals, and that it ranged in concentration from 3 to 60 ppm. Others have cited a range in nickel content in U.S. coals from 0.4 to 104 ppm (Los Alamos Scientific Laboratory, 1976; Wewerka and others, 1976). Swanson and others (1976) reported an average nickel content of 12.5 ppm in 601 U.S. coals. The U.S. National Committee for Geochemistry (1980) cited an average nickel concentration in coal of 15 ppm. Nickel ranges in content from 0 to 1,200 ppm in ashes of U.S. coals, and exhibits the following average concentrations by rank in coal ashes: anthracites, 220 ppm; low-volatile bituminous coals, 141 ppm; medium-volatile bituminous coals, 263 ppm; high-volatile bituminous coals, 154 ppm; and subbituminous coals and lignites, 129 ppm (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Swanson and others (1976) reported a geometric mean nickel concentration of 15 ppm in 331 Appalachian region whole-coal samples. Los Alamos Scientific Laboratory (1976) reported an average concentration of 14 ppm in 73 Appalachian region coals. Gluskoter and others (1977) found a geometric mean nickel concentration of 14 ppm in 23 Appalachian coals.

Interior region. Swanson and others (1976) reported a geometric mean nickel content of 18 ppm in 194 Interior region whole-coal samples. Los Alamos Scientific Laboratory (1976) reported an average nickel content of 15 ppm in 53 Eastern Interior coals. Gluskoter and others (1977) cited a geometric mean nickel content of 19 ppm in 113 Illinois basin whole-coal samples.

Western region. Swanson and others (1976) reported a geometric mean nickel content of 2 ppm in 93 Western region whole-coal samples and 15 ppm in 34 Texas whole-coal samples. Los Alamos Scientific Laboratory (1976) cited an average nickel content of 14 ppm in 48 Western and Southwestern Interior region whole-coal samples and 7.2 ppm in 51 Northern Great Plains region coals. Gluskoter and others (1977) cited a geometric mean nickel content of 4.4 ppm in 29 Western U.S. coals.

Alaska Coals

There exists an abundant amount of geochemical data relating to nickel concentrations in Alaska coals and coal ashes. Compared to other U.S. coals, the content of nickel in Alaskan coals is generally higher.

Northern Alaska province. Rao (1968) reported an average concentration of 7.3 ppm nickel in 12 Northern Alaska whole-coal samples; ash samples of the same coals contained an average of 80 ppm lead. Conwell and Triplehorn (1976) found an average content of 1,500 ppm in a Kukpuk River coal-ash sample and 70 ppm in a Cape Thompson coal-ash sample. They concluded that the Kukpuk River sample contained anomalously high concentrations of nickel. Rao (1980) analyzed and reported on nickel concentrations in some 38 Cape Beaufort region whole-coal and coal-ash samples. He concluded that although certain of the Cape Beaufort region coals showed high concentrations of nickel, its average concentration was quite low compared to other U.S. coals. In the raw coals, nickel ranged from 2.5 to 23 ppm and had a mean content of 8.1 ppm; in the coal-ash samples, nickel ranged from 10 to 106 ppm and had a mean content of 41 ppm (Rao, 1980). Rao and Wolff (1981) found 4.9 ppm nickel in a whole-coal sample of a subbituminous B seam from the Wainwright field, Northern Alaska; ash of the same coal contained 102 ppm nickel. They reported a whole-coal nickel content of 21 ppm in a subbituminous B seam from Meade River, Northern Alaska; ash of the same coal contained 260 ppm nickel. Additionally, they cited a whole-coal lead content of 33 ppm in a high-volatile bituminous seam from Sagwon Bluffs, Northern Alaska; ash of this coal contained 60 ppm nickel (Rao and Wolff, 1981). Affolter and others (1981) reported a range in nickel concentration of 3 to 30 ppm for 54 Utukok River Quadrangle whole-coal samples and a geometric mean content of 1.7 ppm.

Cook Inlet-Susitna province. Rao (1968) reported an average nickel content of 22.8 ppm in 22 Matanuska Valley whole-coal samples and an average nickel content of 181 ppm in ash samples of the same coals. Rao and Wolff (1981) found a nickel content of 18 ppm in a whole-coal sample of the high-volatile bituminous lower seam, Castle Mountain mine, Matanuska field; an ash sample of the same coal contained 90 ppm nickel. They also reported a nickel content of 58 ppm in a whole-coal sample of a high-volatile bituminous seam from the Premier mine, Matanuska field; an ash sample of this coal contained 200 ppm nickel. Merritt (1985b) found a mean nickel concentration of 7 ppm in 31 Matanuska Valley coal-ash samples.

Rao (1968) reported an average nickel content of 7.3 ppm in eight Kenai field whole-coal samples; ash samples of the same coals contained an average 69 ppm nickel. Rao and Wolff (1981) found a nickel content of 13 ppm in a whole-coal sample of the subbituminous C-ranked Cabin bed, Kenai field; an ash sample of the coal showed 105 ppm nickel. Affolter and others (1981) reported a range in nickel content from 7 to 20 ppm in 10 Kenai Quadrangle whole-coal samples, and a geometric mean nickel content of 10 ppm. Additionally, they cited a range in nickel content from 5 to 20 ppm in 34 Seldovia Quadrangle whole-coal samples, and a geometric mean nickel content of 10 ppm. Merritt and others (1987) cited a mean nickel concentration of 166 ppm in ash samples of 31 Kenai field coals.

Conwell (1977) reported a range in nickel content from 70 to 100 ppm and a mean content of 87 ppm in seven Beluga field coal-ash samples. Rao and Wolff (1981) reported a nickel content of 19 ppm in a whole-coal sample of the subbituminous C-ranked Waterfall seam, Beluga field; and ash sample of the same coal contained 121 ppm nickel. They also reported a nickel content of 5.0 ppm (whole-coal basis) in a Sunflower Creek lignite from the Yentna field; an ash sample of the same coal contained 148 ppm nickel. Merritt (1987a) found a range in nickel content from 39 to 709 ppm and an average content of 162 ppm for ash samples of 45 Susitna lowland coals. Rao and Smith (1987) reported nickel concentrations in five coal seams from the Chuitna district, Beluga field. Average nickel contents decrease downsection as follows: Blue Seam (15 samples), 200 ppm; Red 3 Seam (13 samples), 180 ppm; Red 2 Seam (26 samples), 157 ppm; Red 1 Seam (16 samples), 102 ppm; and Purple Seam (5 samples), 86 ppm.

Rao and Wolff (1981) analyzed a lignite seam from Coal Creek, Broad Pass field. A raw coal sample showed a nickel content of 35 ppm, and a coal-ash sample contained 124 ppm nickel.

Nenana province. Rao (1968) reported an average nickel concentration of 4.8 ppm in 25 Nenana basin whole-coal samples; ash samples of the coals contained an average 51 ppm nickel. Rao and Wolff (1981) analyzed seven samples of five different seams, including the No. 2, No. 4, No. 6 (three splits, top, middle, and lower), Moose, and Caribou seams, all of subbituminous C rank. The whole-coal samples contained an average nickel content of 20 ppm and the coal-ash samples contained an average nickel content of 128 ppm. Affolter and others (1981) cited a range of 5 to 30 ppm nickel in 20 Healy Quadrangle whole-coal samples and a geometric mean nickel content of 10 ppm. Affolter and Stricker (1987) found an average 6.9 ppm nickel in

two whole-coal samples of seam No. 3, Usibelli Mine. Merritt (1985a) reported a general factor of enrichment for nickel of 1.6X based on Nenana basin coal-ash samples.

Rao (1968) reported an average nickel concentration of 2.6 ppm in three Jarvis Creek field whole-coal samples; ash samples of the same coals revealed an average nickel content of 26 ppm. Rao and Wolff (1981) cited a nickel content of 19 ppm in a whole-coal sample of an Ober Creek subbituminous C-ranked seam, Jarvis Creek field; an ash sample contained 145 ppm nickel. Belowich (1987) found an average nickel content of 21 ppm in 27 Jarvis Creek field whole-coal samples.

Rao and Wolff (1981) also analyzed the subbituminous C-ranked main seam of the Little Tonzona River field, western Nenana province. A whole-coal sample contained 25 ppm nickel, and a coal-ash sample contained 175 ppm nickel.

Alaska Peninsula province. Conwell and Triplehorn (1978) cited an average nickel concentration of 37 ppm in eight Alaska Peninsula coal-ash samples.

Gulf of Alaska province. Rao (1968) reported an average nickel content of 3.2 ppm in five Bering River field whole-coal samples and an average 131 ppm nickel in ash samples of the same coals. Smith and Rao (1987) cited an average concentration of 273 ppm nickel in 20 Bering River field coal-ash samples.

Yukon-Koyukuk province. Rao and Wolff (1981) cited a whole-coal nickel concentration of 26 ppm and a coal-ash nickel concentration of 79 ppm in a high-volatile bituminous seam of the Tramway Bar field.

PROFILE 43 - NIOBIUM

Symbol: Nb Atomic number: 41 Atomic weight: 92.906

	Coal	Ash
Alaska	0.5-10 ppm	5-50 ppm
U.S.	5-50 ppm	N.E.
World	N.E.	N.E.

Niobium is a ductile metallic element that occurs chiefly in columbite [$(Fe,Mn)Nb_2O_6$]. Turekian and Wedepohl (1961) reported the following average niobium concentrations in common sedimentary rocks: shales, 11 ppm; sandstones, 0.0X ppm; and carbonates, 0.3 ppm. Orheim (1979) cited these clarke values for niobium: earth's crust, 20 ppm; soil, 15 ppm; and plant ash, 0.3 ppm.

United States Coals

Sharkey and others (1975) found that niobium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 5 to 41 ppm. The U.S. National Committee for Geochemistry (1980) cited an average niobium concentration in 799 U.S. coals of 4.5 ppm. Swanson and others (1976) reported an average niobium content of 2.2 ppm in 601 U.S. coals; they also found that lignites showed a lower average concentration of niobium (2.7 ppm) than subbituminous coals (5.4 ppm). Additionally, they cited the following geometric mean niobium concentrations in whole-coal samples of the U.S. by region: Eastern U.S. (331), 3 ppm; Interior region (194), 0.7 ppm; Western region (93), 3 ppm; and Texas (34), 2 ppm.

Alaska Coals

Compared to other U.S. coals, the content of niobium in Alaska coals is similar.

Northern Alaska province. Conwell and Triplehorn (1976) found niobium contents of 50 ppm in Kukpuk River and Cape Thompson coal-ash samples. Affolter and others (1981) reported a range in niobium content of 0.7 to 10 ppm in 54 Utukok River Quadrangle whole-coal samples and a geometric mean of 0.5 ppm.

Cook Inlet-Susitna province. Merritt (1985b) found a mean niobium content of 9 ppm in 31 Matanuska Valley coal-ash samples. Affolter and others (1981) reported a range in niobium content of <2 to 7 ppm and a geometric mean of 3 ppm in 10 Kenai Quadrangle whole-coal samples. In addition, they found a range of <1.5 to 5 ppm niobium and a geometric mean of 0.7 ppm niobium in 34 Seldovia Quadrangle whole-coal samples. Conwell (1977) reported a range of 20 to 30 ppm niobium and a mean of 23 ppm niobium in seven Beluga field coal-ash samples.

Nenana province. Affolter and others (1981) reported a range of <1.5 to 7 ppm niobium and a geometric mean of 1.5 ppm niobium in 20 Healy Quadrangle whole-coal samples. Affolter and Stricker (1987) found an average niobium content of 1.0 ppm in two whole-coal samples of Seam No. 3, Usibelli Mine.

PROFILE 44 - NITROGEN

Symbol: N Atomic number: 7 Atomic weight: 14.0067

	Coal	Ash
Alaska	5,000-18,000 ppm	- -
U.S.	5,500-18,000 ppm	- -
World	5,000-25,000 ppm	- -

Nitrogen is a nonmetallic element that occurs as an almost inert diatomic gas (N_2); it composes approximately 80 percent of air by volume. It belongs to the organic mineral group of elements in coal (Wewerka and others, 1978).

Nitrogen constitutes part of the ultimate coal analysis. Nitrogen can be considered an impurity of coal along with sulfur, iron, and other inorganics. Gluskoter and others (1977) reported a geometric mean nitrogen content of 1.3 percent in 22 Appalachian region whole-coal samples, 1.3 percent in 110 Illinois basin whole-coal samples, and 0.98 percent in 22 Western U.S. whole-coal samples.

Alaska coals are similar in nitrogen composition to other U.S. coals when considered by rank. For example, a high-volatile A bituminous coal from the Matanuska Valley contains about 1.6 percent nitrogen, whereas Nenana and Beluga subbituminous coals contain 0.6 percent nitrogen (equilibrium bed moisture basis).

PROFILE 45 - OSMIUM

Symbol: Os Atomic number: 76 Atomic weight: 190.2

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	<0.2 ppm	N.E.
World	N.E.	N.E.

Osmium is a hard metallic element found in small quantities in ores of osmiridium, nickel, and platinum. Sharkey and others (1975) found that osmium contents were <0.2 ppm in 13 U.S. raw coals analyzed. Somerville and Elder (1977) reported an osmium content below the 0.1 ppm detection limit in North Dakota lignites.

There is no available data on osmium concentrations in Alaska coals.

PROFILE 46 - OXYGEN

Symbol: O Atomic number: 8 Atomic weight: 15.9994

	Coal	Ash
Alaska	110,000-450,000 ppm	- -
U.S.	40,000-220,000 ppm	- -
World	40,000-480,000 ppm	- -

Oxygen is a gaseous element constituting about 20 percent of the atmosphere by volume. It combines readily with most elements and is required for all combustion processes.

Oxygen forms a part of the ultimate coal analysis. Gluskoter and others (1977) reported a geometric mean nitrogen content of 7.0 percent in 22 Appalachian region whole-coal samples, 8.0 percent in 109 Illinois basin whole-coal samples, and 17.0 percent in 29 Western U.S. whole-coal samples.

High-rank Alaskan coals are similar in oxygen content to other U.S. coals of similar rank. For example, a high-volatile A bituminous coal from the Matanuska Valley contains about 6.1 percent oxygen. Low-rank Alaska coals, as Nenana and Beluga subbituminous coals, contain about 35.0 percent oxygen (equilibrium bed moisture basis), an amount significantly higher than other U.S. coals of similar rank.

PROFILE 47 - PALLADIUM

Symbol: Pa Atomic number: 46 Atomic weight: 106.4

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	<0.1 ppm	N.E.
World	N.E.	N.E.

Palladium is a metallic element occurring naturally with platinum, most commonly in ores of gold, nickel, and copper. It is used as a catalyst in hydrogenation processes. Sharkey and others (1976) found that palladium content was <0.1 ppm in 13 U.S. raw coals analyzed. Somerville and Elder (1977) found that palladium content was below the detection limit of 0.1 ppm in North Dakota lignites.

There is no available data on palladium concentrations in Alaska coals and coal ashes.

PROFILE 48 - PHOSPHORUS

Symbol: P Atomic number: 15 Atomic weight: 30.9738

	Coal	Ash
Alaska	30-2,400 ppm	N.E.
U.S.	5-1,500 ppm	400-3,500 ppm
World	N.E.	N.E.

Phosphorus is a highly reactive, poisonous, nonmetallic element that occurs naturally in phosphate minerals, especially apatite $[Ca_5(PO_4)_3 (F,CO_3)]$ and fluorapatite $[Ca_5(PO_4)_3 (F,OH)]$. Turekian and Wedepohl (1961) reported the following average phosphorus concentrations in common sedimentary rocks: shales, 700 ppm; sandstones, 170 ppm; and carbonates, 400 ppm. Orheim (1979) reported these clarke values for phosphorus: earth's crust, 100 ppm; soil, 40 ppm; plant ash, 65 ppm; and water, 0.07 ppm.

Although it generally occurs in lower concentration than its estimated average concentration in the earth's crust (Averitt, 1975), phosphorus can be a major element in the mineral constituents of coal. Phosphorus is one of the elements associated with both organic and inorganic matter, although it is more closely allied with organic fractions (Ruch and others, 1974).

World Coals

The U.S. National Committee for Geochemistry (1980) cited a worldwide average phosphorus content in coal of 0.05 percent.

United States Coals

Sharkey and others (1975) found that phosphorus occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 6 to 310 ppm. Elsewhere, phosphorus has been reported to range in U.S. coals from 5 to 1,430 ppm and in the ashes of U.S. coals from <440 to 3,360 ppm (Los Alamos Scientific Laboratory, 1976). Gluskoter and others (1977) cited the following geometric mean phosphorus concentrations in U.S. whole-coal samples by region: Appalachian region (23), 81 ppm; Illinois basin (113), 45 ppm; and Western region (29), 82 ppm.

Alaska Coals

Affolter and others (1981) reported geometric mean iron concentrations of 0.003 percent, 0.04 percent, 0.03 percent, and 0.03 percent in whole-coal samples of the Healy (20), Kenai (10), Seldovia (34), and Utukok River (54) Quadrangles, respectively. Merritt (1985b) cited a mean phosphorus content of 319 ppm in six Matanuska Valley coal-ash samples.

PROFILE 49 - PLATINUM

Symbol: Pt Atomic number: 78 Atomic weight: 195.09

	Coal	Ash
Alaska	<0.1 ppm	N.E.
U.S.	<0.3 ppm	N.E.
World	<1 ppm	N.E.

Platinum is a metallic element found worldwide, commonly occurring in ores with other metals as iridium, osmium, and nickel. Platinum does not oxidize in air. Orheim (1979) reported a clarke value for platinum in the earth's crust of 0.005 ppm. Berkowitz (1979) found that platinum's maximum concentration in coal ash was 0.7 gm/ton. Sharkey and others (1975) found that platinum content was <0.3 ppm in 13 U.S. raw coals analyzed. Somerville and Elder (1977) reported that platinum was below the 0.1 ppm detection limit in North Dakota lignites. Conwell and Triplehorn (1976) found the concentration of platinum to be below the detection limit in ash samples of two Northern Alaska coals from Kukpuk River and Cape Thompson.

PROFILE 50 - POTASSIUM

Symbol: K Atomic number: 19 Atomic weight: 39.102

	Coal	Ash
Alaska	100-14,000 ppm	N.E.
U.S.	100-7,000 ppm	6,000-15,000 ppm
World	N.E.	N.E.

Potassium is a highly reactive or explosive element that is mainly contained in the aluminosilicate mineral group. Turekian and Wedepohl (1961) reported the following average potassium concentrations in common sedimentary rocks: shales, 26,600 ppm; sandstones, 10,700 ppm; and carbonates, 2,700 ppm.

Potassium is a major inorganic element in the mineral constituents of coal, and potassium oxide is one of the main constituents of coal ash. Potassium has an important effect on the use of coal in combustion and cokemaking.

World Coals

Abernethy and Gibson (1963) cited an average potassium concentration in coal of 1,540 ppm. The U.S. National Committee for Geochemistry (1980) reported a worldwide average potassium content in coal of 0.01 percent.

United States Coals

Sharkey and others (1975) found that potassium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 300 to 6,500 ppm. Elsewhere, phosphorus has been found to range in concentration in U.S. coals from 0.02 to 0.43 percent (Los Alamos Scientific Laboratory, 1976; Wewerka and others, 1976). Swanson and others (1976) reported an average potassium content of 0.1 percent in 601 U.S. coals. The U.S. National Committee for Geochemistry (1980) cited an average potassium content in U.S. coals of 0.18 percent, and the following average potassium concentrations by rank: anthracites, 0.24 percent; bituminous coals, 0.21 percent; subbituminous coals, 0.06 percent; and lignites, 0.20 percent. Ashes of U.S. coals show a range in potassium content of 0.66 to 1.32 percent (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Swanson and others (1976) reported a geometric mean potassium content of 0.13 percent in 331 Appalachian region whole-coal samples. Gluskoter and others (1977) cited a geometric mean of 0.21 percent potassium in 23 Appalachian region coals.

Interior region. Swanson and others (1976) reported a geometric mean potassium content of 0.11 percent in 194 Interior region whole-coal samples. Gluskoter and others (1977) cited a geometric mean of 0.16 percent potassium in 113 Illinois basin coals.

Western region. Swanson and others (1976) reported a geometric mean potassium content of 0.028 percent in 93 Western region whole-coal samples and 0.15 percent in 34 Texas coals. Gluskoter and others (1977) cited a geometric mean of 0.03 percent potassium in 29 Western U.S. coals.

Alaska Coals

Affolter and others (1981) reported geometric mean potassium concentrations of 0.091 percent, 0.14 percent, 0.16 percent, and 0.07 percent in whole-coal samples of the Healy (20), Kenai (10), Seldovia (34) and Utukok River (54) Quadrangles, respectively. Compared to potassium contents in 410 Powder River region and 295 Rocky Mountain province coal samples, the potassium content of these Alaskan coals is significantly higher. Based on samples of six coal beds from the Tyonek Formation, Beluga field, Affolter and Stricker (1984) found that the concentration of potassium varied directly with the ash content of the coals.

PROFILE 51 - PRASEODYMIUM

Symbol: Pr Atomic number: 59 Atomic weight: 140.907

	Coal	Ash
Alaska	N.E.	<10 ppm
U.S.	1-10 ppm	N.E.
World	0-10 ppm	N.E.

Praseodymium is a rare-earth element. Turekian and Wedepohl (1961) reported the following average praseodymium concentrations in common sedimentary rocks: shales, 5.6 ppm; sandstones, 8.8 ppm; and carbonates, 1.1 ppm. The U.S. National Committee for Geochemistry (1980) cited a worldwide average praseodymium concentration in coal of 2.2 ppm.

Sharkey and others (1975) found that praseodymium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 1 to 8 ppm. The U.S. average praseodymium content in coal is 2.7 ppm; for U.S. subbituminous coals, it is 6.1 ppm, and for U.S. lignites, it is 2.7 ppm (U.S. National Committee for Geochemistry, 1980).

Merritt (1985b) found a mean praseodymium content of 4 ppm in ash samples of 31 Matanuska Valley coals.

PROFILE 52 - RHENIUM

Symbol: Re Atomic number: 75 Atomic weight: 186.2

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	<0.2 ppm	N.E.
World	N.E.	N.E.

Rhenium is a metallic element. Orheim (1979) reported the following clarke values for rhenium: earth's crust, 0.0005 ppm; soil, 0.005 ppm; and plant ash, 0.005 ppm. Sharkey and others (1975) found that rhenium content was <0.2 ppm in 13 U.S. raw coals analyzed. Somerville and Elder (1977) found that rhenium content was below the 0.1 ppm detection limit in North Dakota lignite samples. There is no available data on rhenium concentrations in Alaska coals and coal ashes.

PROFILE 53 - RHODIUM

Symbol: Rh Atomic number: 45 Atomic weight: 102.905

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	<0.1 ppm	N.E.
World	N.E.	N.E.

Rhodium, a metallic element, has been reported to be below the detection limit of 0.1 ppm in North Dakota lignites (Somerville and Elder, 1977). Sharkey and others (1975) found that rhodium content was <0.1 ppm in 13 U.S. raw coals analyzed. There is no available data on rhodium content in Alaska coals.

PROFILE 54 - RUBIDIUM

Symbol: Rb Atomic number: 37 Atomic weight: 85.47

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	0.3-150 ppm	50-1,100 ppm
World	N.E.	N.E.

Rubidium is an alkali element. Turekian and Wedepohl (1961) reported the following average rubidium concentrations in common sedimentary rocks: shales, 140 ppm; sandstones, 60 ppm; and carbonates, 3 ppm. Orheim (1979) reported the following clarke values for rubidium: earth's crust, 90 ppm; soil, 300 ppm; plant ash, 2 ppm; and water, 0.12 ppm.

Abernethy and Gibson (1963) found an average rubidium content of 15.5 ppm in coal. The U.S. National Committee for Geochemistry (1980) reported an average worldwide concentration of 100 ppm rubidium in coal.

Sharkey and others (1975) found that rubidium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 1 to 150 ppm. The U.S. National Committee for Geochemistry (1980) reported an average rubidium content in U.S. coals of 2.90 ppm. Gluskoter and others (1977) reported a geometric mean rubidium content of 19 ppm in 14 Appalachian region whole-coal samples, 17 ppm in 56 Illinois basin whole-coal samples, and 2.4 ppm in 29 Western U.S. whole-coal samples. Los Alamos Scientific Laboratory (1976) cited a rubidium range in concentration of <91 to 1,100 ppm in ashes of U.S. coals.

Merritt (1985b) reported a mean rubidium content of 19 ppm in ash samples of 31 Matanuska Valley coals.

PROFILE 55 - RUTHENIUM

Symbol: Ru Atomic number: 44 Atomic weight: 101.07

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	<0.1 ppm	N.E.
World	N.E.	N.E.

Ruthenium, a metallic element found in platinum ores, was reported to be below the detection limit of 0.1 ppm in North Dakota lignites (Somerville and Elder, 1977). Sharkey and others (1975) found that ruthenium content was <0.1 ppm in 13 U.S. raw coals analyzed. There is no available data on ruthenium concentrations in Alaska coals.

PROFILE 56 - SAMARIUM

Symbol: Sm Atomic number: 62 Atomic weight: 150.35

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	0.2-10 ppm	N.E.
World	0-10 ppm	N.E.

Samarium is a metallic rare-earth element associated with silicate minerals. Turekian and Wedepohl (1961) reported the following average samarium concentrations in sedimentary rocks: shales, 6.4 ppm; sandstones, 10 ppm; and carbonates, 1.3 ppm.

Abernethy and Gibson (1963) found an average samarium content of 1.0 ppm in coal. The U.S. National Committee for Geochemistry (1980) reported an average worldwide concentration of 1.6 ppm samarium in coal.

Sharkey and others (1975) found that samarium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 1 to 6 ppm. Elsewhere, it has been reported that U.S. coals contain an average samarium content of 0.42 ppm; furthermore, a typical U.S. subbituminous coal contains 0.50 ppm samarium, and a typical U.S. lignite contains 0.27 ppm samarium (U.S. National Committee for Geochemistry, 1980). Gluskoter and others (1977) reported a geometric mean samarium content of 2.4 ppm in 14 Appalachian region whole-coal samples, 1.1 ppm samarium in 56 Illinois basin whole-coal samples, and 0.56 ppm samarium in 21 Western U.S. whole-coal samples.

Merritt (1985b) reported a mean samarium concentration of 4.8 ppm in ash samples of 28 Matanuska Valley coals.

PROFILE 57 - SCANDIUM

Symbol: Sc Atomic number: 21 Atomic weight: 44.956

	Coal	Ash
Alaska	0.3-20 ppm	20-200 ppm
U.S.	0-100 ppm	2-160 ppm
World	0-100 ppm	N.E.

Scandium is a metallic element found in various rare minerals, especially silicates. It can be separated as a by-product during the processing of uranium ores. Turekian and Wedepohl (1961) reported the following average scandium concentrations in common sedimentary rocks: shales, 13 ppm; sandstones, 1 ppm; and carbonates, 1 ppm. Scandium generally occurs in coal in appreciably greater concentration than its estimated average concentration in the earth's crust (Averitt, 1975).

World Coals

Abernethy and Gibson (1963) cited an average scandium concentration in coal of 2.2 ppm. The U.S. National Committee for Geochemistry (1980) reported a worldwide average scandium content in coal of 5 ppm.

United States Coals

Sharkey and others (1975) found that scandium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 3 to 30 ppm. Others have cited a range in scandium content in U.S. coals from <10 to 100 ppm (Los Alamos Scientific Laboratory, 1976). Swanson and others (1976) reported an average scandium content of 3.1 ppm in 601 U.S. coals. The U.S. National Committee for Geochemistry (1980) cited an average scandium content in U.S. coals of 3 ppm.

Scandium ranges in content in ashes of U.S. coals from 2 to 155 ppm, and shows average contents by rank as follows: anthracites, 61 ppm; low-volatile bituminous coals, 50 ppm; medium-volatile bituminous coals, 56 ppm; high-volatile bituminous coals, 32 ppm; and subbituminous coals and lignites, 18 ppm (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Swanson and others (1976) reported a geometric mean scandium content of 3 ppm in 331 Appalachian region whole-coal samples. Gluskoter and others (1977) cited a geometric mean scandium content of 4.5 ppm in 14 Appalachian region coals.

Interior region. Swanson and others (1976) reported a geometric mean scandium content of 3 ppm in 194 Interior region whole-coal samples. Gluskoter and others (1977) cited a geometric mean scandium content of 2.5 ppm in 56 Illinois basin coals.

Western region. Swanson and others (1976) reported a geometric mean scandium content of 1.5 ppm in 93 Western region whole-coal samples and 5 ppm in 34 Texas coals. Gluskoter and others (1977) cited a geometric mean scandium content of 1.5 ppm in 22 Western U.S. coals.

Alaska Coals

Compared to other U.S. coals, the content of scandium is higher in Alaskan coals.

Northern Alaska province. Conwell and Triplehorn (1976) found a scandium content of 200 ppm in a Kukpuk River coal-ash sample and 30 ppm in a Cape Thompson coal-ash sample. Affolter and others (1981) reported a range of 0.3 to 20 ppm scandium and a geometric mean scandium content of 2 ppm in 54 Utukok River Quadrangle whole-coal samples.

Cook Inlet-Susitna province. Merritt (1985b) cited a mean scandium content of 23 ppm in 31 Matanuska Valley coal-ash samples. Affolter and others (1981) reported a range of 1 to 7 ppm scandium and a geometric mean of 3 ppm scandium in 10 Kenai Quadrangle whole-coal samples. Additionally, they found a range of 1 to 15 ppm scandium and a geometric mean of 3 ppm scandium in 34 Seldovia Quadrangle whole-coal samples.

Conwell (1977) reported a range in scandium concentration of 30 to 50 ppm and a mean scandium content of 38 ppm in seven Beluga field coal-ash samples. Based on samples of six coal beds from the Tyonek Formation, Beluga field, Affolter and Stricker (1984) found that the concentration of scandium varied directly with the ash content of the coals.

Nenana province. Affolter and others (1981) reported a range of 1.5 to 10 ppm scandium and a geometric mean of 3 ppm scandium in 20 Healy Quadrangle whole-coal samples. Affolter and Stricker (1987) found an average scandium content of 2.2 ppm in two whole-coal samples of Seam No. 3, Usibelli Mine. Merritt (1985a) cited a general factor of enrichment of 1.2X for scandium based on its abundance in Nenana basin coal-ash samples.

Alaska Peninsula province. Conwell and Triplehorn (1978) reported an average scandium concentration of 26 ppm in eight Alaska Peninsula coal-ash samples.

PROFILE 58 - SELENIUM

Symbol: Se Atomic number: 34 Atomic weight: 78.96

	Coal	Ash
Alaska	0.5-11 ppm	N.E.
U.S.	0.1-150 ppm	N.E.
World	N.E.	N.E.

Selenium is a nonmetallic element resembling sulfur in character and associated with the sulfide group of minerals. It is obtained primarily as a by-product of electrolytic copper refining. Turekian and Wedepohl (1961) reported the following average selenium concentrations in common sedimentary rocks: shales, 0.6 ppm; sandstones, 0.05 ppm; and carbonates, 0.08 ppm. Orheim (1979) cited these clarke values for selenium: earth's crust, 0.05 ppm; soil, 0.5 ppm; plant ash, 1.0 ppm; and water, 0.004 ppm.

Selenium generally occurs in coal in appreciably greater concentration than its estimated average concentration in the earth's crust or its clarke value (Averitt, 1975; Gluskoter and others, 1977). It shows a very marked enrichment factor of 82X in coal (U.S. National Committee for Geochemistry, 1980).

Selenium is associated with both organic and inorganic matter, but is more closely allied with inorganic fractions (Ruch and others, 1974). It is one of the elements of environmental concern in coal, and can be enriched on the surfaces of fly-ash particles from coal-fired plants (Mraw and others, 1983). Selenium is presumed to be retained in high-temperature ash, and over 95 percent is retained in low-temperature ash (Ruch and others, 1974).

Abernethy and Gibson (1963) cited a general average selenium concentration in coal of 2.2 ppm.

United States Coals

Sharkey and others (1975) found that selenium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 0.04 to 0.3 ppm. Others have cited a range of 0.4 to 8 ppm selenium for U.S. coals (Los Alamos Scientific Laboratory, 1976; Wewerka and others, 1976). Swanson and others (1976) found an average selenium concentration of 3.1 ppm in 601 U.S. whole-coal samples.

Appalachian region. Swanson and others (1976) reported a geometric mean selenium content of 3.5 ppm in 331 Eastern U.S. whole-coal samples. Gluskoter and others (1977) cited a geometric mean of 3.4 ppm selenium in 23 Appalachian coals.

Interior region. Swanson and others (1976) reported a geometric mean selenium content of 2.8 ppm in 194 Interior region whole-coal samples. Gluskoter and others (1977) cited a geometric mean of 2.0 ppm selenium in 113 Illinois basin coals.

Western region. Swanson and others (1976) reported a geometric mean selenium content of 0.5 ppm in 93 Western U.S. whole-coal samples and 5.8 ppm in 34 Texas coals. Gluskoter and others (1977) cited a geometric mean of 1 to 3 ppm selenium in 29 Western U.S. coals.

Alaska Coals

Compared to other U.S. coals, the content of selenium is low in Alaska coals.

Northern Alaska province. Conwell and Triplehorn (1978) reported a selenium content of 1.4 ppm in a Kukpuk River coal-ash sample and 1.8 ppm in a Cape Thompson coal-ash sample. Affolter and others (1981) cited a range in selenium concentration of 0.1 to 1.2 ppm and a geometric mean of 0.3 ppm in 54 Utukok River Quadrangle whole-coal samples.

Cook Inlet-Susitna province. Merritt (1985b) found a mean of 4 ppm selenium in 23 Matanuska Valley coal-ash samples. Affolter and others (1981) reported a range in selenium content of <0.1 to 0.3 ppm and a geometric mean of 0.1 ppm in 10 Kenai Quadrangle whole-coal samples. In addition, they reported a range of 0.1 to 2.1 ppm selenium and a geometric mean of 0.4 ppm selenium in 34 Seldovia Quadrangle coals. Conwell (1977) found a range of <0.1 to 0.4 ppm selenium and a mean of <0.2 ppm selenium in seven Beluga field raw coal samples.

Nenana province. Affolter and others (1981) reported a range of 0.3 to 11 ppm selenium and a geometric mean of 8 ppm selenium in 20 Healy Quadrangle whole-coal samples. Affolter and Stricker (1987) found an average selenium content of 0.8 ppm in two whole-coal samples of Seam No. 3, Usibelli Mine.

Alaska Peninsula province. Conwell and Triplehorn (1978) reported an average selenium concentration of 0.6 ppm in eight Alaska Peninsula raw coal samples.

PROFILE 59 - SILICON

Symbol: Si Atomic number: 14 Atomic weight: 28.086

	Coal	Ash
Alaska	500-110,000 ppm	N.E.
U.S.	3,500-70,000 ppm	90,000-300,000 ppm
World	0-100,000 ppm	N.E.

Silicon is a nonmetallic element that occurs extensively in the earth's crust and contained mainly in silicate and aluminosilicate minerals. Silicon dioxide (SiO_2) or quartz is one of the main constituents of coal ash, and silicon is one of the major inorganic elements in coal. It has an important effect on the use of coal in combustion and cokemaking. Turekian and Wedepohl (1961) reported the following average silicon concentrations in common sedimentary rocks: shales, 73,000 ppm; sandstones, 368,000 ppm; and carbonates, 24,000 ppm.

World Coals

Abernethy and Gibson (1963) cited an average silicon concentration in coal of 23,100 ppm. The U.S. National Committee for Geochemistry (1980) reported a worldwide average silicon content in coal of 2.8 percent.

United States Coals

Sharkey and others (1975) found that silicon occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 5,000 to 41,000 ppm. Others have cited a range in silicon content from 0.58 to 6.09 percent (Los Alamos Scientific Laboratory, 1976; Wewerka and others, 1976). Swanson and others (1976) reported an average U.S. silicon concentration in 601 U.S. coals of 2.0 percent. The U.S. National Committee for Geochemistry (1980) listed an average silicon content in U.S. coals of 2.6 percent. Silicon has been found to range in content from 9.3 to 28 percent in the ashes of U.S. coals.

Appalachian region. Swanson and others (1976) reported a geometric mean silicon concentration of 1.2 percent in 331 Eastern U.S. whole-coal samples. Gluskoter and others (1977) cited a geometric mean silicon content of 2.6 percent in 23 Appalachian region coals.

Interior region. Swanson and others (1976) reported a geometric mean silicon content of 1.4 percent in 194 Interior region whole-coal samples. Gluskoter and others (1977) cited a geometric mean silicon content of 2.3 percent in 113 Illinois basin coals.

Western region. Swanson and others (1976) reported a geometric mean silicon content of 1.1 percent in 93 Western region coals and 4.2 percent in 34 Texas coals. Gluskoter and others (1977) cited a geometric mean silicon content of 1.3 percent in 29 Western U.S. Coals.

Alaska Coals

Affolter and others (1981) reported geometric mean silicon concentrations of 1.8 percent, 2.4 percent, 2.1 percent, and 0.93 percent in whole-coal samples of the Healy (20), Kenai (10), Seldovia (34), and Utukok River (54) Quadrangles, respectively. Compared to the silicon content in 410 Powder River region coal samples, the silicon content of the Healy, Kenai, and Seldovia subbituminous coals is significantly higher. Compared to the silicon content of 295 Rocky Mountain province coal samples, the silicon content of the Utukok River Quadrangle bituminous coals is significantly lower. Based on samples of six coal beds from the Tyonek Formation, Beluga field, Affolter and Stricker (1984) found that the concentration of silicon varied directly with the ash content of the coals.

PROFILE 60 - SILVER

Symbol: Ag Atomic number: 47 Atomic weight: 107.870

	Coal	Ash
Alaska	0.05-0.5 ppm	1-3 ppm
U.S.	<0.01-3 ppm	<1-90 ppm
World	N.E.	N.E.

Silver is a metallic element with the highest thermal and electrical conductivity of the metals. It occurs uncombined and in ores such as argentite (Ag_2S), and may also occur as a component of the mineral galena in coal. Turekian and Wedepohl (1961) reported the following average silver concentrations in common sedimentary rocks: shales, 0.07 ppm; sandstones, 0.0X ppm; and carbonates, 0.0X ppm. Orheim (1979) cited these clarke values for silver: earth's crust, 0.07 ppm; soil, 1.0 ppm; plant ash, 1 ppm; and water, 0.0003 ppm.

World Coals

Silver generally occurs in coal in appreciably greater concentration than its estimated average concentration in the earth's crust (Averitt, 1975). The U.S. National Committee for Geochemistry (1980) cited a worldwide average silver content in coal of 0.50 ppm. Berkowitz (1979) cited maximum silver concentrations in coal ash of 10 gm/ton, and an average concentration of 2 gm/ton.

United States Coals

Sharkey and others (1975) found that silver occurred in 92 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from <0.01 to 3 ppm. The U.S. National Committee for Geochemistry (1980) cited an average U.S. silver content in coal of 0.20 ppm.

Gluskoter and others (1977) reported the following geometric mean silver concentrations in U.S. whole-coal samples by region: Appalachian region (13), 0.02 ppm, Illinois basin (37), 0.03 ppm, and Western U.S. (22), 0.02 ppm. Silver exhibits a range in the ashes of U.S. coals of <1 to 84 ppm, and has a mean value <1 ppm in all ranks of coal (Los Alamos Scientific Laboratory, 1976).

Alaska Coals

There exists abundant data concerning silver concentrations in Alaska coals and coal ashes.

Northern Alaska province. Conwell and Triplehorn (1976) analyzed two coal-ash samples from Kukpuk River and Cape Thompson, Northern Alaska for silver concentration, but it was undetected in both of the samples. Rao (1980) found a range of <1 to 7.8 ppm silver and a mean of <1.4 ppm silver in 38 Cape Beaufort region raw coal samples. In addition, he reported a range

of <2 to 17 ppm silver and a mean of <4 ppm silver in ash samples of the same coals. Rao (1980) stated that the concentration of silver was <2 ppm in the majority of the Cape Beaufort region coal ashes. Rao and Wolff (1981) analyzed subbituminous B-ranked coals from Wainwright and Meade River areas, Northern Alaska and a high-volatile bituminous coal from Sagwon Bluffs and found no detectable silver in any of the samples.

Cook Inlet-Susitna province. Rao and Wolff (1981) reported that silver was not detected in high-volatile bituminous coals from the Castle Mountain and Premier Mines, Matanuska Valley. Merritt (1985b) found silver to be present in only one of 31 samples analyzed from ash samples of Matanuska Valley coals; it contained 0.6 ppm silver. Rao and Wolff (1981) did not find detectable silver in either raw coal or coal ash samples of the subbituminous C-ranked Cabin bed, Kenai field. Additionally, they reported that silver was not detected in coal and ash samples of the subbituminous C Waterfall bed, Beluga field, but did occur in the Sunflower Creek lignite seam from the Yentna field. A raw coal sample of the lignite bed contained 0.06 ppm silver and a coal-ash sample contained 1.4 ppm silver. A Broad Pass field lignite from Coal Creek also did not show detectable silver in raw-coal and coal-ash samples (Rao and Wolff, 1981).

Nenana province, Silver was not detected in raw coals or coal ashes of four Nenana basin subbituminous C seams---No. 2, No. 4, No. 6 (including three splits, top, middle, and lower), and Moose seams (Rao and Wolff, 1981). However, the Caribou Seam showed 1.3 ppm silver in coal ashes and 0.16 ppm in the raw coal. Affolter and others (1981) reported a range of 0.07 to 0.3 ppm silver and a geometric mean of 0.06 ppm silver in 20 Healy Quadrangle whole-coal samples. Two whole-coal samples of Seam No. 3, Usibelli Mine, showed a silver content of 0.036 ppm (Affolter and Stricker, 1987). Merritt (1985a) noted a general factor of enrichment of 13X for silver based on its abundance in Nenana basin coal-ash samples.

A subbituminous C seam from Ober Creek, Jarvis Creek field showed 1.5 ppm silver in coal ashes and 0.17 ppm silver in a raw-coal sample. The subbituminous C main seam at Little Tonzona River, western Nenana province, showed 2.9 ppm silver in a coal-ash sample and 0.40 ppm in a raw-coal sample (Rao and Wolff, 1981).

Yukon-Koyukuk province. Silver was not detected in coal-ash or raw-coal samples of the high-volatile bituminous main seam from the Tramway Bar field, upper Koyukuk basin.

PROFILE 61 - SODIUM

Symbol: Na Atomic number: 11 Atomic weight: 22.9898

	Coal	Ash
Alaska	<100-7,000 ppm	N.E.
U.S.	100-6,000 ppm	5,000-30,000 ppm
World	0-10,000 ppm	N.E.

Sodium is a metallic element that is naturally abundant in combined forms, especially as common salt. It is contained mainly in silicate and aluminosilicate minerals. Turekian and Wedepohl (1961) reported the following sodium concentrations in common sedimentary rocks: shales, 9,600 ppm; sandstones, 3,300 ppm; and carbonates, 400 ppm.

Sodium is one of the major inorganic elements in the mineral constituents of coal. Sodium oxide is one of the important constituents of coal ash. Sodium has an important effect on the use of coal in combustion and cokemaking.

World Coals

Abernethy and Gibson (1963) cited a general sodium concentration in coal of 696 ppm. The U.S. National Committee for Geochemistry (1980) reported a worldwide average sodium concentration in coal of 0.02 percent.

United States Coals

Sharkey and others (1975) found that sodium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 100 to 1,000 ppm. Others have cited a range in sodium content in U.S. coals from 0 to 0.20 percent (Los Alamos Scientific Laboratory, 1976; Wewerka and others, 1976). Swanson and others (1976) found an average sodium concentration of 0.04 percent in 601 U.S. coals. The U.S. National Committee for Geochemistry (1980) reported an average sodium content in U.S. coals of 0.06 percent. Sodium content ranges from 0.71 to 2.72 percent in the ashes of U.S. coals (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Swanson and others (1976) reported a geometric mean sodium concentration of 0.025 percent in 331 Eastern U.S. whole-coal samples. Gluskoter and others (1977) cited a geometric mean sodium content of 0.03 percent in 23 Appalachian coals.

Interior region. Swanson and others (1976) reported a geometric mean sodium concentration of 0.026 percent in 194 Interior region whole-coal samples. Gluskoter and others (1977) cited a geometric mean sodium content of 0.03 percent in 113 Illinois basin coals.

Western region. Swanson and others (1976) reported a geometric mean sodium concentration of 0.1 percent in 93 Western region whole-coal samples and 0.009 percent in 34 Texas coals. Gluskoter and others (1977) cited a geometric mean sodium content of 0.06 percent in 29 Western U.S. coals.

Alaska Coals

Conwell and Triplehorn (1976) cited a sodium content of 500 ppm in an ash sample from a Kukpuk River, Northern Alaska coal. Affolter and others (1981) reported geometric mean sodium concentrations of 0.012 percent, 0.21 percent, 0.10 percent, and 0.087 percent in whole-coal samples of the Healy (20), Kenai (10), Seldovia (34), and Utukok River (34) Quadrangles, respectively. Compared with 410 Powder River region coal samples, the Healy Quadrangle coals are significantly lower in sodium, and coals of the Kenai and Seldovia Quadrangles are significantly higher in sodium. Compared to 295 Rocky Mountain province coals, the Utukok River Quadrangle coals are significantly higher in sodium.

PROFILE 62 - STRONTIUM

Symbol: Sr Atomic number: 38 Atomic weight: 87.62

	Coal	Ash
Alaska	<100-2,000 ppm	<500 ppm
U.S.	0-1,000 ppm	<100-10,000 ppm
World	0-2,000 ppm	N.E.

Strontium is an easily oxidizable metallic element that is associated with the hydrous aluminum phosphates of the goyazite group. Turekian and Wedepohl (1961) reported the following average strontium concentrations in common sedimentary rocks: shales, 300 ppm; sandstones, 20 ppm; and carbonates, 610 ppm. Orheim (1979) cited these clarke values for strontium: earth's crust, 375 ppm; soil, 300 ppm; plant ash, 30 ppm; and water, 8 ppm.

Strontium occurs in coal in appreciably greater concentration than its estimated average concentration in the earth's crust (Averitt, 1961). It results chiefly from the remaining constituents of original plant cells, but secondary amounts appear to result from enrichment by circulating groundwater (Averitt, 1961).

World Coals

Abernethy and Gibson (1963) cited an average strontium content in coal of 23 ppm. The U.S. National Committee for Geochemistry (1980) reported a worldwide average strontium concentration of 500 ppm.

United States Coals

Sharkey and others (1975) found that strontium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 17 to 1,000 ppm. Swanson and others (1976) reported an average strontium content of 112.5 ppm in 601 U.S. coals. The U.S. National Committee for Geochemistry (1980) noted an average strontium content in U.S. coals of 100 ppm.

Strontium ranges from 0.009 to 0.96 percent in ashes of U.S. coals, and occurs in the following average concentrations by rank: anthracites, 177 ppm; low-volatile bituminous coals, 818 ppm; medium-volatile bituminous coals, 668 ppm; high-volatile bituminous coals, 1,987 ppm; and subbituminous coals and lignites, 4,660 ppm (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Swanson and others (1976) reported a geometric mean strontium content of 70 ppm in 331 Eastern U.S. whole-coal samples. Gluskoter and others (1977) cited a geometric mean strontium content of 100 ppm in 14 Appalachian coals.

Interior region. Swanson and others (1976) reported a geometric mean strontium content of 30 ppm in 194 Interior region whole-coal samples. Gluskoter and others (1977) cited a geometric mean strontium content of 30 ppm in 56 Illinois basin coals.

Western region. Swanson and others (1976) reported a geometric mean strontium content of 100 ppm in 93 Western region whole-coal samples and 150 ppm in 34 Texas coals. Gluskoter and others (1977) cited a geometric mean strontium content of 220 ppm in 22 Western U.S. coals.

Alaska Coals

Northern Alaska province. Conwell and Triplehorn (1976) found a strontium content of 2,000 ppm in a Kukpuk River coal-ash sample, and 200 ppm in a Cape Thompson coal-ash sample. Affolter and others (1981) reported a range in strontium content of 30 to 2,000 ppm and a geometric mean of 150 ppm in 54 Utukok River Quadrangle whole-coal samples.

Cook Inlet-Susitna province. Merritt (1985b) cited a mean strontium concentration of 199 ppm in 29 Matanuska Valley coal-ash samples. Affolter and others (1981) reported a range in strontium content of 50 to 300 ppm and a geometric mean of 100 ppm strontium in 10 Kenai Quadrangle whole-coal samples. Additionally, they reported a range of 100 to 500 ppm strontium and a geometric mean of 200 ppm strontium in 34 Seldovia Quadrangle whole-coal samples. Merritt and others (1987) reported an average strontium content of 1,472 ppm in 31 coal-ash samples from the Kenai field.

Conwell (1977) listed a range of 700 to 1,500 ppm strontium and a geometric mean of 1,170 ppm strontium in seven Beluga field coal-ash samples. Rao and Smith (1987) analyzed strontium concentrations in coal-ash samples of five seams from the Chuitna district, Beluga field. They reported average strontium contents in multiple samples of the seams going downsection, as follows: Blue Seam (15 samples), 2,850 ppm; Red 3 Seam (13 samples), 3,092 ppm; Red 2 Seam (26 samples), 1,756 ppm; Red 1 Seam (16 samples), 2,778 ppm; and Purple Seam (5 samples), 2,078 ppm.

Nenana province. Affolter and others (1981) reported a range in strontium content of 70 to 200 ppm and a geometric mean of 100 ppm in 20 Healy Quadrangle whole-coal samples. Affolter and Stricker (1987) found an average strontium content of 295 ppm in two whole-coal samples of Seam No. 3, Usibelli Mine. Belowich (1987) cited an average strontium concentration of 120 ppm in 27 Jarvis Creek field whole-coal samples.

Alaska Peninsula province. Conwell and Triplehorn (1978) reported an average strontium concentration of 431 ppm in eight Alaska Peninsula coal-ash samples.

Gulf of Alaska province. Smith and Rao (1987) reported an average strontium concentration of 4,007 ppm in 20 Bering River field coal-ash samples.

PROFILE 63 - SULFUR

Symbol: S Atomic number: 16 Atomic weight: 32.064

	Coal	Ash
Alaska	1,000-13,000 ppm	- -
U.S.	3,000-55,000 ppm	- -
World	3,000-60,000 ppm	- -

Sulfur is a nonmetallic element that occurs widely in nature in both free and combined forms. It is most typically associated with the sulfide mineral group. Turekian and Wedepohl (1961) reported the following average sulfur concentrations in common sedimentary rocks: shales, 2,400 ppm; sandstones, 240 ppm; and carbonates, 1,200 ppm.

Sulfur is one of the major elements in the mineral constituents of coal, and sulfur trioxide is one of the major constituents of coal ash. Sulfur forms a part of the ultimate coal analysis, and it is one of the elements of chief environmental concern in coal. Sulfur has an important effect on the use of coal in combustion and cokemaking.

The average worldwide and U.S. sulfur content in coal is 2.0 percent (U.S. National Committee for Geochemistry, 1980). Sharkey and others (1975) found that sulfur occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 700 to 10,000 ppm. Gluskoter and others (1977) reported a geometric mean sulfur content of 1.9 percent in 23 Appalachian region whole-coal samples, 3.4 percent in 113 Illinois basin whole-coal samples, and 0.70 percent in 29 Western U.S. whole-coal samples.

Alaskan coals are generally significantly lower in sulfur content than other U.S. coals (Merritt, 1987b). Affolter and Stricker (1984) found that those trace elements that normally show a positive correlation with sulfur in most U.S. coals, such as Fe, As, Cd, Co, Mo, Ni, Pb, and Zn are low in concentration in coals of the Beluga field, southcentral Alaska.

PROFILE 64 - TANTALUM

Symbol: Ta Atomic number: 73 Atomic weight: 180.948

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	<0.1-10 ppm	N.E.
World	N.E.	N.E.

Tantalum, a metallic element, has been found to have an average concentration in coal of 0.11 ppm (Abernethy and Gibson, 1963). Sharkey and others (1975) found that tantalum occurred in 62 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from <0.1 to 8 ppm. Gluskoter and others (1977) reported a geometric mean tantalum content of 0.26 ppm in 14 Appalachian region whole-coal samples, 0.14 ppm tantalum in 56 Illinois basin whole-coal samples, and 0.12 ppm tantalum in 22 Western U.S. whole-coal samples. Wewerka and others (1979) cited a range in tantalum concentration in ashes of Illinois basin coals of 0.3 to 1.0 ppm and a mean tantalum concentration of 0.7 ppm.

There is no available data on tantalum concentrations in Alaska coals.

PROFILE 65 - TELLURIUM

Symbol: Te Atomic number: 52 Atomic weight: 127.60

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	<0.1-0.5 ppm	N.E.
World	N.E.	N.E.

Tellurium is a metallic element that occurs naturally combined with gold and other metals. It is a by-product of electrolytic refining of copper. Tellurium generally occurs in coal in lower concentration than its estimated average concentration in the earth's crust (Averitt, 1975).

Sharkey and others (1975) found that tellurium occurred in 85 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from <0.1 to 0.4 ppm. The average U.S. tellurium content in coal is 0.1 ppm (U.S. National Committee for Geochemistry, 1980). Somerville and Elder (1977) cited an average tellurium concentration in North Dakota lignites of 0.27 ppm.

Conwell and Triplehorn (1976) found tellurium content in two Northern Alaska coals from Kukpuk River and Cape Thompson to be below the detection limit. Merritt (1985b) reported a mean tellurium content of 1.7 ppm in ash samples of 26 Matanuska Valley coals.

PROFILE 66 - TERBIUM

Symbol: Tb Atomic number: 65 Atomic weight: 158.924

	Coal	Ash
Alaska	N.E.	<1 ppm
U.S.	0.04-3 ppm	N.E.
World	N.E.	N.E.

Terbium is a metallic rare-earth element. Turekian and Wedepohl (1961) reported the following average terbium concentrations in common sedimentary rocks: shales, 1.0 ppm; sandstones, 1.6 ppm; and carbonates, 0.2 ppm.

The average worldwide terbium content in coal is 0.3 ppm (U.S. National Committee for Geochemistry, 1980). Sharkey and others (1975) found that terbium occurred in 85 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from <0.1 to 2 ppm. The average U.S. terbium content in coal is 0.1 ppm; for U.S. subbituminous coals, it averages 0.1 ppm, and for U.S. lignites, it averages 0.1 ppm (U.S. National Committee for Geochemistry, 1980).

Gluskoter and others (1977) reported a geometric mean terbium content of 0.28 ppm in 14 Appalachian region whole-coal samples, 0.18 ppm terbium in 41 Illinois basin whole-coal samples, and 0.17 ppm in 18 Western U.S. whole-coal samples.

Terbium content was reported to be below the detection limit in all but one of 31 Matanuska Valley coal-ash samples analyzed; that sample contained 0.4 ppm terbium (Merritt, 1985b).

PROFILE 67 - THALLIUM

Symbol: Tl Atomic number: 81 Atomic weight: 204.37

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	<0.1-0.5 ppm	N.E.
World	N.E.	<5 ppm

Thallium is a highly toxic metallic element. It generally occurs in coal in lower concentration than its estimated average concentration in the earth's crust (Averitt, 1975). Thallium can be enriched on the surfaces of fly-ash particles from coal-fired plants (Mraw and others, 1983). Berkowitz (1979) reported a maximum concentration of thallium in coal ash of 5 gm/ton. Turekian and Wedepohl (1961) reported the following average thallium contents in common sedimentary rocks: shales, 1.4 ppm, sandstones, 0.82 ppm, and carbonates 0.0X ppm.

Sharkey and others (1975) found that thallium occurred in 31 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from <0.1 to 0.3 ppm. The U.S. National Committee for Geochemistry (1980) cited an average U.S. thallium concentration in coal of 0.1 ppm. Gluskoter and others (1977) found a geometric mean thallium content of 0.59 ppm in 25 Illinois basin whole-coal samples. There is no available data on thallium concentrations in Alaska coals.

PROFILE 68 - THORIUM

Symbol: Th Atomic number: 90 Atomic weight: 232.038

	Coal	Ash
Alaska	0.3-18 ppm	N.E.
U.S.	<0.1-10 ppm	N.E.
World	0-10 ppm	N.E.

Thorium is a metallic element with many isotopes, but only Th 232 occurs naturally. Thorium is found in association with various silicate minerals. Turekian and Wedepohl (1961) reported the following average thorium concentrations in common sedimentary rocks: shales, 12 ppm; sandstones, 1.7 ppm; and carbonates, 1.7 ppm. Abernethy and Gibson (1963) cited an average thorium concentration in coal of 2.1 ppm.

United States Coals

Sharkey and others (1975) found that thorium occurred in 92 percent of 13 U.S. raw coals analyzed and that it ranged in concentration from <0.1 to 5 ppm. Swanson and others (1976) found an average thorium content in 601 U.S. coals of 2.4 ppm. The U.S. National Committee for Geochemistry (1980) reported an average thorium concentration in U.S. coals of 1.9 ppm.

Appalachian region. Swanson and others (1976) reported a geometric mean thorium content of 2.8 ppm in 331 Appalachian region whole-coal samples. Gluskoter and others (1977) cited a geometric mean thorium content of 4.0 ppm in 14 Appalachian region coals.

Interior region. Swanson and others (1976) reported a geometric mean thorium content of 1.6 ppm in 194 Interior region whole-coal samples. Gluskoter and others (1977) cited a geometric mean thorium content of 1.9 ppm in 56 Illinois basin coals.

Western region. Swanson and others (1976) reported a geometric mean thorium content of 2.4 ppm in 93 Western whole-coal samples and 3 ppm in 34 Texas coals. Gluskoter and others (1977) cited a geometric mean thorium content of 1.8 ppm in 22 Western U.S. coals.

Alaska Coals

Northern Alaska province. Conwell and Triplehorn (1976) found an average concentration of 4.8 ppm thorium in a Cape Thompson, Northern Alaska raw coal sample. Affolter and others (1981) reported a range in thorium content of 0.3 to 15 ppm and a geometric mean of 1.6 ppm in 54 Utukok River Quadrangle whole-coal samples.

Cook Inlet-Susitna province. Merritt (1985b) cited a mean thorium concentration of 8.8 ppm in 26 Matanuska Valley coal-ash samples. Affolter and others (1981) reported a range in thorium content of 1.9 to 6.9 ppm and a geometric mean of 2.2 ppm thorium in 34 Seldovia Quadrangle whole-coal

samples. Conwell (1977) found a range of <3.0 to 5.9 ppm thorium and a mean of <3.8 ppm in seven Beluga field raw coal samples. Based on samples of six coal beds from the Tyonek Formation, Beluga field, Affolter and Stricker (1984) found that the concentration of thorium varied directly with the ash content of the coals.

Nenana province. Affolter and others (1981) reported a range in thorium content of 0.7 to 18 ppm and a geometric mean of 2.5 ppm in 20 Healy Quadrangle whole-coal samples. Affolter and Stricker (1987) cited an average thorium content of 0.6 ppm in two whole-coal samples of Seam No. 3, Usibelli Mine.

Alaska Peninsula province. Conwell and Triplehorn (1978) reported an average thorium concentration of <3.4 ppm in eight Alaska Peninsula raw coal samples.

PROFILE 69 - THULIUM

Symbol: Tm Atomic number: 69 Atomic weight: 168.934

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	<0.1 ppm	N.E.
World	N.E.	N.E.

Thulium is a rare-earth element with isotope mass numbers ranging from 161 to 176. Turekian and Wedepohl (1961) reported the following average thulium contents in common sedimentary rocks: shales, 0.2 ppm; sandstones, 0.3 ppm; and carbonates, 0.04 ppm.

Sharkey and others (1975) found that thulium content was <0.1 ppm in 13 U.S. raw coals analyzed. The U.S. average thulium concentration in coal is 0.07 ppm; for U.S. subbituminous coals, it averages 0.07 ppm, and for U.S. lignites, it averages 0.07 ppm (U.S. National Committee for Geochemistry, 1980).

There is no available data on thulium concentrations in Alaska coals.

PROFILE 70 - TIN

Symbol: Sn Atomic number: 50 Atomic weight: 118.69

	Coal	Ash
Alaska	0.5-10 ppm	10-50 ppm
U.S.	<0.01-5 ppm	0-5,000 ppm
World	N.E.	N.E.

Tin is a metallic element obtained chiefly from cassiterite (SnO_2). Turekian and Wedepohl (1961) reported the following average tin concentrations in common sedimentary rocks: shales, 6.0 ppm; sandstones, 0.X ppm; and carbonates, 0.X ppm. Orheim (1979) cited these clarke values for tin: earth's crust, 32 ppm; soil, 10 ppm; plant ash, 1.0 ppm.

Tin generally occurs in coal in appreciably greater concentration than its estimated average concentration in the earth's crust (Averitt, 1975). Tin is generally retained in high-temperature ash (Ruch and others, 1974). Berkowitz (1979) reported a maximum tin concentration in coal ash of 500 gm/ton and an average concentration of 200 gm/ton.

United States Coals

Sharkey and others (1975) found that tin occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 1 to 47 ppm. Valkovic (1983) reported a range in U.S. coals of 0 to 51 ppm tin. The U.S. National Committee for Geochemistry (1980) cited a U.S. average concentration in coal of 1.6 ppm tin. Tin has been found to range from 0 to 4,250 ppm in ashes of U.S. coals and shows the following average concentrations by rank: anthracites, 962 ppm; low-volatile bituminous coals, 92 ppm; medium-volatile bituminous coals, 75 ppm; high-volatile bituminous coals, 171 ppm; subbituminous coals and lignites, 156 ppm (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Los Alamos Scientific Laboratory (1976) reported an average concentration of 0.4 ppm tin in 73 Appalachian region whole-coal samples. Gluskoter and others (1977) cited a geometric mean of 0.97 ppm tin in 19 Appalachian coals.

Interior region. Los Alamos Scientific Laboratory (1976) reported an average concentration of 1.5 ppm tin in 53 Eastern Interior whole-coal samples. Gluskoter and others (1977) cited a geometric mean tin concentration of 0.94 ppm in 60 Illinois basin coals.

Western region. Los Alamos Scientific Laboratory (1976) reported an average concentration of 1.3 ppm tin in 48 Western and Southwestern Interior region whole-coal samples and 0.9 ppm in 51 Northern Great Plains region coals. Gluskoter and others (1977) cited a geometric mean tin concentration of 0.43 ppm in 26 Western U.S. coals.

Alaska Coals

Northern Alaska province. Rao (1980) reported that several Cape Beaufort region samples showed abnormally high concentrations of tin, but he made no investigation to determine the mode of occurrence of tin in these samples. In 38 raw coal samples, he found a range in tin content from 2.6 to 570 ppm and a mean content <40 ppm. In ash samples of the same coals, he cited a range in tin content of <10 to 4,600 ppm and a mean of <297 ppm.

Cook Inlet-Susitna province. Merritt (1985b) reported a mean tin content of 5 ppm in 29 Matanuska Valley coal-ash samples. Rao (1968) cited an average tin concentration of 0.8 ppm in eight Kenai field raw coal samples and 8.4 ppm tin in ash samples of the same coals. Rao and Wolff (1981) analyzed tin contents in coal samples of upper and lower benches of a Sunflower Creek seam from the Yentna field. Average raw-coal tin content in this lignite was 1.6 ppm, and ash samples contained an average tin content of 38 ppm. A Coal Creek, Broad Pass field, lignite contained 5.3 ppm tin in a raw-coal sample and 27 ppm tin in a coal-ash sample (Rao and Wolff, 1981).

Nenana province. Rao (1968) reported an average tin concentration of 2.4 ppm in 25 Nenana basin raw-coal samples and 29.6 ppm tin in ash samples of the same coals. Rao and Wolff (1981) found 5.4 ppm tin in a raw-coal sample of the lower bench, No. 6 seam, Nenana basin. Ash of this subbituminous C-ranked coal contained 39 ppm tin. An average tin concentration of 1.2 ppm has been reported for three raw-coal samples of the Jarvis Creek field (Rao, 1968); ash samples of these coals contained an average 12.3 ppm tin.

Yukon-Koyukuk province. Rao and Wolff (1981) reported tin concentrations in the high-volatile bituminous main seam from the Tramway Bar field. A raw-coal sample contained 9.9 ppm tin and a coal-ash sample contained 26 ppm tin.

PROFILE 71 - TITANIUM

Symbol: Ti Atomic number: 22 Atomic weight: 47.90

	Coal	Ash
Alaska	100-5,500 ppm	<10,000 ppm
U.S.	<100-4,000 ppm	1,000-30,000 ppm
World	<10,000 ppm	N.E.

Titanium is a metallic element that occurs widely in igneous rocks. It is particularly associated with the minerals rutile (TiO_2) and anatase (TiO_2) and also with various silicate minerals. Turekian and Wedepohl (1961) reported the following average titanium concentrations in common sedimentary rocks: shales, 4,600 ppm; sandstones, 1,500 ppm; and carbonates, 400 ppm. Orheim (1979) cited these clarke values for titanium: earth's crust, 5,700 ppm; soil, 5,000 ppm; plant ash, 2 ppm; and water, 0.001 ppm.

Titanium is one of the major inorganic elements in the mineral constituents of coal. It generally occurs in coal in lower concentration than its estimated average concentration in the earth's crust (Averitt, 1975). Titanium is associated with both organic and inorganic matter, but is more closely allied with organic fractions (Ruch and others, 1974). It tends to be carried with the dissolved coal substance in solvent refining or similar solution techniques (Rao, 1976). Even a few ppm titanium in carbon electrodes is detrimental to the production of aluminum by the electrolytic process since it causes brittleness in the finished metal (Stach and others, 1982).

World Coals

Abernethy and Gibson (1963) cited an average titanium concentration in coal of 506 ppm. The U.S. National Committee for Geochemistry (1980) reported a worldwide average titanium content of 0.05 percent in coal.

United States Coals

Sharkey and others (1975) found that titanium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 200 to 1,800 ppm. Others have cited a range in titanium content in U.S. coals from 0.002 to 0.32 percent (Los Alamos Scientific Laboratory, 1976; Wewerka and others, 1976). Swanson and others (1976) reported an average titanium content in 601 U.S. coals of 0.1 percent. The U.S. National Committee for Geochemistry (1980) cited an average titanium content in U.S. coals of 0.08 percent. Titanium ranges in content from 0.1 to 2.6 percent in the ashes of U.S. coals (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Los Alamos Scientific Laboratory (1976) listed an average titanium content of 350 ppm in 73 Appalachian region whole-coal samples. Swanson and others (1976) reported a geometric mean titanium concentration of 0.074 percent in 331 Eastern U.S. coals. Gluskoter and others (1977) cited a geometric mean titanium content of 0.09 percent in 23 Appalachian coals.

Interior region. Los Alamos Scientific Laboratory (1976) listed an average titanium content of 450 ppm in 53 Eastern Interior region whole-coal samples. Swanson and others (1976) reported a geometric mean titanium concentration of 0.04 percent in 194 Interior region coals. Gluskoter and others (1977) cited a geometric mean titanium content of 0.06 percent in 113 Illinois basin coals.

Western region. Los Alamos Scientific Laboratory (1976) listed an average titanium content of 250 ppm in 48 Western and Southwestern Interior region whole-coal samples and 591 ppm in 51 Northern Great Plains region whole-coal samples. Swanson and others (1976) reported a geometric mean titanium concentration of 0.037 percent in 93 Western coals and 0.11 percent in 34 Texas coals. Gluskoter and others (1977) cited a geometric mean titanium content of 0.05 percent in 29 Western U.S. coals.

Alaska Coals

Northern Alaska province. Rao (1968) reported an average titanium concentration of 698 ppm in 12 Northern Alaska raw-coal samples; ash samples of the same coals contained an average 5,334 ppm titanium.

Cook Inlet-Susitna province. Rao (1968) cited an average titanium content of 1,045 ppm in 22 Matanuska Valley raw-coal samples and 6,509 ppm titanium in each samples of the same coals. In addition, he reported an average titanium concentration of 154 ppm in eight Kenai field raw-coal samples and 1,473 ppm titanium in ash samples of the same coals.

Conwell (1977) reported a range of 2,000 to 7,000 ppm titanium and a mean of 4,570 ppm titanium in seven Beluga field coal-ash samples. Based on samples of six coal beds from the Tyonek Formation, Beluga field, Affolter and Stricker (1984) found that the concentration of titanium varied directly with the ash content of the coals.

Nenana province. Rao (1968) found an average titanium content of 341 ppm in 25 Nenana basin raw-coal samples and 2,634 ppm in ash samples of the same coals. In addition, he reported an average titanium content of 177 ppm in three Jarvis Creek field raw-coal samples and 1,847 ppm titanium in ash samples of the same coals.

Gulf of Alaska province. Rao (1968) cited an average titanium content of 213 ppm in five Bering River field raw coal samples and 7,480 ppm titanium in ash samples of the same coals.

PROFILE 72 - TUNGSTEN

Symbol: W Atomic number: 74 Atomic weight: 183.85

	Coal	Ash
Alaska	N.E.	N.E.
U.S.	<0.1-0.5 ppm	<10-200 ppm
World	N.E.	N.E.

Tungsten is an element with the highest melting point of all metals. It is extracted from wolframite [$(Fe,Mn)WO_4$], scheelite ($CaWO_4$), and other minerals. Turekian and Wedepohl (1961) reported the following average tungsten contents in common sedimentary rocks: shales, 1.8 ppm; sandstones, 1.6 ppm; and carbonates, 0.6 ppm. Orheim (1979) cited these clarke values for tungsten: earth's crust, 1.5 ppm; soil, 1.0 ppm; plant ash, 0.5 ppm; and water, 0.00003 ppm. Tungsten generally occurs in coal in lower concentration than its estimated average concentration in the earth's crust (Averitt, 1975).

United States Coals

Sharkey and others (1975) found that tungsten occurred in 69 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from <0.1 to 0.4 ppm. Somerville and Elder (1977) cited an average tungsten concentration in 12 samples of North Dakota lignites of 0.58 ppm. Wewerka and others (1979) cited a range in tungsten content from 0.5 to 1.2 ppm in Illinois basin coals. The U.S. National Committee for Geochemistry (1980) listed an average tungsten content in U.S. coals of 2.5 ppm. Gluskoter and others (1977) found the following geometric mean tungsten contents in U.S. whole-coal samples by region, as follows: Appalachian region (14 samples), 0.62 ppm; Illinois basin (56 samples), 0.63 ppm; and Western U.S. (22 samples), 0.58 ppm. Los Alamos Scientific Laboratory (1976) reported a range in tungsten content of <10 to 182 ppm in ashes of U.S. coals.

Alaska Coals

There exists very little data concerning tungsten concentrations in Alaska coals and coal ashes. Conwell and Triplehorn (1976) did not find detectable tungsten in Kukpuk River and Cape Thompson, Northern Alaska coal-ash samples. Merritt (1985b) found that tungsten was present in only 2 of 31 samples of Matanuska Valley coal-ashes analyzed. In these two samples, tungsten concentrations were <3 ppm.

PROFILE 73 - URANIUM

Symbol: U Atomic number: 92 Atomic weight: 238.03

	Coal	Ash
Alaska	0.2-7 ppm	N.E.
U.S.	<10-1,000 ppm	N.E.
World	N.E.	N.E.

Uranium is a metallic element that is easily oxidizable. It is a radioactive element with numerous isotopes, U_{238} being the most abundant in nature. Uranium occurs in several minerals including pitchblende or uraninite (UO_2) and carnotite [$K_2(UO_2)_2(VO_4)_2 \cdot nH_2O$]. It may be associated with anomalously high contents of arsenic, germanium, selenium, cobalt, and zirconium, and occurs as compounds or complexes intimately associated with the organic constituents of coal (Averitt, 1961). It has been found that uranium has a strong chemical affinity for carbonaceous material; it can be leached by groundwater from overlying rocks and carried downward to be precipitated on or in underlying carbonaceous rocks (Averitt, 1961). Uranium formed in part during the first stage in the coalification process (Stach and others, 1982).

Turekian and Wedepohl (1961) reported the following average uranium concentrations in common sedimentary rocks: shales, 3.7 ppm; sandstones, 0.45 ppm; and carbonates, 2.2 ppm. Orheim (1979) cited these clarke values for uranium: earth's crust, 2.7 ppm; soil, 1.0 ppm; plant ash, 0.6 ppm; and water, 0.003 ppm.

Uranium is one of the elements of chief environmental concern in coal. It occurs in coal in vastly greater concentration than its estimated average concentration in the earth's crust (Averitt, 1961). Unusual concentrations of uranium occur in some coals and lignites of Texas and North Dakota, and much consideration and research has been devoted to recovering commercial quantities of uranium from coal (Altschuler and Johnston, 1976; Stach and others, 1982).

World Coals

Abernethy and Gibson (1963) cited an average uranium content in coal of 2.18 ppm. The U.S. National Committee on Geochemistry (1980) reported a worldwide average uranium concentration in coal of 1.0 ppm.

United States Coals

Sharkey and others (1975) found that uranium occurred in 92 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from <0.1 to 1 ppm. Others found that uranium content ranges in U.S. coals from <10 to 1,000 ppm (Los Alamos Scientific Laboratory, 1976). Swanson and others (1976) found an average uranium content in 601 U.S. coals of 1.4 ppm. The U.S. National Committee for Geochemistry (1980) reported an average uranium concentration in coal of 1.6 ppm.

Appalachian region. Swanson and others (1976) cited a geometric mean uranium content of 1 ppm in 331 Eastern U.S. whole-coal samples. Gluskoter and others (1977) listed a geometric mean uranium content of 1.3 ppm in 14 Appalachian coals.

Interior region. Swanson and others (1976) cited a geometric mean uranium content of 1.4 ppm in 194 Interior region whole-coal samples. Gluskoter and others (1977) listed a geometric mean uranium content of 1.3 ppm in 56 Illinois basin coals.

Western region. Swanson and others (1976) cited a geometric mean uranium content of 0.7 ppm in 93 Western coals and 2.4 ppm uranium in 34 Texas coals. Gluskoter and others (1977) listed a geometric mean uranium content of 0.99 ppm in 22 Western U.S. coals.

Alaska Coals

Compared to other U.S. coals, the content of uranium in Alaskan coals is similar.

Northern Alaska province. Conwell and Triplehorn (1976) found a high uranium concentration of 12.1 ppm in a Cape Thompson, Northern Alaska, raw-coal sample. Affolter and others (1981) cited a range in uranium content of 0.2 to 6.2 ppm in 54 Utukok River Quadrangle whole-coal samples and a geometric mean of 1.0 ppm.

Cook Inlet-Susitna province. Merritt (1985b) found a mean uranium content of 4 ppm in 30 Matanuska Valley coal-ash samples. Affolter and others (1981) reported a range in uranium content of <0.5 to 1.2 ppm and a geometric mean of 0.7 ppm in 10 Kenai Quadrangle whole-coal samples. Additionally, they reported a range in uranium content of 0.3 to 3.1 ppm and a geometric mean of 0.5 ppm uranium in 34 Seldovia Quadrangle whole-coal samples. Conwell (1977) found a range in uranium content of <0.2 to 1.8 ppm and a mean of <1.0 ppm uranium in seven Beluga field raw-coal samples. Based on samples of six coal beds from the Tyonek Formation, Beluga field, Affolter and Stricker (1984) found that the concentration of uranium varied directly with the ash content of the coals.

Nenana province. Affolter and others (1981) listed a range in uranium concentration of 0.4 to 5.2 ppm and a geometric mean of 1.1 ppm in 20 Healy Quadrangle whole-coal samples. Affolter and Stricker (1987) cited an average uranium content of 0.5 ppm in two whole-coal samples of Seam No. 3, Usibelli Mine.

Alaska Peninsula province. Conwell and Triplehorn (1978) reported an average uranium content of 1.4 ppm in eight Alaska Peninsula whole-coal samples.

PROFILE 74 - VANADIUM

Symbol: V Atomic number: 23 Atomic weight: 50.942

	Coal	Ash
Alaska	2-200 ppm	100-600 ppm
U.S.	0-1,300 ppm	5-50,000 ppm
World	N.E.	60-79,000 ppm

Vanadium is a metallic element found in several minerals, especially vanadinite [$Pb_5Cl(VO_4)_3$] and carnotite [$K_2(UO_2)_2(VO_4)_2 \cdot nH_2O$]. It is one of the elements associated with both organic and inorganic matter, but is more closely allied with organic fractions (Ruch and others, 1974). It generally occurs in coal in appreciably greater concentration than its estimated average concentration in the earth's crust (Averitt, 1975). Even a few ppm of vanadium in carbon electrodes is harmful to the production of aluminum by the electrolytic process since it causes brittleness in the finished metal (Stach and others, 1982). Over 95 percent of vanadium is retained in low-temperature ash, and possibly up to 25 percent is retained in high-temperature ash (Ruch and others, 1974).

Turekian and Wedepohl (1961) reported the following average vanadium concentrations in common sedimentary rocks: shales, 130 ppm; sandstones, 20 ppm; and carbonates, 20 ppm. Orheim (1979) cited these clarke values for vanadium: earth's crust, 135 ppm; soil, 100 ppm; plant ash, 22 ppm; and water, 0.002 ppm.

World Coals

Abernethy and Gibson (1963) reported a general average vanadium concentration in coal of 28.5 ppm. The U.S. National Committee for Geochemistry (1980) cited a worldwide average vanadium content in coal of 25 ppm.

United States Coals

Sharkey and others (1975) found that vanadium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 2 to 77 ppm. Others have cited a range in vanadium content in U.S. coals of 0 to 1,281 ppm (Los Alamos Scientific Laboratory, 1976). Swanson and others (1976) reported an average vanadium content in 601 U.S. coals of 19.2 ppm. The U.S. National Committee for Geochemistry (1980) listed an average vanadium concentration in U.S. coals of 20 ppm. Vanadium ranges from 6 to 3,800 ppm in ashes of U.S. coals, and shows the following average concentrations by rank: anthracites, 248 ppm; low-volatile bituminous coals, 278 ppm; medium-volatile bituminous coals, 390 ppm; high-volatile bituminous coals, 249 ppm; and subbituminous coals and lignites, 125 ppm (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Los Alamos Scientific Laboratory (1976) reported an average vanadium concentration of 21 ppm in 73 Appalachian region whole-coal samples. Swanson and others (1976) cited a geometric mean vanadium content

of 20 ppm in 331 Eastern U.S. coals. Gluskoter and others (1977) listed a geometric mean vanadium content of 35 ppm in 23 Appalachian coals.

Interior region. Los Alamos Scientific Laboratory (1976) reported an average vanadium concentration of 35 ppm in 53 Eastern Interior region whole-coal samples. Swanson and others (1976) cited a geometric mean vanadium content of 20 ppm in 194 Interior region coals. Gluskoter and others (1977) listed a geometric mean vanadium content of 29 ppm in 113 Illinois basin coals.

Western region. Los Alamos Scientific Laboratory (1976) reported an average vanadium concentration of 18 ppm in 48 Western and Southwestern Interior region whole-coal samples and 16 ppm in 51 Northern Great Plains region whole-coal samples. Swanson and others (1976) cited a geometric mean vanadium content of 7 ppm in 93 Western region coals and 30 ppm in 34 Texas coals. Gluskoter and others (1977) listed a geometric mean vanadium content of 12 ppm in 29 Western U.S. coals.

Alaska Coals

There exists an abundant amount of geochemical data relating to vanadium concentrations in Alaska coals and coal ashes. Compared to other U.S. coals, the content of vanadium is generally higher in Alaskan coals.

Northern Alaska province. Rao (1968) reported an average vanadium content of 9.1 ppm in 12 Northern Alaska raw-coal samples; ash samples of the same coals contained an average 66 ppm vanadium. Conwell and Triplehorn (1976) reported anomalously high values of vanadium (1,500 ppm) in a Kukpuk River, Northern Alaska coal-ash sample. A similar coal-ash sample from Cape Thompson, Northern Alaska contained 1,000 ppm vanadium. Rao (1980) found a range in vanadium content of 7 to 133 ppm and a mean of 31 ppm vanadium in 38 Cape Beaufort region raw-coal samples. In addition, he reported vanadium contents in ash samples of the same coals; the range cited was 51 to 257 ppm and the mean was 132 ppm. Rao and Wolff (1981) reported vanadium contents for two Northern Alaska coals, a subbituminous B seam from Meade River and a high-volatile bituminous seam from Sagwon Bluffs. The former registered 12 ppm vanadium on a raw-coal basis and 270 ppm vanadium on a coal-ash basis; the latter contained 200 ppm vanadium on a raw-coal basis and 310 ppm vanadium on a coal-ash basis. Affolter and others (1981) listed a range in vanadium content of 2 to 200 ppm and a geometric mean of 15 ppm in 54 Utukok River Quadrangle whole-coal samples.

Cook Inlet-Susitna province. Rao (1968) reported an average vanadium concentration of 31.1 ppm in 22 Matanuska Valley raw-coal samples; ash samples of the same coals contained an average content of 189 ppm vanadium. Rao and Wolff (1981) analyzed and reported on vanadium concentrations in seams from the Castle Mountain and Premier mines of the Matanuska Valley. The lower seam from the Castle Mountain mine, a high-volatile bituminous coal contained 58 ppm vanadium on a raw-coal basis and 320 ppm vanadium on a coal-ash basis. A high-volatile bituminous coal from the Premier mine contained 58 ppm vanadium on a raw-coal basis and 380 ppm vanadium on a coal-ash basis. Merritt (1985b) listed a mean content of 80 ppm vanadium in 31 Matanuska Valley coal-ash samples.

Rao (1968) reported an average vanadium concentration of 6.7 ppm in eight Kenai field raw-coal samples; ash samples of the same coals contained an average content of 65 ppm vanadium. Rao and Wolff (1981) cited a vanadium concentration of 45 ppm in a raw-coal sample of the subbituminous C-ranked Cabin bed of the Kenai field; a coal-ash sample of this seam contained 400 ppm vanadium. Affolter and others (1981) found a range of 15 to 100 ppm vanadium and a geometric mean of 50 ppm vanadium in 10 Kenai Quadrangle whole-coal samples. In addition, they reported a range of 10 to 200 ppm vanadium and a geometric mean of 50 ppm vanadium in 34 Seldovia Quadrangle whole-coal samples. Merritt and others (1987) cited an average vanadium content of 385 ppm in 31 Kenai field coal-ash samples.

Conwell (1977) found a range of 300 to 700 ppm vanadium and a mean content of 500 ppm vanadium in seven Beluga field coal-ash samples. Rao and Wolff (1981) reported vanadium contents of two coals from the Susitna lowland of southcentral Alaska. The subbituminous C Waterfall seam of the Beluga field contained 37 ppm vanadium on a raw-coal basis and 360 ppm on a coal-ash basis. Lower and upper benches of a Sunflower Creek lignite of the Yentna field contained an average of 9.2 ppm vanadium on a raw-coal basis and 230 ppm vanadium on a coal-ash basis. Based on samples of six coal beds from the Tyonek Formation, Beluga field, Affolter and Stricker (1984) found that the concentration of vanadium varied directly with the ash content of the coals. Rao and Smith (1987) reported vanadium concentrations in coal-ash samples of five seams from the Chuitna district, Beluga field. The average vanadium contents of the seams going downsection are as follows: Blue Seam (15 samples), 236 ppm; Red 3 Seam (13 samples), 308 ppm; Red 2 Seam (26 samples), 206 ppm; Red 1 Seam (16 samples), 343 ppm; and the Purple Seam (5 samples), 420 ppm.

Rao and Wolff (1981) also analyzed and reported on vanadium content in a lignite seam from Coal Creek, Broad Pass field. A raw-coal sample contained 69 ppm vanadium and a coal-ash sample contained 350 ppm vanadium.

Nenana province. Rao (1968) listed an average vanadium content of 9.1 ppm in 25 Nenana basin whole-coal samples; ash samples of the same coals contained an average 69 ppm vanadium. Rao and Wolff (1981) reported average vanadium concentrations in seven samples of five seams from the Nenana basin, including the No. 2, No. 4, No. 6 (three splits——top, middle, and lower), Moose, and Caribou seams, all of subbituminous C rank. Raw coal samples contained an average 39 ppm vanadium and coal-ash samples contained an average 300 ppm vanadium. Affolter and others (1984) found a range of 15 to 100 ppm vanadium and a geometric mean of 20 ppm vanadium in 20 Healy Quadrangle whole-coal samples. Affolter and Stricker (1987) listed an average vanadium concentration of 16 ppm in two whole-coal samples of Seam No. 3, Usibelli Mine.

Rao (1968) reported an average vanadium content of 4.8 ppm in three raw-coal samples of the Jarvis Creek field; ash samples of the same coals contained an average 47 ppm vanadium. Rao and Wolff (1981) found a vanadium content of 32 ppm in a raw-coal sample of a subbituminous C-ranked seam from Ober Creek, Jarvis Creek field; an ash sample of this coal contained 280 ppm vanadium. Belowich (1987) listed an average vanadium content of 30 ppm in 27 Jarvis Creek field whole-coal samples.

Rao and Wolff (1981) analyzed the subbituminous C-ranked main seam from the Little Tonzona River field, western Nenana province. A raw-coal sample contained 77 ppm vanadium and a coal-ash sample contained 560 ppm vanadium.

Alaska Peninsula province. Conwell and Triplehorn (1978) found an average vanadium concentration of 161 ppm in eight Alaska Peninsula coal-ash samples.

Gulf of Alaska province. Rao (1968) reported an average vanadium concentration of 2.0 ppm in five Bering River field raw-coal samples and an average 88 ppm vanadium in ash samples of the same coals. Smith and Rao (1987) cited an average concentration of 198 ppm vanadium in 20 Bering River field coal-ash samples.

Yukon-Koyukuk province. Rao and Wolff (1981) analyzed and reported vanadium contents in the high-volatile bituminous main seam of the Tramway Bar field. A raw-coal sample showed 120 ppm vanadium and a coal-ash sample showed 320 ppm vanadium.

PROFILE 75 - YTTERBIUM

Symbol: Yb Atomic number: 70 Atomic weight: 173.04

	Coal	Ash
Alaska	0.2-3 ppm	0-30 ppm
U.S.	<0.1-1.5 ppm	<2-25 ppm
World	N.E.	N.E.

Ytterbium is a rare-earth element associated with silicate minerals. Turekian and Wedepohl (1961) reported the following average ytterbium concentrations in common sedimentary rocks: shales, 2.6 ppm; sandstones, 4.0 ppm; and carbonates, 0.5 ppm. The U.S. National Committee for Geochemistry (1980) cited an average worldwide ytterbium concentration in coal of 0.5 ppm.

United States Coals

Sharkey and others (1975) found that ytterbium occurred in 62 percent of 13 U.S. raw coals analyzed and that it ranged in concentration from <0.1 to 0.5 ppm. Swanson and others (1976) found an average ytterbium concentration of 0.8 ppm in 601 U.S. whole-coal samples. The U.S. National Committee for Geochemistry (1980) reported an average overall ytterbium concentration in U.S. coals of 1.0 ppm. In addition, they cited an average ytterbium content of 0.5 ppm for U.S. subbituminous coals and 1.5 ppm for U.S. lignites. Ytterbium ranges from <0.2 to 23 ppm in the ashes of U.S. coals and exhibits the following average concentrations in coals of various rank: anthracites, 8 ppm; low-volatile bituminous coals, 10 ppm; medium-volatile bituminous coals, 9 ppm; high-volatile bituminous coals, 10 ppm; and subbituminous coals and lignites, 4 ppm (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Swanson and others (1976) reported a geometric mean of 0.7 ppm ytterbium in 331 Eastern U.S. whole-coal samples. Gluskoter and others (1977) listed a geometric mean of 0.73 ppm ytterbium in 14 Appalachian region coals.

Interior region. Swanson and others (1976) reported a geometric mean ytterbium content of 0.7 ppm in 194 Interior region whole-coal samples. Gluskoter and others (1977) listed a geometric mean of 0.53 ppm ytterbium in 56 Illinois basin coals.

Western region. Swanson and others (1976) reported a geometric mean ytterbium content of 0.3 ppm in 93 Western region whole-coal samples and 1.5 ppm in 34 Texas whole-coal samples. Gluskoter and others (1977) listed a geometric mean of 0.34 ppm ytterbium in 22 Western U.S. coals.

Alaska Coals

Compared to other U.S. coals, the content of ytterbium is higher in Alaska coals.

Northern Alaska province. Conwell and Triplehorn (1976) reported a ytterbium content of 30 ppm in a Kukpuk River coal-ash sample and 7 ppm in a Cape Thompson coal-ash sample. Affolter and others (1981) found a range in ytterbium concentration of <1 to 3 ppm and a geometric mean of 0.5 ppm in 54 Utukok River Quadrangle whole-coal samples.

Cook Inlet-Susitna province. Affolter and others (1981) reported a range in ytterbium content of 0.5 to 2 ppm and a geometric mean of 1 ppm in 10 Kenai Quadrangle whole-coal samples. In addition, they listed a range of 0.2 to 2 ppm ytterbium and a geometric mean of 0.5 ppm ytterbium in 34 Seldovia Quadrangle whole-coal samples.

Conwell (1977) cited a range of 7 to 15 ppm ytterbium and a mean of 12 ppm ytterbium in seven Beluga field coal-ash samples. Based on samples of six coal beds from the Tyonek Formation, Beluga field, Affolter and Stricker (1984) found that the concentration of ytterbium varied directly with the ash content of the coals.

Nenana province. Affolter and others (1981) reported a range of 0.3 to 3 ppm ytterbium and a geometric mean of 0.7 ppm ytterbium in 20 Healy Quadrangle whole-coal samples. Affolter and Stricker (1987) listed an average ytterbium content of 0.4 ppm in two whole-coal samples of Seam No. 3, Usibelli Mine.

Alaska Peninsula province. Conwell and Triplehorn (1978) cited an average ytterbium content of 5 ppm in eight Alaska Peninsula coal-ash samples.

PROFILE 76 - YTTRIUM

Symbol: Y Atomic number: 39 Atomic weight: 88.905

	Coal	Ash
Alaska	0.5-3.0 ppm	0-300 ppm
U.S.	<0.1-60 ppm	0-700 ppm
World	0-100 ppm	0-800 ppm

Yttrium is a metallic element that has many metallurgical applications. It is not a rare-earth element, but it occurs in many rare-earth minerals. It is found in association with various silicate minerals. Turekian and Wedepohl (1961) reported the following average yttrium concentrations in common sedimentary rocks: shales, 26 ppm; sandstones, 40 ppm; and carbonates, 30 ppm.

Yttrium is one of the elements of environmental concern in coal. It generally occurs in coal in appreciably greater concentration than its estimated average concentration in the earth's crust (Averitt, 1975).

World Coals

Berkowitz (1979) reported a maximum yttrium concentration in coal ash of 800 gm/ton and an average yttrium concentration of 100 gm/ton. The U.S. National Committee for Geochemistry (1981) cited a worldwide average yttrium content in coal of 10 ppm.

United States Coals

Sharkey and others (1975) found that yttrium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 3 to 25 ppm. Others have reported a range in yttrium content in coal of <0.1 to 59 ppm (Los Alamos Scientific Laboratory, 1976; Wewerka and others, 1976). Swanson and others (1976) cited an average yttrium content of 8 ppm in 601 U.S. whole-coal samples. The U.S. National Committee for Geochemistry (1980) listed a U.S. average concentration in coal of 10 ppm. Yttrium ranges from 0 to 620 ppm in ashes of U.S. coals, and exhibits the following average concentrations by rank: anthracites, 106 ppm; low-volatile bituminous coals, 152 ppm; medium-volatile bituminous coals, 151 ppm; high-volatile bituminous coals, 102 ppm; and subbituminous coals and lignites, 51 ppm (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Los Alamos Scientific Laboratory (1976) listed an average yttrium concentration of 14 ppm in 73 Appalachian region whole-coal samples. Swanson and others (1976) cited a geometric mean yttrium content of 7 ppm in 331 Eastern U.S. coals.

Interior region. Los Alamos Scientific Laboratory (1976) listed an average yttrium concentration of 7.7 ppm in 53 Eastern Interior region whole-coal samples. Swanson and others (1976) cited a geometric mean yttrium content of 7 ppm in 194 Interior region coals.

Western region. Los Alamos Scientific Laboratory (1976) listed an average yttrium concentration of 7.4 ppm in 48 Western and Southwestern Interior region whole-coal samples and 13 ppm in 51 Northern Great Plains region whole-coal samples. Swanson and others (1976) cited a geometric mean yttrium content of 3 ppm in 93 Western U.S. coals and 15 ppm yttrium in 34 Texas coals.

Alaska Coals

Compared to other U.S. coals, the content of yttrium is higher in Alaskan coals.

Northern Alaska province. Conwell and Triplehorn (1976) reported a yttrium content of 300 ppm in a Kukpuk River coal-ash sample and 50 ppm in a Cape Thompson coal-ash sample. Affolter and others (1981) listed a range in yttrium content of 0.5 to 30 ppm and a geometric mean of 5 ppm yttrium in 54 Utukok River Quadrangle whole-coal samples.

Cook Inlet-Susitna province. Merritt (1985b) cited a mean yttrium content of 18 ppm in 31 Matanuska Valley coal-ash samples. Affolter and others (1981) found a range of 5 to 20 ppm yttrium and a geometric mean of 10 ppm yttrium in 10 Kenai Quadrangle whole-coal samples. In addition, they found a range of 2 to 20 ppm yttrium and a geometric mean of 5 ppm yttrium in 34 Seldovia Quadrangle whole-coal samples.

Conwell (1977) found a range of 70 to 150 ppm yttrium and a mean of 94 ppm yttrium in seven Beluga field coal-ash samples. Based on samples of six coal beds from the Tyonek Formation, Beluga field, Affolter and Stricker (1984) found that the concentration of yttrium varied directly with the ash content of the coals.

Nenana province. Affolter and others (1981) reported a range of 3 to 20 ppm yttrium and a geometric mean of 7 ppm yttrium in 20 Healy Quadrangle whole-coal samples. Affolter and Stricker (1987) cited an average yttrium content of 3.2 ppm in two whole-coal samples of Seam No. 3, Usibelli Mine.

Alaska Peninsula province. Conwell and Triplehorn (1978) found an average yttrium content of 53 ppm in eight Alaska Peninsula coal-ash samples.

PROFILE 77 - ZINC

Symbol: Zn Atomic number: 30 Atomic weight: 65.37

	Coal	Ash
Alaska	2-110 ppm	50-500 ppm
U.S.	0-6,000 ppm	0-20,000 ppm
World	N.E.	0-10,000 ppm

Zinc is a metallic element that is found in the mineral sphalerite (ZnS) or zinc blende. Turekian and Wedepohl (1961) reported the following average zinc concentrations in common sedimentary rocks: shales, 95 ppm; sandstones, 16 ppm; and carbonates, 20 ppm. Orheim (1979) cited these clarke values for zinc: earth's crust, 70 ppm; soil, 50 ppm; plant ash, 1,400 ppm; and water, 0.01 ppm. Zinc occurs in coal in appreciably greater concentration than its estimated average concentration in the earth's crust (Averitt, 1975). Unusual concentrations of zinc are found in some coals and lignites of Texas and North Dakota and may be recovered in commercial quantities (Altschuler and Johnston, 1976).

Zinc is one of the elements of environmental concern in coal, and one of the elements generally inorganically combined in coal and showing least organic affinity (Ruch and others, 1974). It is typically concentrated in the mineral matter of coal, being retained in high-temperature ash and over 95 percent retained in low-temperature ash. Even a few ppm of zinc in carbon electrodes is harmful to the production of aluminum by the electrolytic process since it causes brittleness of the finished metal (Stach and others, 1982). Anomalously high zinc may result from core-hole samples contaminated by drilling fluids and drill pipe.

World Coals

Abernethy and Gibson (1963) cited an average zinc concentration in coal of 46 ppm. The U.S. National Committee for Geochemistry (1980) listed an average zinc content of 50 ppm in U.S. coals. Berkowitz (1979) found a maximum zinc concentration in coal ash of 10,000 gm/ton and an average zinc concentration of 200 gm/ton.

United States Coals

Sharkey and others (1975) found that zinc occurred in 100 percent of 13 U.S. raw coals analyzed and that it ranged in concentration from 3 to 80 ppm. Others have cited a range of 0 to 51 ppm zinc in U.S. coals (Los Alamos Scientific Laboratory, 1976). Swanson and others (1976) listed an average zinc content in 601 U.S. coals of 27.9 ppm. The U.S. National Committee for Geochemistry (1980) reported an average zinc content of 39 ppm in U.S. coals.

Zinc has been found to range from 0 to 1.6 percent in ashes of U.S. coals and exhibits the following average concentrations by rank: low-volatile bituminous coals, 231 ppm; medium-volatile bituminous coals, 195 ppm; and high-volatile bituminous coals, 310 ppm (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Los Alamos Scientific Laboratory (1976) reported an average zinc content of 7.6 ppm in 73 Appalachian whole-coal samples. Swanson and others (1976) cited a geometric mean zinc content of 12.8 ppm in 331 Eastern U.S. coals. Gluskoter and others (1977) listed a geometric mean zinc content of 19 ppm in 23 Appalachian coals.

Interior region. Los Alamos Scientific Laboratory (1976) reported an average zinc content of 44 ppm in 53 Eastern Interior region whole-coal samples. Swanson and others (1976) cited a geometric mean zinc content of 58 ppm in 194 Interior region coals. Gluskoter and others (1977) listed a geometric mean zinc content of 87 ppm in 113 Illinois basin coals.

Western region. Los Alamos Scientific Laboratory (1976) reported an average zinc content of 108 ppm in 48 Western and Southwestern Interior region whole-coal samples and 59 ppm in 51 Northern Great Plains region whole-coal samples. Swanson and others (1976) cited a geometric mean zinc content of 12.8 ppm in 93 Western region coals and 28 ppm in 34 Texas coals. Gluskoter and others (1977) listed a geometric mean zinc content of 5.0 ppm in 29 Western U.S. coals.

Alaska Coals

There exists an abundant amount of geochemical data relating to zinc concentrations in Alaska coals and coal ashes. Compared to other U.S. coals, the content of zinc in Alaskan coals is similar.

Northern Alaska province. Conwell and Triplehorn (1976) reported anomalously high values of zinc (2,650 ppm) in a Kukpuk River, Northern Alaska coal-ash sample. In addition, they reported a zinc content of 177 ppm in a Cape Thompson coal-ash sample. Rao (1980) found the concentration of zinc in 38 Cape Beaufort region samples to be within the range of other U.S. coals. He quoted a range of 5.8 to 107 ppm and a mean of 26 ppm zinc in raw-coal samples; coal ashes of the samples showed a range of 47 to 290 ppm zinc and a mean of 110 ppm zinc. Rao and Wolff (1981) reported zinc contents in raw-coal and coal-ash samples of three Northern Alaska coals: a subbituminous B-ranked seam from Wainwright contained 14 ppm zinc in a raw-coal sample and 237 ppm zinc in a coal-ash sample; a subbituminous B-ranked seam from Meade River contained 16 ppm zinc in a raw-coal sample and 366 ppm zinc in a coal-ash sample; and a high-volatile bituminous coal from Sagwon Bluffs contained 64 ppm zinc in a raw-coal sample and 101 ppm zinc in a coal-ash sample. Affolter and others (1981) listed a range of 2 to 67 ppm zinc and a geometric mean of 7.7 ppm zinc in 54 Utukok River Quadrangle whole-coal samples.

Cook Inlet-Susitna province. Rao and Wolff (1981) cited a zinc content of 18 ppm in a raw coal sample of the high-volatile bituminous lower seam of the Castle Mountain mine, Matanuska Valley; a coal-ash sample of the same coal contained 99 ppm zinc. Rao and Wolff (1981) also analyzed a high-volatile bituminous seam from the Premier Mine, Matanuska Valley; a raw-coal sample contained 57 ppm zinc, and a coal-ash sample contained 370 ppm zinc. Merritt (1985b) cited a mean zinc concentration of 22 ppm in 31 Matanuska Valley coal-ash samples.

Rao and Wolff (1981) found a zinc content of 11 ppm in a raw-coal sample of the subbituminous C Cabin bed from the Kenai field; a coal-ash sample of the same coal contained 95 ppm zinc. Affolter and others (1981) reported a range of 2.6 to 24 ppm zinc and a geometric mean of 7.1 ppm zinc in 10 Kenai Quadrangle whole-coal samples. In addition, they listed a range of 2.1 to 110 ppm zinc and a geometric mean of 7 ppm zinc in 34 Seldovia Quadrangle whole-coal samples. Merritt and others (1987) cited an average zinc content of 58 ppm in 31 Kenai field coal-ash samples.

Conwell (1977) found a range of 70 to 163 ppm zinc and a mean of 118 ppm zinc in seven Beluga field coal-ash samples. Rao and Wolff (1981) reported a raw-coal zinc concentration of 19 ppm and a coal-ash zinc concentration of 182 ppm in the subbituminous C-ranked Waterfall seam of the Beluga field. They also analyzed upper and lower benches of a Sunflower Creek lignite seam from the Yentna field; a raw-coal sample showed 4.4 ppm zinc and a coal-ash sample showed 110 ppm zinc. Merritt (1987a) listed a range of 20 to 563 ppm zinc and an average content of 122 ppm zinc in 45 Susitna lowland coal-ash samples. Rao and Smith (1987) presented data for zinc contents in coal-ash samples of five seams from the Chuitna district, Beluga coal field. Average zinc concentrations by seam going downsection are as follows: Blue Seam (15 samples), 285 ppm; Red Seam (13 samples), 197 ppm; Red 2 Seam (26 samples), 206 ppm; Red 1 Seam (16 samples), 126 ppm; and Purple Seam (5 samples), 104 ppm.

Rao and Wolff (1981) cited a raw-coal zinc content of 22 ppm and a coal-ash zinc content of 110 ppm in a lignite seam from Coal Creek, Broad Pass field.

Nenana province. Rao and Wolff (1981) reported average zinc contents in seven samples of five different seams from the Nenana basin. The subbituminous C seams include the No. 2, No. 4, No. 6 (top, middle, and lower benches), Moose, and Caribou seams. Raw-coal samples contained an average 19 ppm zinc, and coal-ash samples contained an average 86 ppm zinc. Affolter and others (1981) reported a range of 2.3 to 46 ppm zinc and a geometric mean of 8.8 ppm zinc in 20 Healy Quadrangle whole-coal samples. Affolter and Stricker (1987) found an average zinc concentration of 2.2 ppm in two whole-coal samples of Seam No. 3, Usibelli Mine.

Rao and Wolff (1981) cited a raw-coal zinc content of 18 ppm in a subbituminous C seam from Ober Creek, Jarvis Creek field; an ash sample of the same coal contained 160 ppm zinc. Belowich (1987) listed an average zinc content of 614 ppm in 27 Jarvis Creek field whole-coal samples.

Rao and Wolff (1981) also analyzed the subbituminous C main seam from the Little Tonzona River field. A raw coal sample contained 55 ppm zinc and a coal-ash sample contained 403 ppm zinc.

Alaska Peninsula province. Conwell and Triplehorn (1978) reported an average zinc concentration of 117 ppm in eight Alaska Peninsula coal-ash samples.

Gulf of Alaska province. Smith and Rao (1987) cited an average zinc concentration of 677 ppm in 20 Bering River field coal-ash samples.

PROFILE 78 - ZIRCONIUM

Symbol: Zr Atomic number: 40 Atomic weight: 91.22

	Coal	Ash
Alaska	2-150 ppm	100-800 ppm
U.S.	5-300 ppm	100-1,500 ppm
World	N.E.	0-5,000 ppm

Zirconium is a metallic element that is found predominantly in the mineral zircon ($ZrSiO_4$) but also commonly associated with other silicate minerals. Turekian and Wedepohl (1961) reported the following average zirconium concentrations in common sedimentary rocks: shales, 160 ppm; sandstones, 220 ppm; and carbonates, 19 ppm.

Zirconium generally occurs in coal in appreciably greater concentration than its estimated average concentration in the earth's crust (Averitt, 1975). It is one of the elements showing least organic affinity, and is generally concentrated in the mineral matter of coal (Ruch and others, 1974). Berkowitz (1979) cited a maximum zirconium concentration in coal of 5,000 gm/ton.

United States Coals

Sharkey and others (1975) found that zirconium occurred in 100 percent of 13 U.S. raw coals analyzed, and that it ranged in concentration from 28 to 300 ppm. Others have reported a range of zirconium content in U.S. coals of 8 to 133 ppm (Los Alamos Scientific Laboratory, 1976). Swanson and others (1976) cited an average zirconium concentration of 26.2 ppm in 601 U.S. coals. The U.S. National Committee for Geochemistry (1980) reported an average zirconium content of 30 ppm in U.S. coals.

Zirconium has been found to range in content in ashes of U.S. coals from 100 to 1,450 ppm, and shows the following average concentrations by rank: anthracites, 688 ppm; low-volatile bituminous coals, 458 ppm; medium-volatile bituminous coals, 326 ppm; high-volatile bituminous coals, 411 ppm; and subbituminous coals and lignites, 245 ppm (Los Alamos Scientific Laboratory, 1976).

Appalachian region. Swanson and others (1976) cited a geometric mean zirconium concentration of 30 ppm in 331 Eastern U.S. whole-coal samples. Gluskoter and others (1977) listed a geometric mean zirconium concentration of 41 ppm in 19 Appalachian coals.

Interior region. Swanson and others (1976) cited a geometric mean zirconium concentration of 10 ppm in 194 Interior region whole-coal samples. Gluskoter and others (1977) listed a geometric mean zirconium concentration of 41 ppm in 88 Illinois basin coals.

Western region. Swanson and others (1976) cited a geometric mean zirconium concentration of 15 ppm in 93 Western region whole-coal samples and 50 ppm in 34 Texas whole-coal samples. Gluskoter and others (1977) listed a geometric mean zirconium concentration of 26 ppm in 26 Western U.S. coals.

Alaska Coals

There exists abundant data on zirconium concentrations in Alaska coals and coal ashes. Compared to other U.S. coals, the content of zirconium in Alaskan coals is similar.

Northern Alaska province. Rao (1968) reported an average zirconium content of 24.4 ppm in 12 Northern Alaska raw-coal samples; ash samples of the same coals contained an average 192 ppm zirconium. Conwell and Triplehorn (1976) found a zirconium content of 300 ppm in a Kukpuk River, Northern Alaska coal-ash sample and 200 ppm in a Cape Thompson coal-ash sample. Rao (1980) found the concentration of zirconium in 38 Cape Beaufort region coals to be within the range of other U.S. coals. Zirconium ranged from 21 to 253 ppm in raw-coal samples and had a mean content of 103 ppm. It ranged from 47 to 1,170 ppm in coal-ash samples and had a mean content of 508 ppm. Rao and Wolff (1981) analyzed three Northern Alaska coals: a subbituminous B seam from Wainwright contained 28 ppm zirconium on a raw-coal basis and 470 ppm zirconium on a coal-ash basis; a subbituminous B seam from Meade River contained 25 ppm zirconium on a raw-coal basis and 580 ppm zirconium on a coal-ash basis; and a high-volatile bituminous coal from Sagwon Bluffs contained 110 ppm zirconium on a raw-coal basis and 170 ppm zirconium on a coal-ash basis. Affolter and others (1981) found a range of 2 to 100 ppm and a geometric mean of 20 ppm in 54 Utukok River Quadrangle whole-coal samples.

Cook Inlet-Susitna province. Rao (1968) cited an average zirconium content of 41.0 ppm in 22 Matanuska Valley raw-coal samples and 348 ppm zirconium in ash samples of the same coals. Rao and Wolff (1981) found a raw-coal zirconium content of 67 ppm and a coal-ash zirconium content of 370 ppm in the high-volatile bituminous lower seam of the Castle Mountain mine, Matanuska Valley. A high-volatile bituminous coal from the Premier mine, Matanuska Valley contained 40 ppm zirconium on a raw-coal basis and 260 ppm on a coal-ash basis. Merritt (1985b) listed a mean zirconium content of 71 ppm in 31 Matanuska Valley coal-ash samples.

Rao (1968) cited an average zirconium content of 6.2 ppm in eight Kenai field raw-coal samples and 63 ppm zirconium in ash samples of the same coals. Rao and Wolff (1981) reported a zirconium content of 46 ppm in a raw-coal sample of the subbituminous C Cabin bed of the Kenai field; an ash sample of the same coal contained 410 ppm zirconium. Affolter and others (1981) listed a range in zirconium content of 7 to 50 ppm and a geometric mean zirconium content of 20 ppm in 10 Kenai Quadrangle whole-coal samples. In addition, they listed a range of 7 to 70 ppm zirconium and a geometric mean of 15 ppm zirconium in 34 Seldovia Quadrangle whole-coal samples. Merritt and others (1987) found an average zirconium content of 216 ppm in 31 Kenai field coal-ash samples.

Conwell (1977) reported a range in zirconium content of 150 to 300 ppm and a mean content of 178 ppm zirconium in seven Beluga field coal-ash samples. Rao and Wolff (1981) reported zirconium contents of 43 ppm and 420 ppm for raw-coal and coal-ash samples of the subbituminous C-ranked Waterfall seam, Beluga field. In addition, they reported average zirconium

contents of 24 ppm and 615 ppm for raw-coal and coal-ash samples of the lower and upper benches of a Sunflower Creek lignite from the Yentna field. Based on samples of six coal beds from the Tyonek Formation, Beluga field, Affolter and Stricker (1984) found that the concentration of zirconium varied directly with the ash content of the coals. Rao and Smith (1987) analyzed and reported on zirconium concentrations in five seams from the Chuitna district, Beluga field. Average zirconium contents by seam going downsection are as follows: Blue Seam (15 samples), 171 ppm; Red 3 Seam (13 samples), 153 ppm; Red 2 Seam (26 samples), 195 ppm; Red 1 Seam (16 samples), 152 ppm; and Purple Seam (5 samples), 244 ppm.

Rao and Wolff (1981) reported a raw-coal zirconium content of 79 ppm and a coal-ash zirconium content of 400 ppm in a Coal Creek lignite seam from the Broad Pass field.

Nenana province. Rao (1968) cited an average zirconium concentration of 7.2 ppm in 25 Nenana basin whole-coal samples and 60 ppm zirconium in ash samples of the same coals. Rao and Wolff (1981) analyzed seven samples of five subbituminous C seams from the Nenana basin including the No. 2, No. 4, No. 6 (top, middle, and lower benches), Moose, and Caribou seams; they found an average raw-coal zirconium content of 38 ppm and a coal-ash zirconium content of 293 ppm. Affolter and others (1981) reported a range in zirconium content of 7 to 70 ppm and a geometric mean of 15 ppm in 20 Healy Quadrangle whole-coal samples. Affolter and Stricker (1987) found an average zirconium content of 16 ppm in two whole-coal samples of Seam No. 3, Usibelli Mine.

Rao (1968) listed an average zirconium content of 5.7 ppm in three Jarvis Creek field raw-coal samples and an average 61 ppm zirconium in ash samples. Rao and Wolff (1981) found 57 ppm zirconium in a raw-coal sample of a subbituminous C seam from Ober Creek, Jarvis Creek field; an ash sample of the same coal contained 500 ppm zirconium. Belowich (1987) found an average zirconium concentration of 16 ppm in 27 Jarvis Creek field whole-coal samples.

Rao and Wolff (1981) also analyzed and reported zirconium contents in the subbituminous C main seam from the Little Tonzona River field; a raw coal contained 44 ppm zirconium and a coal-ash sample contained 320 ppm zirconium.

Alaska Peninsula province. Conwell and Triplehorn (1978) cited an average zirconium concentration of 238 ppm in eight Alaska Peninsula coal-ash samples.

Gulf of Alaska province. Rao (1968) found an average zirconium content of 10.7 ppm in five Bering River field raw-coal samples; ash samples of the same coals contained an average zirconium content of 341 ppm. Smith and Rao (1987) reported an average zirconium content of 232 ppm in 20 Bering River field coal-ash samples.

Yukon-Koyukuk province. Rao and Wolff (1981) analyzed the high-volatile bituminous main seam from the Tramway Bar field. They reported a raw-coal zirconium content of 130 ppm and a coal-ash zirconium content of 330 ppm.

GLOSSARY

Accessory elements --- trace elements.

Baseline concentrations --- the existent abundances of certain minor or trace elements in coals or associated rocks.

Chemical constitution of coal --- the elements or component parts of coal.

Clarke --- the average concentration of an element in the earth's crust.

Coal analysis --- the determination of the various constituents of coal by chemical methods.

Concentration --- accumulation of elements or compounds in a coal that add or detract from its value.

Contaminant --- undesirable elements or compounds within or intimately associated with a coal.

Contamination --- infiltration of trace elements or other harmful agents into surface or groundwater resources.

Content --- amount of a given element in a unit amount of coal, usually in weight-percent or ppm basis.

Control technology --- system for the prevention of toxic trace element emission or infiltration.

Fly ash --- particulate matter in stack gases on which may be entrained certain toxic trace elements.

Heavy metals --- metallic elements with an atomic number over 21 and generally found in trace amounts in coal.

Impurity --- contaminants of coal, including various trace elements, that detract from its value.

Minor elements --- trace or accessory elements.

Nontoxic --- without harmful concentrations of trace elements or other substances.

Parts per million (ppm) --- a method of stating the content of an element in coal or other substance.

Toxic --- harmful or poisonous concentrations of trace elements or other substances.

Trace element --- an element present in very small concentrations in coal or other substances; minor or accessory elements.

Washability curve --- a curve or graph showing the results of a series of float-and-sink tests.

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