SHORT COURSE A

Health Impacts of Coal:

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Health Impacts of Coal: Should We Be Concerned?

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Health Impacts of Coal: Should We Be Concerned?

This short course will sort out the facts and fallacies that have been interwoven in this sensitive issue. We will explore questions such as: Are there confirmed cases of health problems? Under what conditions would coal present a threat to human health? What properties of coal are most dangerous? What can the coal science community do about it?

Course Outline:

- Welcome, Introductions, Course Summary
- Health Impacts of Coal: Facts and Fallacies
- Health Impacts of Residential Coal Use in China
- Naturally-occurring Coal May Pose Risks: Balkan Endemic Nephropathy
- Summary and Questions

Health Impacts of Coal: Facts and Fallacies -- This lecture will provide an overview of the issue. We will discuss situations in which health problems have been confirmed and where the health impacts of coal have been distorted. We will briefly review the current situation with regard to mercury in coal. (Robert B. Finkelman)

Health Impacts of Residential Coal Use in China -- Lecture on arseniasis and fluorosis in China. (Robert B. Finkelman)

Naturally-occurring Coal May Pose Risks: Balkan Endemic Nephropathy (BEN) -- A summary of the relationship between BEN and the leaching of organic compounds from lignites. (Joseph E. Bunnell)

Instructors:

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Bob Finkelman has worked for the U.S. Geological Survey for 30 years interrupted by 7 years with Exxon Production Research Company. For the past 25 years, he has been involved with various coal quality issues. During the last 10 years, he has focused attention on the health impacts of geologic materials including coal. He has conducted research on Balkan endemic nephropathy in Yugoslavia and Romania and he has worked extensively in China on arseniasis and fluorosis caused by residential coal combustion. He has also lectured extensively on *Medical Geology*, the health impacts of geologic materials and geologic processes.

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Joe Bunnell received a Ph.D. degree in Public Health from The Johns Hopkins University in 2000. Since 2001, he has worked with the USGS Energy Program on a variety of health-related coal issues. His research has included work on Balkan endemic nephropathy, a possibly similar situation in the USA, and respiratory health effects of coal combustion in the Navajo Nation.

Abstract

Health problems caused by coal are derived from either the use of poor quality coal (high ash, high sulfur, or high content of toxic trace elements) or by the improper use of coal. When poor quality coal is used in an improper way the resultant health problems can be widespread and severe. In millions of houses in many developing countries coal and other biomass fuels are burned in unvented stoves causing severe indoor air pollution. In Guizhou Province, southwest China, the situation is exacerbated by the use of coal that has concentrated toxic elements to an extraordinary degree. Thousands of people in this region are suffering from severe arsenic poisoning. The primary source of the arsenic appears to be consumption of chili peppers dried over fires fueled with high-arsenic coal. Coal samples in the region were found to contain up to 35,000 ppm arsenic. Chili peppers dried over high-arsenic coal fires adsorb 500 ppm arsenic on average. More than 10 million people in Guizhou Province and surrounding areas suffer from dental and skeletal fluorosis. The excess fluorine is due to eating corn dried over burning briquettes made from high-fluorine coals and high-fluorine clay binders. An unusual situation exists in the Balkans where there may be health problems caused by coal in the ground. Well waters containing nitrogenated and aromatic amines and other hydrocarbons leached from low-rank coals may be the cause of, or a contributing factor of, Balkan Endemic Nephropathy, an interstitial nephropathy, that is believed to have killed more than 100,000 people in Yugoslavia alone. Investigation is underway to determine if BEN-like situations exist in other parts of the world where lignite deposits occur, including the USA. Not all of the allegations of health problems caused by coal are legitimate. Concerns expressed about exposure to radioactivity from coal and coal combustion products are misplaced. The products of commercial coal combustion (fly ash, bottom ash) do have uranium and thorium concentrations about 5-10 times higher than that of the coal. But the uranium and thorium in the coal byproducts should not cause concern because they are mostly in insoluble forms at concentration levels similar to most soils.

Health Impacts of Coal Combustion:

Should we be concerned?

Table 1. Main anthropogenic emission sources of trace elements in Europe in 1979[*].

Element	main sources (% contribution to the total emission)	
As	metallurgical (82)	>coal combustion (7)
Be	coal combustion (almost 100)	
Cd	metallurgical (83)	>coal combustion (5)
Co	oil combustion (58)	>coal combustion (43)
Cr	metallurgical (80)	>coal combustion (13)
Cu	metallurgical (61)	>coal combustion (12)
Mn	metallurgical (84)	>coal combustion (11)
Mo	coal combustion (70)	>oil combustion (29)
Ni	oil combustion (60)	>coal combustion (17)
Pb	gasoline combustion (60)	>metallurgical (34)
Sb	coal combustion (74)	>refuse incinerators (25)
Se*	coal combustion (50)	>oil combustion (39)
V	oil combustion (almost 100)	
Zn	metallurgical (73)	>refuse incinerators (17)
Zr	coal combustion (almost 100)	

*Modified from Pacyna, 1984.

Coal has been cited as the main anthropogenic source for potentially toxic trace elements. Note: no information on mercury is presented. See Appendix for a Periodic Table of the elements illustrating their health significance.

Table 2. Selected trace elements emitted by coal-fired power stations with known toxic responses in test systems and in humans*.

element	health effects
As	anemia, gastric disturbance, renal symptoms, ulceration; skin and lung carcinogen in humans; a suspected teratogen (birth defects)
Be	respiratory disease and lymphatic, liver, spleen, and kidney effects; an animal and probable human carcinogen
Cd	emphysema and fibrosis of the lung, renal injury, possible cardiovascular effects; an animal and possible human carcinogen; testicular toxicity in mice and rats; teratogenic in rodents
Hg	neural and renal damage, cardiovascular disease; methylmercury is teratogenic in humans
Mn	respiratory and other effects
Ni	dermatitis, intestinal disorders; Ni and nickel oxide dusts are carcinogenic to guinea pigs and rats; nickel refining is associated causally with cancer in humans
Pb	anemia, cardiovascular, neurological, growth retarding, and gastrointestinal effects; some compounds are animal and possible human carcinogens; fetotoxic and probably teratogenic to humans
Se	gastrointestinal disturbance, liver and spleen damage, anemia; a possible carcinogen, a suspected teratogen
V	acute and chronic respiratory dysfunction

*US DOE.

Trace elements can cause a wide range of health problems. Note: dose, speciation, and exposure pathways (ingestion, inhalation, contact with skin, etc.) are some of the critical factors that influence the toxic response. Specific variations in these factors were not considered in this table.

Table 3. Potential hazardous air pollutants [1990 Clean Air Act Amendments]*.

Element	ppm in coal	maximum potential annual emission (tons)
As	24	24,000
Be	2.2	2,200
Cd	0.5	500
Cl	600	600,000
Co	6	6,000
Cr	15	15,000
F	100	100,000
Hg	0.2	200
Mn	43	43,000
Ni	14	14,000
Pb	11	11,000
Sb	1.2	1,200
Se	2.8	2,800
U	2.1	2,100

* Coal data from Finkelman, R.B., 1993. See Appendix for complete list of element concentrations in U.S. coal.

Compared to crustal abundances, many trace elements are concentrated in coal. Although these elements are present at part per million (ppm) levels in coal, the 1 billion tons of coal used annually in the U.S. could mobilize significant amounts of these elements.

But are the maximum potential annual emission estimates realistic?

Table 4. Progressive trace element enrichment in a coal-fired power plant (ppm)*.

sample	Cu	Zn	As	Mo	Sb	Pb	Se	Hg
coal	9.6	7.3	--	0.99	--	--	1.9	0.070
bottom ash	82	58	15	3.50	2.8	<5	7.7	0.140
precipitator ash (inlet)	230	250	120	41.00	14.0	66	27	0.310
precipitator ash (outlet)	320	370	150	60.00	18.0	130	62	--

*Kaakinen *et al.* 1975. Samples were collected at a 180-MW unit.

Volatile elements such as Hg, Cl, and F are largely released with the flue gas. However, most other elements are concentrated in the coal combustion by-products, especially the fly ash that can be captured by electrostatic precipitators or fabric filters (bag houses).

Table 5. Effect of fly ash particle size on the concentration of some trace elements (ppm)*.

	size range (µm)			
Element	>15	8-15	3-8	<3
As	13.7	56	87	132
Be	6.3	8.5	9.5	10.3
Cd	0.4	1.6	2.8	4.6
Co	8.9	16.3	19	21
Cr	28	49	59	63
Cu	56	89	107	137
Ga	43	116	140	178
Mn	207	231	261	317
Mo	9.1	28	40	50
Ni	25	37	44	40
Pb	73	169	226	278
Sb	2.6	8.3	13	20.6
Se	19	59	78	198
U	8.8	16	22	29
V	86	178	244	327
W	3.4	8.6	16	24
Zn	71	194	304	550

*Ondov *et al.* 1979.

Most trace elements are highly concentrated in the finest (respirable) fraction of the fly ash. Most researchers attribute this phenomenon to condensation on the large surface area. However, there may be other causes for this phenomenon.

Table 6. Average percent removal*.

element	coal cleaning	in boiler	Post combustion
As	45	43	97
Be		65	98
Cd	38	60	85
Cr	49	50	97
F	50		
Mn		56	98
Pb	55	52	93
Hg	21	8	
Ni	43		25

Finkelman and French, 1998.

Emission into the atmosphere of a significant proportion of many trace elements can be reduced by selective mining, coal cleaning, differentiation in the boiler, and by post combustion pollution control systems.

Table 7. Percent of atmospheric emissions (1990)*.

Element	percent
Pb	1.5
Ni	2.5
Cd	2.5
As	4.0
Cl	5.0
Hg	34.0
Se	37.5

* EPA, Finkelman and French, 1998

These data indicate that coal combustion contributes only modest amounts of most trace elements into our atmosphere.

Table 8. Known health effects of trace elements in coal

Trace Elements	Known Health Effects
Arsenic	China – Skin Cancer ~10,000 people Former Czechoslovakia – Impaired hearing in children
Fluorine	Fluorosis affects 10 Million+ in China
Selenium	Selenosis in China Fish kills – Texas, N.orthCarolina
Mercury	Various health problems in pregnant women and populations eating Hg-contaminated fish
Beryllium	Increased autoantibodies – former Czechoslovakia
Uranium	None known

Table 9. Predicted cancer fatalities due to ionizing radiation: General population, average dose (assume one cancer fatality per 5000 person-rem).

		radiation fatalities	
	mrem/yr	total number in U.S. per year	per million persons per year
medical diagnostic	70	3080	14
Cosmic radiation	35	1540	7
terrestrial (rocks, soil, etc.)	35	1540	7
potassium-40 in food	20	880	4
nuclear weapons fallout	4.4	194	0.9
use of natural gas in homes	2	89	0.4
BURNING OF COAL	1	44	0.2
sleeping with another person	0.1	4.4	0.02
nuclear power	0.1	4.4	0.02
consumer products (TV, etc.)	0.03	1.3	0.006

There are relatively few cancer fatalities attributed to ionizing radiation from coal combustion.

Health Impacts of Coal:

Should we be concerned?

It Depends

Probably not, if

- high quality coal
- coal beneficiated
- post combustion pollution control
- managed disposal practices

Definitely yes, if

- poor coal quality
- no beneficiation
- no pollution control
- residential use

Health Impacts of Residential Coal Use in China

Introduction

Arsenic poisoning (arsenism) caused by domestic combustion of mineralized coal affects about 10,000 people in southwest China. Fluorine poisoning (fluorosis) may affect as many as 10 million people in the same region.

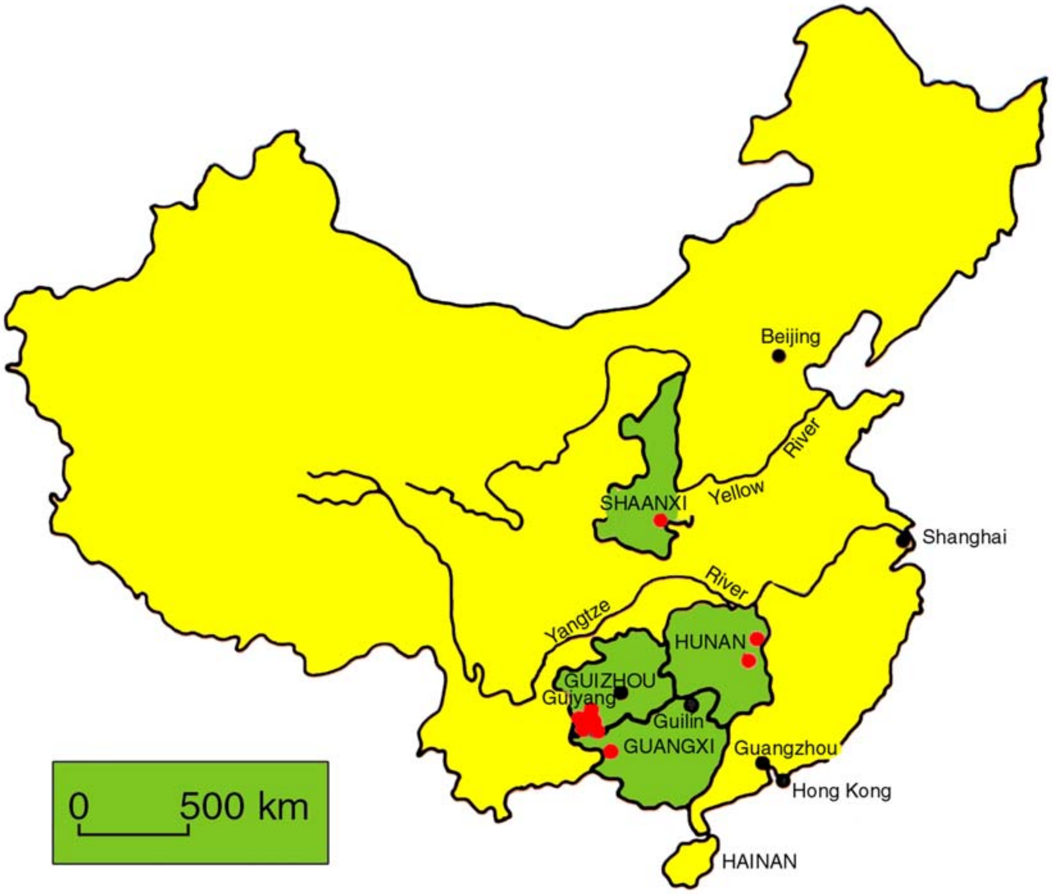


Figure 1. The areas of endemic arsenism are in southwest Guizhou Province. The red dots mark the locations of "carlin-type" sedimentary rock-hosted gold deposits. The emplacement of the gold and arsenic were likely deposited by the same mineralizing fluids.

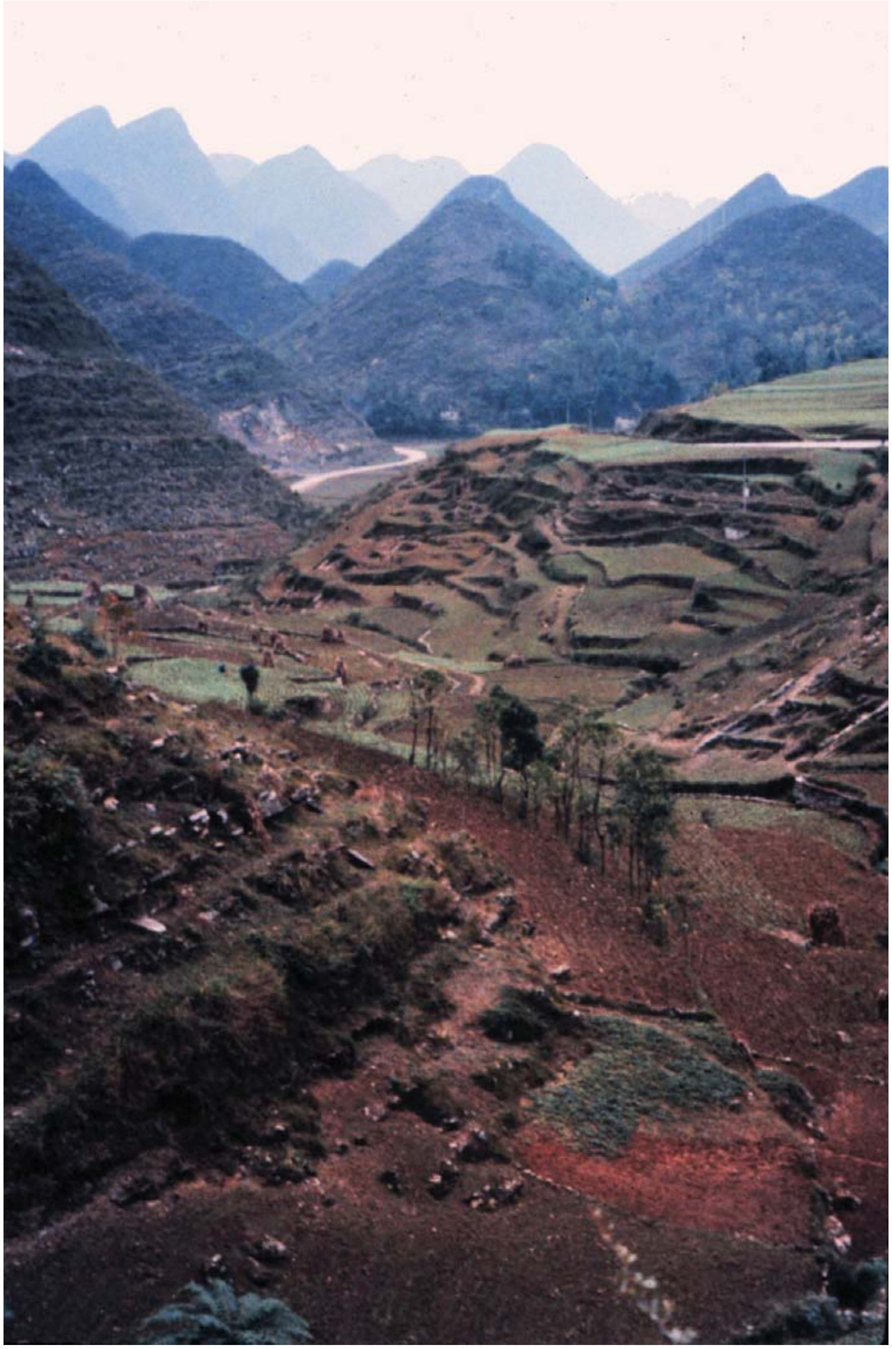


Figure 2. Much of Guizhou Province is underlain by Permian and older limestones on which have developed classic karst topography. The topographic elevations are generally between 2,000 and 3,000 meters. It is chilly and damp in the fall and winter. The health problems in the region are a consequence of the complex interaction of geology, topography, climate, and cultural factors including housing style, food preferences, energy needs, and economic conditions.

Figure 3. A small village in Guizhou Province, China. Note that none of the houses have chimneys, even though all of them contain coal-burning stoves.

Figure 4. Typical small coal mining operation in Guizhou Province, China. As men mine the coal, women load the trucks. By the early 1900s the forests had been essentially denuded and the people turned to the abundant coal resources for their primary energy needs. Unfortunately, some of the coals had experienced mineralization which cause them to be deleterious to human health when improperly combusted.

Figure 5. Even in major cities such as Guiyong, coal is used as the primary fuel for heating shops.

Figure 6. View of a typical coal mine in Guizhou Province, China. Mine opening is approximately 0.5 m wide. Note the absence of timber supports. Coal in the vicinity of this mine contains 35,000 parts per million (ppm) arsenic (As)! U.S. coal has, on average, 20 ppm As. Also nearby is a small gold mining operation. Some of the coal samples have ore grade concentrations of gold (600 ppb to 3 ppm in the coal ash).

Figure 7. The coal is primarily used in open, unvented ovens in homes for cooking, heating, and to boil water. In the fall, foods are brought indoors and dried over the ovens because it is too cool and damp for them to dry outdoors. Fresh chili peppers contain less than 1 ppm As. Chili peppers dried over the high-As coals have as much as 500 ppm As! While some As is inhaled during combustion, the majority enters the body when dried peppers are eaten in meals.

Figure 8. Consequence of eating food (and inhaling fumes) laden with As. The body tries to reject the As by moving it to the hair, fingernails, and urine. If that is not sufficient to purge the As, the body moves the As as far away from the internal organs as possible, to the hands, feet, and skin. The subtle signs of arsenism include a reddening of the skin and skin lesions, here appearing as freckles (melanosis).

Figure 9. Example of typically extensive keratosis (skin disease characterized by horny tissue overgrowths). Dark lesion above left breast was diagnosed as Bowen's disease -- a precancerous lesion of the skin or mucous membranes characterized by small solid elevations covered by thickened horny tissue.

Figure 10. Advanced hyperkeratosis. Extensive lesions covering the hands are common.

Figure 11. Hyperkeratosis of the feet. Note the dark, likely cancerous, lesions on both feet.

Figure 12. Cancer of the thumb which was eventually amputated.

Figure 13. Cancer of the hand. Even though the hand was amputated, the patient subsequently died of cancer.

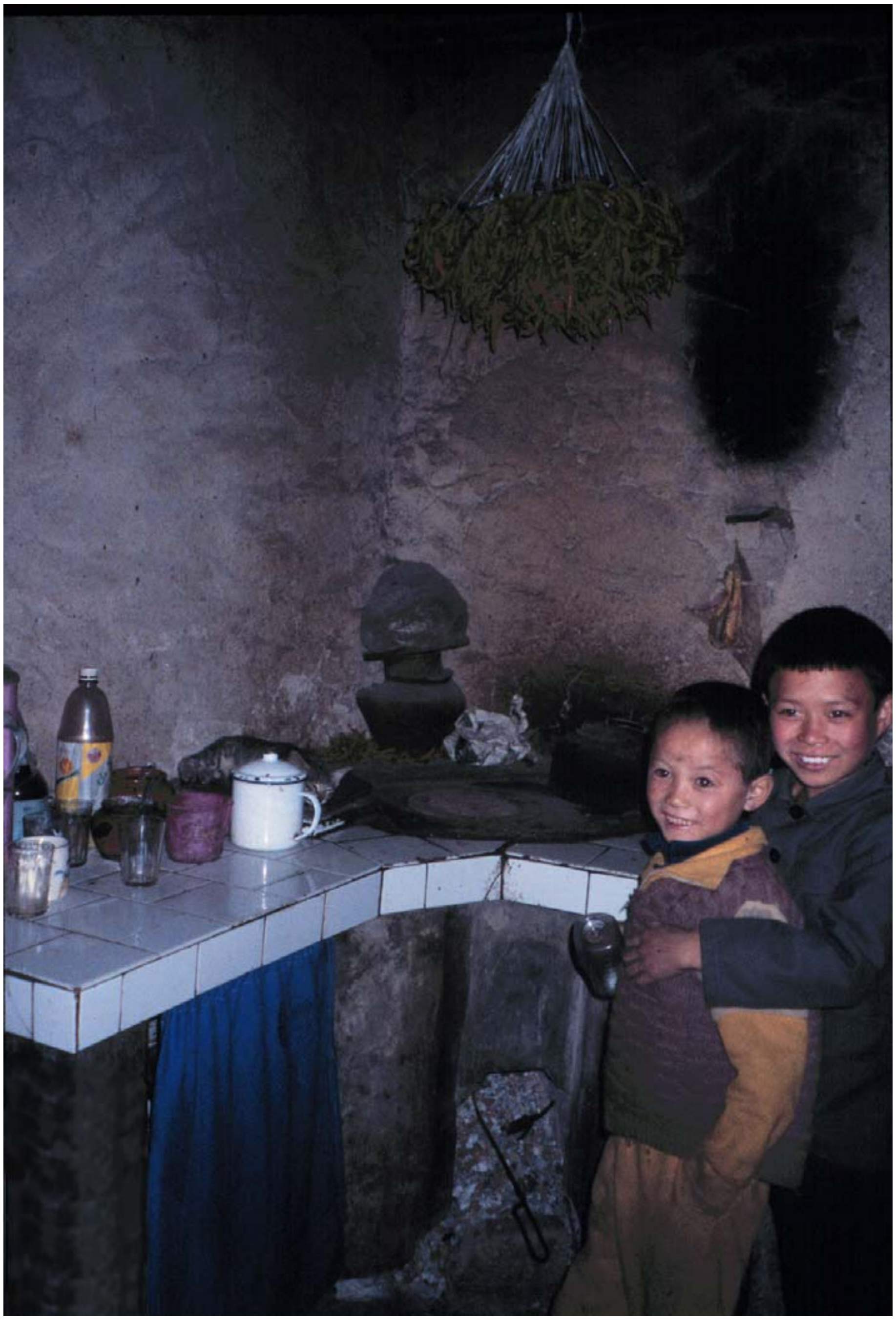


Figure 14. Although severe cases of cancer have become less common in recent years, these problems still persist. This photograph shows young boys in their home. Note the unvented coal-burning oven, scorch marks on the wall, and chili peppers drying over the stove.

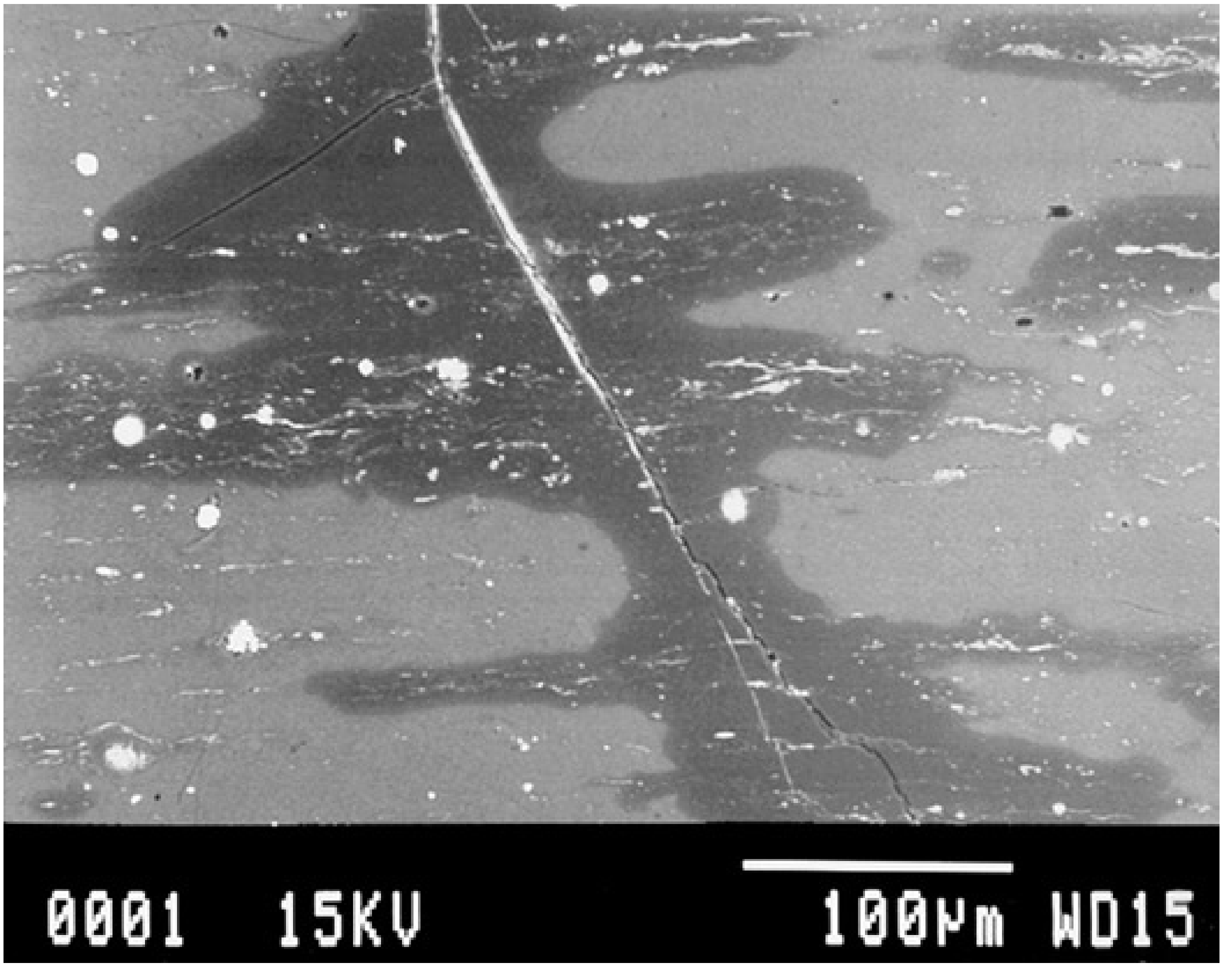


Figure 15. This scanning electron photomicrograph shows a backscattered electron image of a polished block of arsenic-rich coal from Guizhou Province, China. Dark areas are coal, bright areas are minerals (mainly pyrite), milky-colored area is organically-bound arsenic.

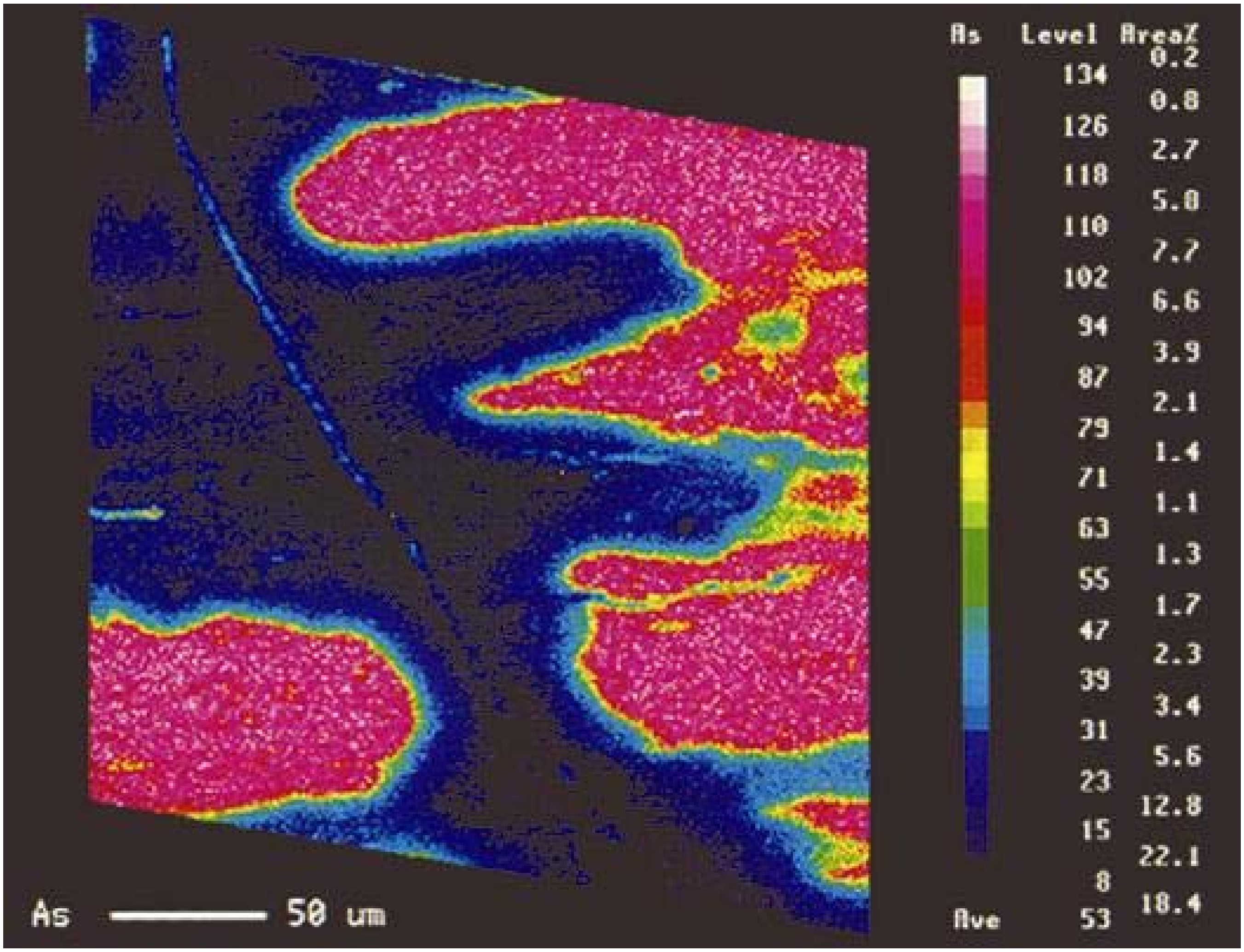


Figure 16. Wavelength-dispersive X-ray map showing the distribution of arsenic in the sample depicted above (see Figure 15). Compare the distribution of the arsenic to the outline of the milky-colored area in the scanning photomicrograph. This indicates that the arsenic is found in the organic matrix of the coal, and not in the mineral (pyrite) fraction as is almost always the case.

Figure 17. Corn drying over an open, unvented coal-burning oven in a villager's house in Guizhou Province, China. Corn is thought to be the primary source of excess fluorine in the diet.

Figure 18. Villagers prepare briquettes by pulverizing moist coal containing 100 - 200 ppm F (in contrast, most coals worldwide have 50 - 100 ppm F). The pulverized coal is then mixed with clay to form briquettes to control combustion temperature and timing. The clay used is the residue of intense weathering of the local limestone. These local residual clays are typically enriched in F (commonly > 1,000 ppm).

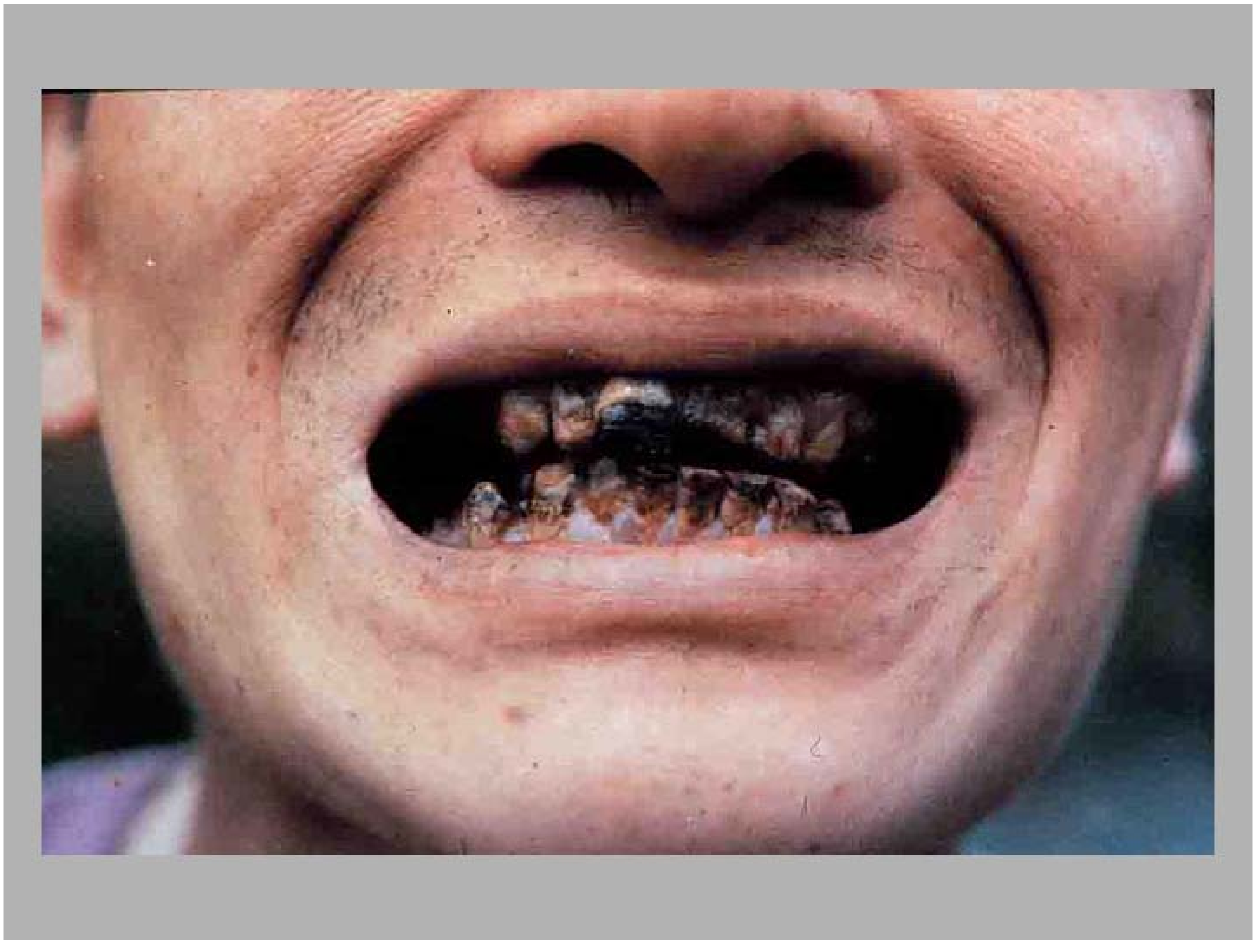


Figure 19. Dental fluorosis: mottling of the teeth is the most common consequence of ingesting high-fluorine corn products and breathing fluorine-rich emissions. About 10 million people in the region suffer from dental fluorosis.

Figure 20. Photo showing skeletal fluorosis, resulting as spinal curvature, a common manifestation.

Figure 21. Consequences of fluorosis and vitamin D deficiency. Entire families have shown these symptoms.

Figure 22. Gathering about a coal fire at night. Exposure to polycyclic aromatic hydrocarbons from the incomplete combustion of the coal may lead to respiratory problems such as lung cancer. About 3.5 billion people worldwide are exposed to indoor air pollution such as this.

Mercury in U.S. Coals

Introduction

Mercury is the only element for which legislation is being considered to reduce emissions from coal combustion in the US. The mercury emitted from the power plants is not harmful; however, in the natural environment the mercury can go through a series of chemical transformations that convert the mercury to a highly toxic form that is concentrated in fish and birds (Figure 23). The most toxic form of mercury is methylmercury, which is an organic form created by bacterial conversion of inorganic mercury. Methylation rates (creation of methylmercury) in ecosystems are a function of mercury availability, bacterial population, nutrient loads, pH and Eh, sediment load, and sedimentation rates (National Research Council, 1978). Methylmercury enters the food chain, particularly in aquatic organisms and bioaccumulates. Cases of mercury poisoning have occurred from eating contaminated fish for prolonged periods, both in the U.S. and abroad. Pregnant woman and subsistence fisherman are particularly vulnerable. Because high levels of mercury have been detected in fish, many U.S. States have issued temporary, regional fishing advisories that restrict fishing.

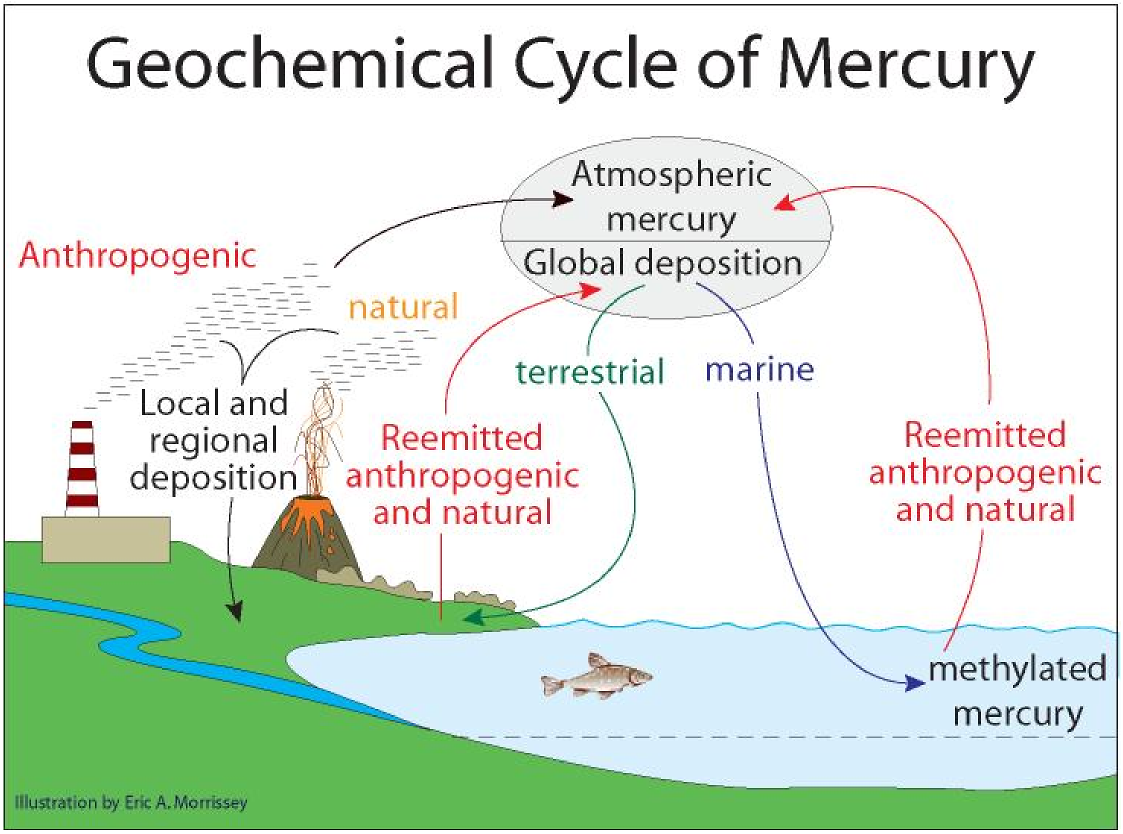


Figure 23. Geochemical cycle of mercury in the environment. Methylation occurs via aquatic microorganisms.

Table 10. Global Emissions of Hg to the Atmosphere per Year

- Total Emissions 6,000 to 8,000 metric tons
- Natural Sources of Hg 3,000 to 3,500 tons
    - Ocean may contribute as much as half
    - Erupting Volcanoes
    - Soil Vapor Flux
    - Geothermal Systems/Hot Springs
    - Degassing Volcanoes and Fumaroles
    - Vapor Flux from Mineralized Areas
    - Active Faults

About 50 tons of mercury are emitted each year from U.S. coal-burning power plants. Coal burning is the largest uncontrolled anthropogenic source of mercury.

One issue under consideration is how much mercury is deposited in the U.S. from coal combustion in Asia?

Table 11. Mercury values in selected U.S. coal areas from the COALQUAL* database.

coal area	mean (ppm**)	maximum (ppm)	number of samples
Appalachian	0.20	2.9	4,399
Eastern interior	0.10	0.4	301
Fort Union	0.13	1.2	300
Green River	0.09	1.0	418
Gulf Coast	0.22	0.6	29
Hams Fork	0.09	1.0	142
Pennsylvania anthracite	0.18	1.3	52
Powder River	0.10	1.4	616
Raton Mesa	0.09	0.5	40
San Juan River	0.08	0.9	194
Southwest Utah	0.10	0.5	42
Uinta	0.08	0.6	271
Western interior	0.18	1.6	311
Wind River	0.18	0.8	42

*COALQUAL = U.S. GEOLOGICAL SURVEY COAL QUALITY (COALQUAL) DATABASE: VERSION 2.0 (http://energy.er.usgs.gov/products/databases/CoalQual/index.htm)
**ppm = parts per million

Data from Bragg et al., 1998

Mercury concentration in coal. This is the way that mercury data are presented in most publications. This may be misleading because, in order to obtain similar energy outputs, more low-rank coal has to be burned than a higher-ranked coal. This can result in a net mobilization of more total mercury to the environment. A better way to compare mercury data for coal is on an equal energy basis.

Table 12. Mercury on equal energy basis, mean values for samples in selected U.S. coal areas.

coal area	mercury (pounds / 10^{12} BTU*)	mean (ppm**)
Appalachian	15.4	0.20
Eastern interior	8.2	0.10
Fort Union	21.8	0.13
Green River	6.6	0.09
Gulf Coast	36.4	0.22
Hams Fork	4.8	0.09
Pennsylvania anthracite	15.4	0.18
Powder River	12.6	0.10
Raton Mesa	6.6	0.09
San Juan River	7.7	0.08
Southwest Utah	11.0	0.10
Uinta	7.3	0.08
Western interior	16.1	0.18
Wind River	18.7	0.18

* BTU = British thermal units
** ppm = parts per million

Data from Bragg et al., 1998

Mercury contents in coal vary between coal basins.

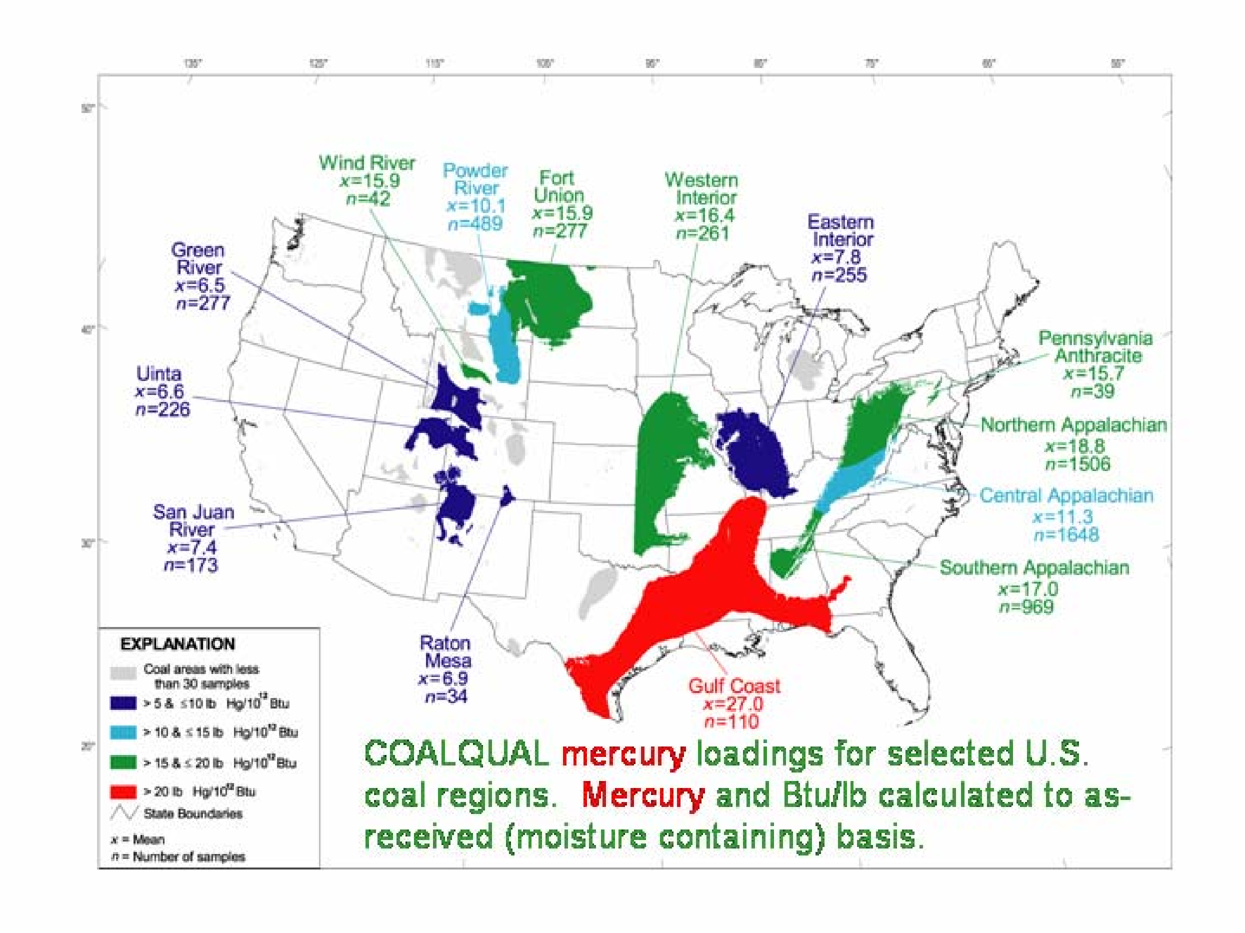


Figure 24. Mercury input loadings (in pounds of Mercury per 10^{12} British thermal units (lbs Hg/10^{12} Btu) of in-ground coal for selected U.S. coal-producing regions. From Tewalt and others, 2001. See footnote to Table 11 for COALQUAL reference.

Table 13. Mercury input loads (pounds / 10^{12} BTU*) for top-producing U.S. coal beds.

coal bed(s)	mean	maximum	number of samples
Wilcox Group (GC[1])	26.4	79.4	34
Upper Freeport (APP[2])	25.1	32.0	226
Lower Freeport (APP)	24.5	120.0	100
Lower Kittanning (APP)	18.5	70.1	182
Middle Kittanning (APP)	17.8	115.0	231
Blue Creek (APP)	15.2	55.3	62
Pittsburgh (APP)	13.9	84.6	128
Alma (APP)	11.9	55.8	18
Stockton-Lewiston (APP)	10.6	51.6	20
Cedar Grove (APP)	9.0	32.0	15
Number 2 Gas Lower Elkhorn (APP)	8.6	32.8	35
Chilton (APP)	7.0	12.6	2
Pocahontas Number 3 (APP)	6.8	47.0	50
Winifrede (APP)	6.8	35.0	20
Coalburg (APP)	4.6	19.4	25
Wyodak, Wyodak-Anderson (PRB[3])	19.0	126.0	36
Rosebud, Rosebud-McKay (PRB[3])	8.6	28.4	10
Number 12 (EINT[4])	10.4	24.9	7
Number 6 (EINT)	8.4	2.38	23
Number 9 (EINT)	6.2	20.7	16
Beulah-Zap (FU[5])	8.6		10

*BTU = British thermal units

1. GC = Gulf Coast
2. APP = Appalachian
3. PRB = Powder River Basin
4. EINT = Eastern Interior

Data from Bragg et al., 1998

Mercury contents vary within coal basins, between coal beds in each basin and within each bed.

Modes of Occurrence of Mercury in Coal

- mercury is generally associated with pyrite, commonly secondary, arsenic-bearing pyrite
- small proportions appear to be associated with clays and the organics
- in coal with low iron content (no pyrite), mercury occurs as a selinide

It is the mode of occurrence of an element that will determine how it will behave during coal cleaning.

Mercury Emission – Reduction

- Physical coal cleaning may be effective in removing mercury. Conventional coal cleaning removes about 37% of the mercury, on average.
- Selective mining may also be a practical option for reducing mercury emissions.
- Modifying combustion conditions, such as using fluidized-bed combustion which operates at lower temperatures than do conventional power plants and as a limestone 'bed' that may capture pollutants.
- Post combustion pollution control – use of electrostatic precipitators or baghouses to capture particulates, or flue-gas desulfurization systems to remove pollutants from the gaseous effluents. New pollution control systems (such as carbon injection) designed specifically for mercury capture are being developed and tested.

Balkan Endemic Nephropathy

Introduction

Toxic organic substances leached from low-rank coal (lignite) beds into groundwater aquifers might be a cause of Balkan endemic nephropathy (BEN), a disease resulting in end-stage kidney failure that affects tens of thousands of people in rural villages of Romania, Bulgaria, Croatia, Serbia, Bosnia, and Kosovo. The causative agent of BEN may also cause cancer of the renal pelvis, which is found in about half of all patients with the disease (in contrast to this cancer's occurrence in less than 1% of the overall population).

Figure 25. A typical panorama of a Balkan endemic nephropathy afflicted village from Romania. Usually the endemic villages are located in alluvial valleys of the Danube River affluents, at low elevations (valley bottoms). Danube River is located across the hills, on the right.

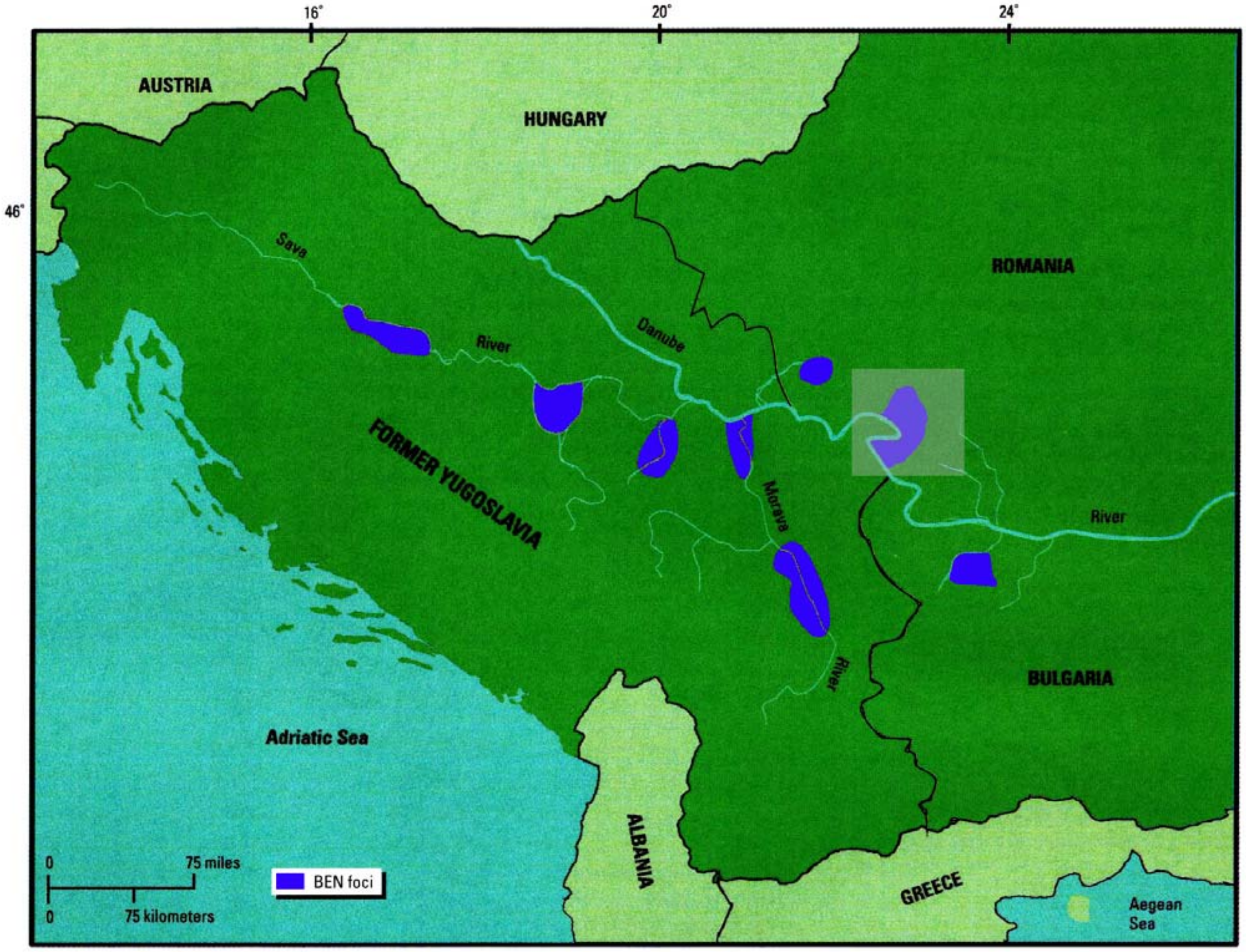


Figure 26. BEN occurs in foci called “endemic areas” located in alluvial valleys of tributaries of the Danube River in Bosnia, Bulgaria, Croatia, Romania, and Serbia.

Figure 27. BEN patient from Southwestern Romania awaiting dialysis treatment at a clinic. BEN patients are transported every 2 to 3 days by ambulance from rural villages to clinics for treatment. Many also acquire hepatitis from overused dialysis equipment.

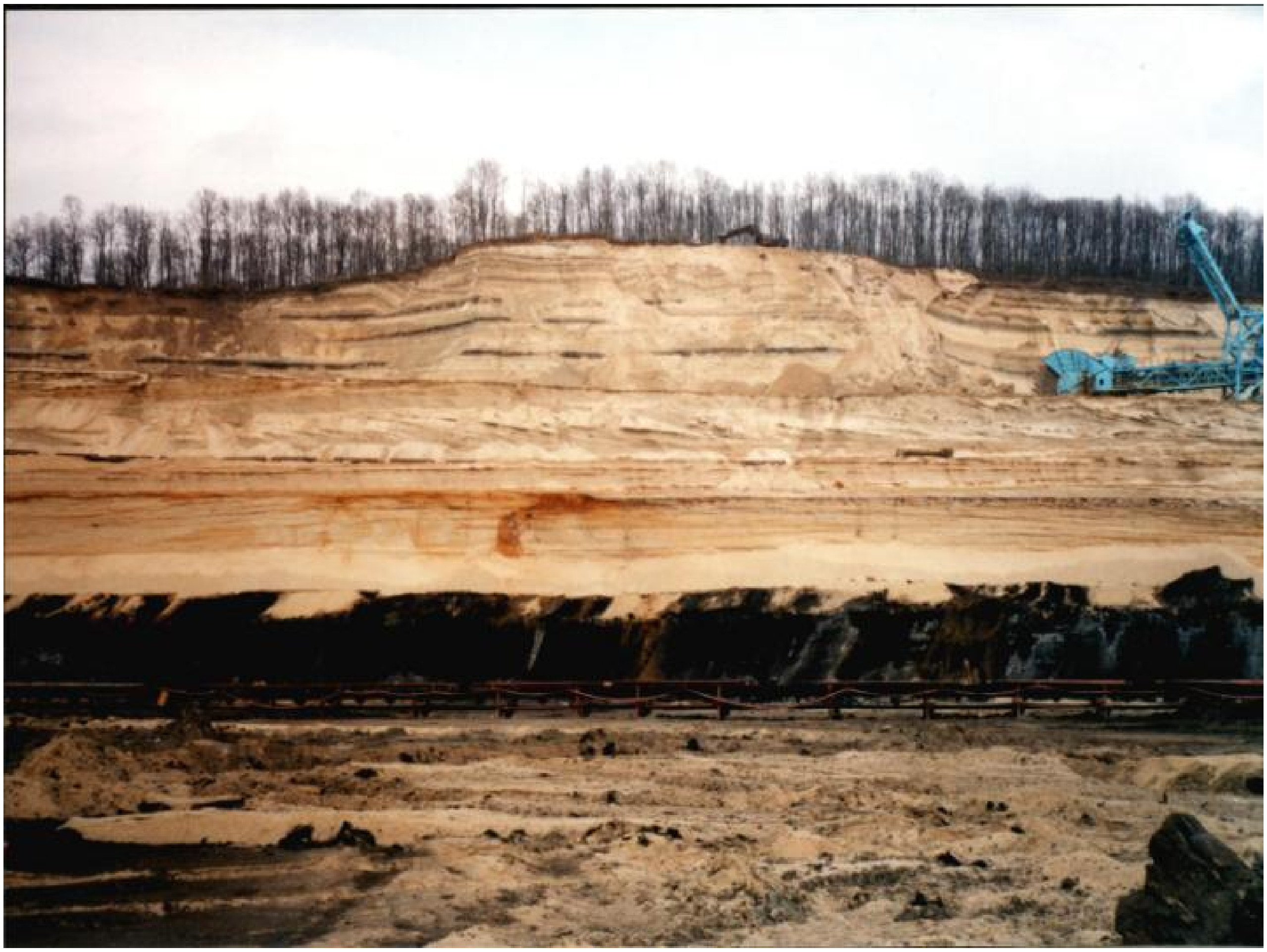


Figure 28. Picture of Pliocene lignite seams from a mine in the endemic area of Romania. These coals lie in the steep hills above the endemic villages and in some cases underlie the villages.

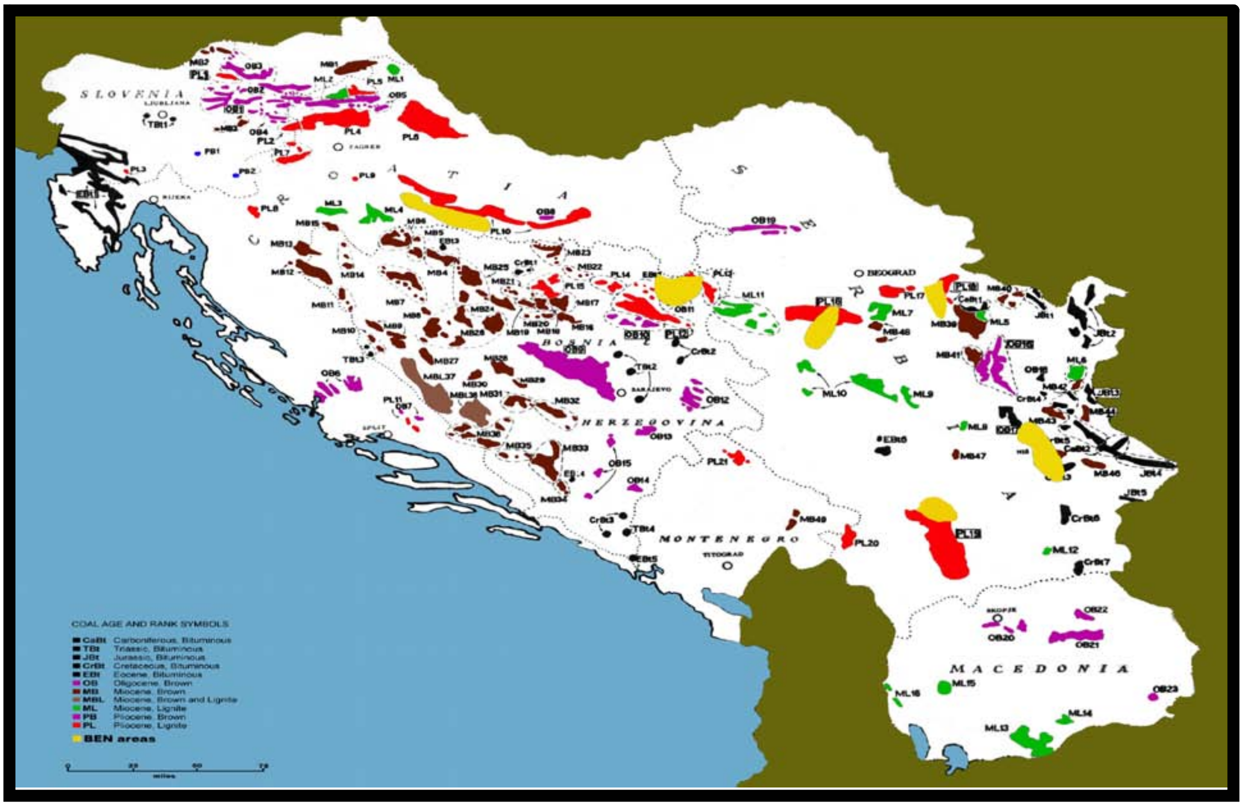


Figure 29. In the early 1990's USGS scientists noted the close geographic correspondence between endemic areas and Pliocene lignite beds in Yugoslavia. Map shows BEN-endemic areas in yellow and locations of Pliocene lignite beds in red (other colors represent coals of other ranks). This observation and subsequent field and laboratory investigations led USGS researchers to generate the "Pliocene lignite hypothesis" to explain the cause of BEN.

Figure 30. USGS scientists taking water sample from a shallow, hand-dug well in an area of Romania endemic for BEN. Note plastic-lined amber bottles in which water samples are shipped to the USA for laboratory analysis. Solvent (3% dichloromethane) is added to the bottles to inhibit algal and microbial growth, and to initiate the organic compound extraction procedure.

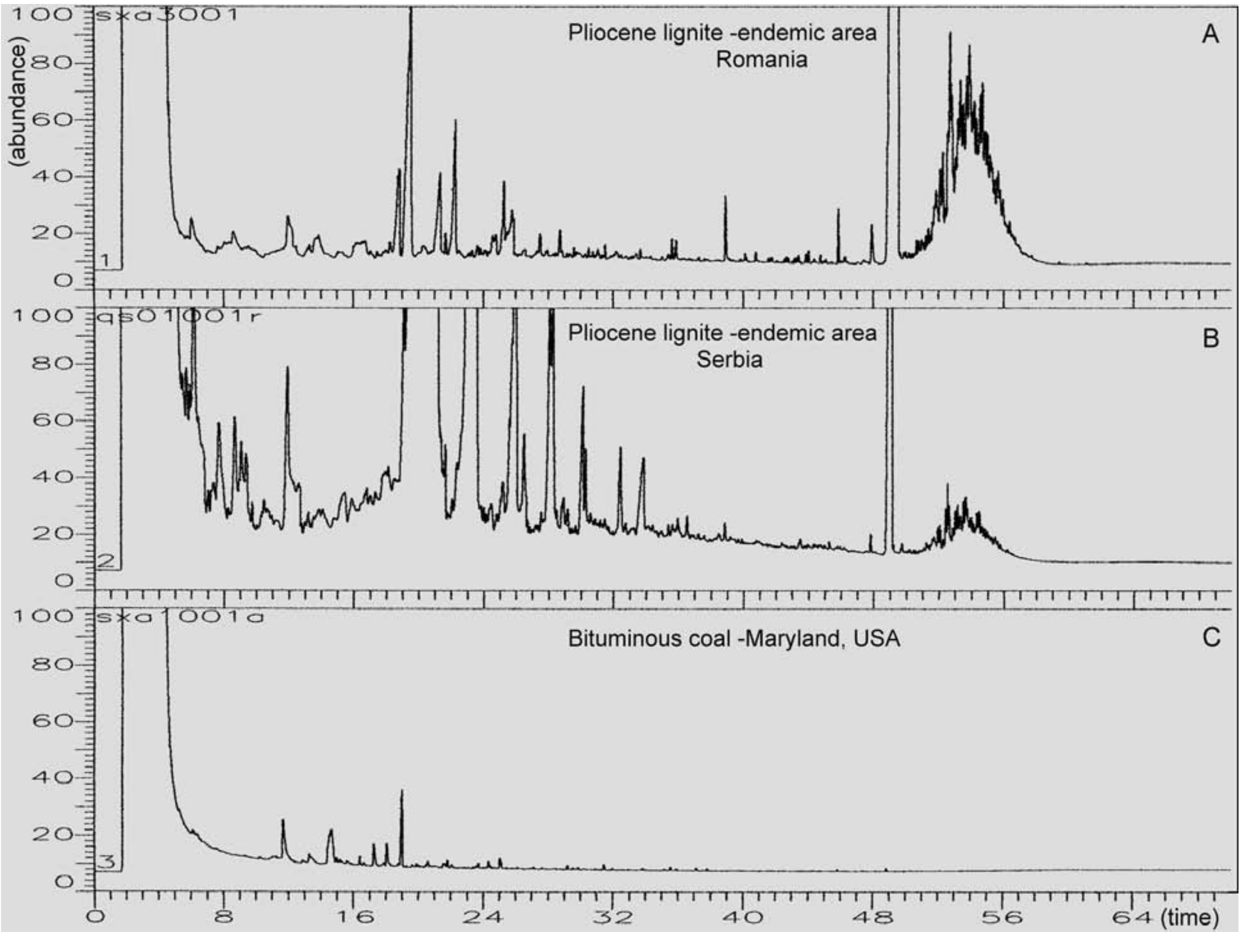


Figure 31. Total ion current (TIC) chromatograms (generated using gas chromatography and mass spectrometry) of laboratory water extracts of Pliocene lignites from two BEN-affected areas -- Romania (A) and Serbia (B) -- and of a bituminous coal from Maryland, USA (C) as a negative control. Peaks indicate the presence of potentially toxic organic compounds. Absorbance units on y-axis indicate the relative concentrations of compounds, while retention time in minutes along the x-axis is used to identify individual compounds or classes of compounds.

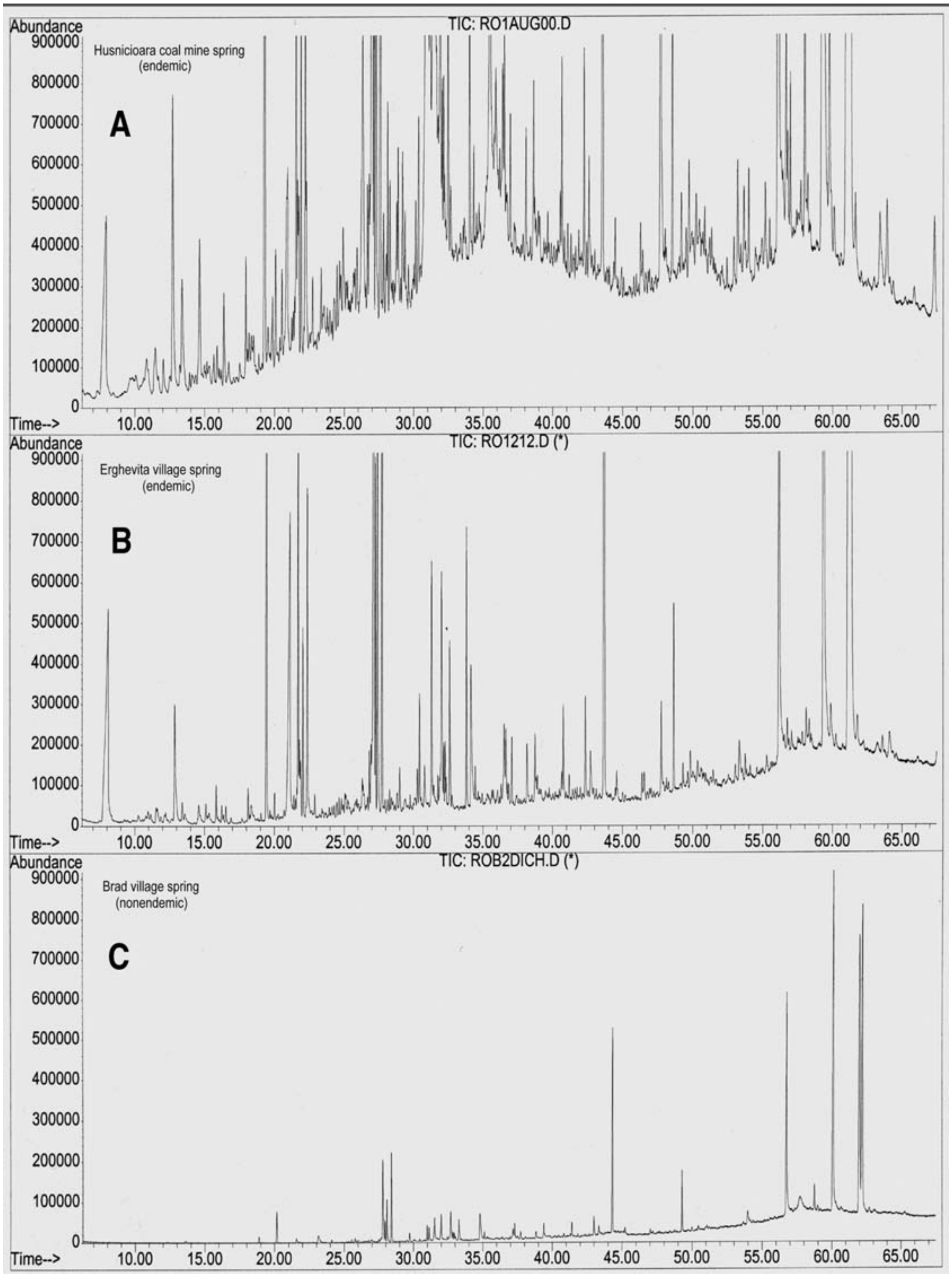
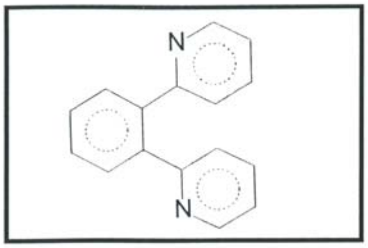
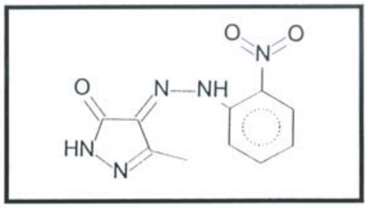


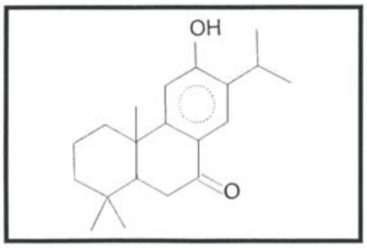
Figure 32. TICs (see caption to Figure 31 for explanation) for water samples. Panel A.) Seep from a Pliocene lignite bed in a BEN-endemic area of Romania; Panel B.) Well water from an endemic village in Romania; Panel C.) Spring water from a nonendemic (control) village in Romania.



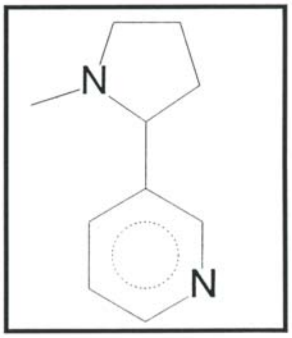
Pyridine, 2,2' – (1,2 – phenylene) bis-



4-O-Nitrophenylhydrazono-3-methyl -2-pyrazolin-5-one



9(1H)-Phenanthrenone, 2,3,4,4a,10,10a-Hexahydr0-6-hydroxy-1,1,4a-trimethyl-7-(1-methylethyl)-, (4aS-trans)-



Pyridine, 3-(1-methyl-2-pyrrolidinyl)-, (S)-

Figure 33. Examples of the types of compounds tentatively identified in well water from endemic villages in Romania, and from water extracts of Pliocene lignites from the endemic region of Romania.

CONCLUSION

Emissions from industrial coal and coal product combustion in the United States do not present a significant acute threat to human health. The burning of coal in residential settings, however, has had a serious impact on human health, especially in developing countries. This is due to the improper use of coal (such as burning in unvented stoves), or the use of inappropriate coal (for example, cooking foodstuffs with arsenic-enriched coal). Coal scientists and technologists are ideally positioned to help medical and public health specialists improve health status in these countries by providing scientific research, analytical data, technical training, and modern technology such as digital maps. The information being generated may help to minimize the health impacts of coal use and help to avoid future threats to human welfare.

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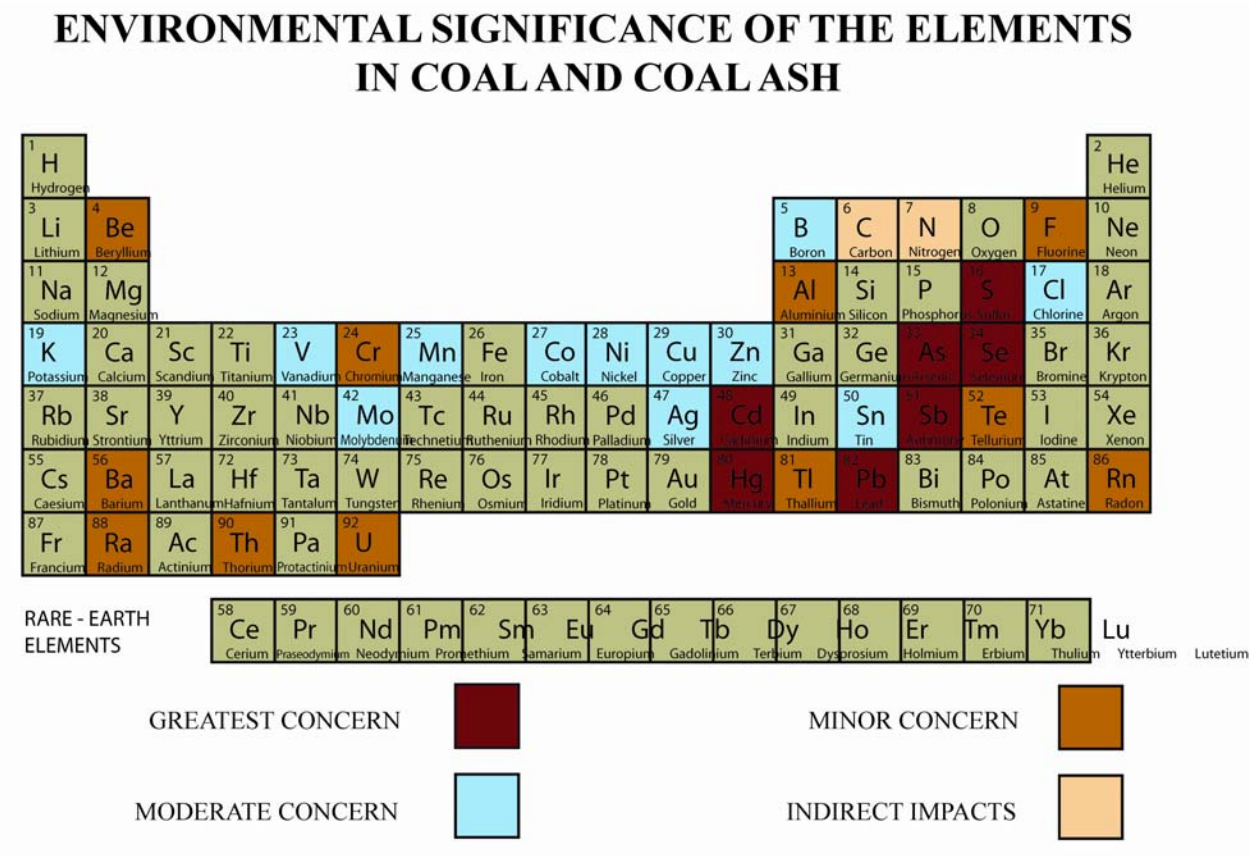
Appendices

Appendix I.



Appendix II.

Arithmetic and geometric means for chemical elements in U.S. coal. All values are on a coal basis. Data are exclusively from the U.S. Geological Survey (USGS) except for estimated values in parenthesis which are based on USGS and literature data. Values in brackets are calculated from cerium and lanthanum data and assuming a chondrite normalized rare-earth-element distribution pattern. (n.d. = no data; S.D. = standard deviation; Max. = maximum; Num. = number of samples)

	Arithmetic		Geometric			
Component	Mean	S.D.	Mean	S.D.	Max.	Num.
Ash %	13.1	8.3	10.9	1.9	50.0	7976
Aluminum (Al) %	1.5	1.1	1.1	2.1	10.6	7882
Antimony (Sb) ppm	1.2	1.6	.61	3.6	35	7473
Arsenic (As) ppm	24	60	6.5	5.5	2200	7676
Barium (Ba) ppm	170	350	93	3.0	22000	7836
Beryllium (Be) ppm	2.2	4.1	1.3	3.5	330	7484
Bismuth (Bi) ppm	(<1.0)	n.d.	n.d.	n.d.	14	920
Boron (B) ppm	49	54	30	3.1	1700	7874
Bromine (Br) ppm	17	19	9.1	4.1	160	4999
Cadmium (Cd) ppm	.47	4.6	.02	18	170	6150
Calcium (Ca) %	.46	1.0	.23	3.3	72	7887
Carbon (C) %	63	15	62	1.3	90	7154
Cerium (Ce) ppm	21	28	5.1	7.1	700	5525
Cesium (Cs) ppm	1.1	1.1	.70	3.2	15	4972
Chlorine (Cl) ppm	614	670	79	41	8800	4171
Chromium (Cr) ppm	15	15	10	2.7	250	7847
Cobalt (Co) ppm	6.1	10	3.7	2.9	500	7800
Copper (Cu) ppm	16	15	12	2.1	280	7911
Dysprosium (Dy) ppm	1.9	2.7	.008	35	28	1510
Erbium (Er) ppm	1.0	1.1	.002	73	11	1792
Europium (Eu) ppm	.40	.33	.12	5.8	4.8	5268
Fluorine (F) ppm	98	160	35	15	4000	7376
Gadolinium (Gd) ppm	(1.8)	n.d.	n.d.	n.d.	39	2376
Gallium (Ga) ppm	5.7	4.2	4.5	2.1	45	7565
Germanium (Ge) ppm	5.7	14	.59	16	780	5689
Gold (Au) ppm	(<0.05)	n.d.	n.d.	n.d.	n.d.	n.d.
Hafnium (Hf) ppm	.73	.68	.04	38	18	5120
Holmium (Ho) ppm	(0.35)	n.d.	n.d.	n.d.	4.5	1130
Hydrogen (H) %	5.2	.09	5.2	1.2	9.5	7155
Indium (In) ppm	(<0.3)	n.d.	n.d.	n.d.	n.d.	n.d.
Iodine (I) ppm	(<1.0)	n.d.	n.d.	n.d.	n.d.	n.d.
Iridium (Ir) ppm	(<0.001)	n.d.	n.d.	n.d.	n.d.	n.d.
Iron (Fe) ppm	1.3	1.5	.75	2.9	24	7882
Lanthanum (La) ppm	12	16	3.9	6.0	300	6235
Lead (Pb) ppm	11	37	5.0	3.7	1900	7469
Lithium (Li) ppm	16	20	9.2	3.3	370	7848
Lutetium (Lu) ppm	.14	.10	.06	4.7	1.8	5008
Magnesium (Mg) %	.11	.12	.07	2.7	1.5	7887

Appendix II (cont.)

	Arithmetic		Geometric			
Component	Mean	S.D.	Mean	S.D.	Max.	Num.
Manganese (Mn) ppm	43	84	19	3.9	2500	7796
Mercury (Hg) ppm	.17	.24	.10	3.1	10	7649
Molybdenum (Mo) ppm	3.3	5.6	1.2	6.5	280	7107
Neodymium (Nd) ppm	(9.5)	n.d.	n.d.	n.d.	230	4749
Nickel (Ni) ppm	14	15	9.0	2.8	340	7900
Niobium (Nb) ppm	2.9	3.1	1.0	7.7	70	6843
Nitrogen (N) %	1.3	0.4	1.3	1.4	13	7153
Osmium (Os) ppm	(<0.001)	n.d.	n.d.	n.d.	n.d.	n.d.
Oxygen (O) %	16	12	12	2.0	60	7151
Palladium (Pd) ppm	(<0.001)	n.d.	n.d.	n.d.	n.d.	n.d.
Phosphorus (P) ppm	430	1500	20	20	58000	5079
Platinum (Pt) ppm	(<0.001)	n.d.	n.d.	n.d.	n.d.	n.d.
Potassium (K) %	.18	.21	.10	3.5	2.0	7830
Praseodymium (Pr) ppm	(2.4)	n.d.	n.d.	n.d.	65	1533
Rhenium (Re) ppm	(<0.001)	n.d.	n.d.	n.d.	n.d.	n.d.
Rhodium (Rh) ppm	(<0.001)	n.d.	n.d.	n.d.	n.d.	n.d.
Rubidium (Rb) ppm	21	20	.62	41	140	2648
Ruthenium (Ru) ppm	(<0.001)	n.d.	n.d.	n.d.	n.d.	n.d.
Samarium (Sm) ppm	1.7	1.4	.35	13	18	5151
Scandium (Sc) ppm	4.2	4.4	3.0	2.3	100	7803
Selenium (Se) ppm	2.8	3.0	1.8	3.1	150	7563
Silicon (Si) %	2.7	2.4	1.9	2.4	20	7846
Silver (Ag) ppm	(<0.1)	.35	.01	9.1	19	5038
Sodium (Na) %	.08	.12	.04	3.5	1.4	7784
Strontium (Sr) ppm	130	150	90	2.5	2800	7842
Sulfur (S) %	1.8	1.8	1.3	2.4	25	7214
Tantalum (Ta) ppm	.22	.19	.02	13	1.7	4622
Tellurium (Te) ppm	(<0.1)	n.d.	n.d.	n.d.	n.d.	n.d.
Terbium (Tb) ppm	.30	.23	.09	7.7	3.9	5024
Thallium (Tl) ppm	1.2	3.4	.00004	205	52	1149
Thorium (Th) ppm	3.2	3.0	1.7	5.0	79	6866
Thulium (Tm) ppm	[0.15]	n.d.	n.d.	n.d.	1.9	365
Tin (Sn) ppm	1.3	4.3	.001	54	140	3004
Titanium (Ti) %	.08	.07	.06	2.2	.74	7653
Tungsten (W) ppm	1.0	7.6	.10	14	400	4714
Uranium (U) ppm	2.1	16	1.1	3.5	1300	6923
Vanadium (V) ppm	22	20	17	2.2	370	7924
Ytterbium (Yb) ppm	[0.95]	n.d.	n.d.	n.d.	20	7522
Yttrium (Y) ppm	8.5	6.7	6.6	2.2	170	7897
Zinc (Zn) ppm	53	440	13	3.4	19000	7908
Zirconium (Zr) ppm	27	32	19	2.4	700	7913