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Health Impacts of Coal: Facts and Fallacies

INTRODUCTION

Coal has contributed enormously to the advance of civilization by providing an abundant, inexpensive, and convenient source of energy. Concurrent with its contributions, coal has extracted a high cost in terms of environmental damage and human health impacts. Coal will remain a key component of the global energy mix for decades to come as well as a major source of global pollutants. Despite its high media profile, misconceptions about coal abound, especially with regard to its human health impacts. Coal also provides several excellent examples of how a geologic material and human health intersect in a variety of surprising ways. Unfortunately, the links between coal use and human health are distorted by a great deal of ignorance and misinformation. This paper discusses the facts and fallacies of the direct health impacts caused by coal (1, 2). There are a number of important health issues caused by coal that fall outside the scope of this review. The health impacts of particulates emitted from coal combustion have received substantial attention since the groundbreaking work of Wilson et al. (3), and through the recent discussions by Davis (4) and Freese (5). The indirect health impacts of coals through their contributions to global climate change, respirable particulates, acid rain, and acid mine drainage are also beyond the scope of this review. Greb et al. provide an excellent general overview of the environmental impacts of coal (6).

The potential for health impacts caused by exposure to trace elements has received considerable attention for the past quarter of a century. The US Environmental Protection Agency conducted an extensive study of this issue and concluded (7) that, with the possible exception of mercury, there was no compelling evidence of health impacts caused by the emission of trace elements from coal-burning electric generating utilities. Nevertheless, documented examples do exist of health impacts caused by trace elements emitted by coal combustion. Bencko and Symon (8) described hearing problems in children living near a power plant burning high arsenic coal in the former Czechoslovakia. But, perhaps the most significant example of health impacts caused by trace element release from coal use occurs in Guizhou Province, southwest China, where millions of people suffer from dental and skeletal fluorosis and thousands suffer from arsenic poisoning due to mobilization of these elements by burning mineralized coals in unvented or poorly vented stoves (Figs. 1a and b).

Health Impacts of Residential Coal Use

Zheng et al. (9) describe chronic arsenic poisoning, affecting several thousand people in Guizhou Province, PRC. Those affected exhibit typical symptoms of arsenic poisoning including hyperpigmentation (flushed appearance, freckles), hyperkeratosis (scaly lesions on the skin, generally concentrated on the hands and feet: Fig. 1a), Bowen's disease (dark, horny, precancerous lesions of the skin), and squamous cell carcinoma.

Belkin and coworkers (10, 11) conducted detailed chemical and mineralogical characterization of coal samples from this region and found several samples with >30 000 ppm arsenic. This is more than 1000 times the average and 15 times the maximum concentration of arsenic in nearly 10 000 coal samples from throughout the United States (12). The effects of burning these mineralized coals in a residential environment are further exacerbated by the practice of drying crops directly over the coal fires.

Zheng et al. have shown that chili peppers dried over open coal-burning stoves may be a principal vehicle for the arsenic poisoning (9). In the autumn it is commonly cool and damp in the higher elevations of Guizhou Province. It is common practice for the residents of this region to dry their corn and chili peppers directly over these coal fires.

Fresh chili peppers have less than 1 part per million (ppm) arsenic. In contrast, chili peppers dried over high-arsenic coal fires can have as much as 500 ppm arsenic. Significant amounts of arsenic may also come from other tainted foods, ingestion of dust (samples of kitchen dust contained as much as 3000 ppm arsenic), and from inhalation of indoor air polluted by arsenic derived from coal combustion. The arsenic content of drinking water samples was not considered to be a significant contributing factor.

The health problems caused by fluorine volatilized during domestic coal use are far more extensive than those caused by arsenic. More than 10 million people in Guizhou Province and surrounding areas suffer from various forms of fluorosis (13), and coal combustion induced fluorosis has also been reported from 13 other provinces, autonomous regions, and municipalities in China (14). Typical signs of fluorosis include mottling of tooth enamel (dental fluorosis: Fig. 1b) and various forms of skeletal fluorosis including osteosclerosis, limited movement of the joints, and outward manifestations such as knock-knees, bowlegs, and spinal curvature.

The cause of this type of fluorosis is similar to that of arsenic poisoning in that the disease is derived from foods dried over coal-burning stoves. Zheng and Huang have demonstrated that adsorption of fluorine by corn dried over unvented ovens burning high-fluorine (>200 ppm) coal is the probable cause of the extensive dental and skeletal fluorosis in southwest China (13). The problem is compounded by the use of clay as a binder for making briquettes. The clay commonly used is a high-fluorine (several hundred parts per million) residue formed by intense leaching of the limestone substrate. Ando et al. estimated that 97% of the fluoride exposure came from food consumption and 2% from direct inhalation (14).

Although there is considerable concern about the health effects of mercury and the proportion of anthropogenic mercury in the environment (15), to date there has been no direct evidence of health problems caused by mercury released from coal, but there are circumstances where poisoning from mercury released from coal combustion may be occurring. In a Guizhou Province village, many elderly villagers exhibit loss of vision. Mineralogical analysis of the coal being used in the homes of people having visual impairment revealed abundant mercury minerals. Chemical analysis of a coal sample being used in this village indicates a mercury concentration of 55 ppm, about 200 times the average mercury concentration in US coals (12). Because mercury acts as a neurotoxin, the loss of vision may be related to the high levels of mercury released from the coal used in this village.

Zheng et al. report nearly 500 cases of human selenosis in southwest China that are attributed to the use of selenium-rich carbonaceous shales known locally as "stone coal" (16). The stone coals may contain as much as several thousand parts per million of selenium. This selenosis is attributed to emission of

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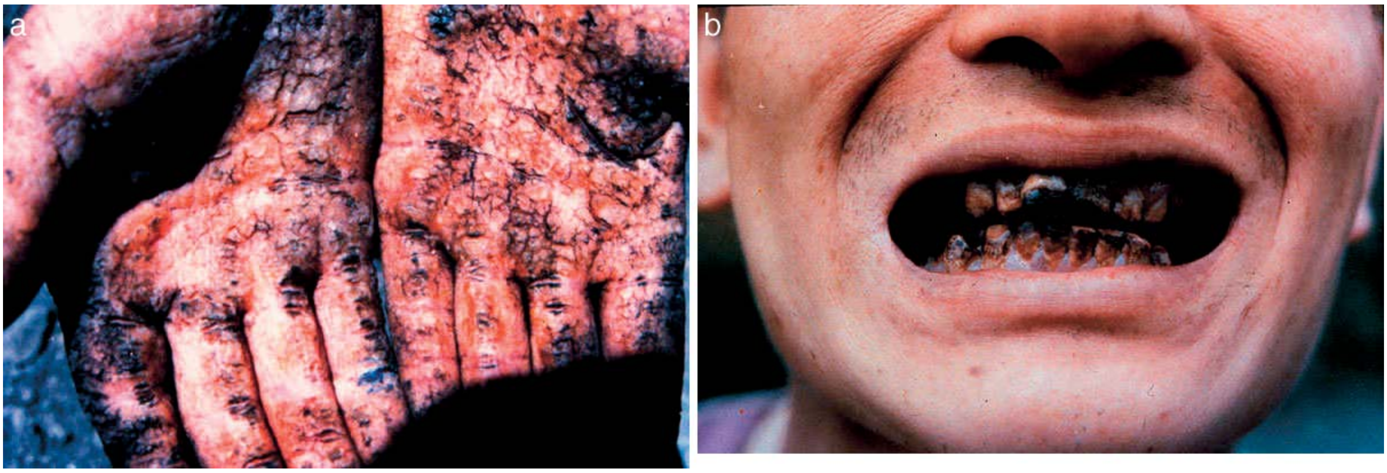

Figure 1. (a) Hyperkeretosis caused by exposure to arsenic mobilized by burning mineralized coals in a residential environment. (b) Dental fluorosis caused by exposure to arsenic mobilized by burning mineralized coals in a residential environment.

selenium from the combustion of the stone coal and the practice of using combustion ash as a soil amendment. This process introduced large amounts of selenium into the soil and resulted in selenium uptake by crops. Symptoms of selenium poisoning include hair and nail loss.

The health problems caused by trace element release by coal combustion can be minimized or eliminated in several ways. Coal quality databases and maps illustrating the coal quality variations can help to identify coal deposits with high trace element contents. Belkin et al. describe a simple test kit than can be used at the mine to test the coal for its arsenic content (17). Improved economic conditions could help to alleviate these problems by allowing villagers to purchase commercial coal, briquettes, and modern stoves.

A HEALTH BENEFIT OF COAL COMBUSTION

Coal combustion is a dirty process. In addition to emitting potentially harmful elements such as arsenic, fluorine, selenium, mercury, and lead, the combustion process also releases particulates, acid gases, and organic compounds, all potentially harmful to human health. It is therefore highly surprising to find a beneficial health impact of coal combustion.

Wang and others report on the occurrence of iodine deficiency disorders (IDD) in Guizhou Province, PRC (18). Communities in the province in which coal is the principal source of residential fuel have a low incidence of IDD whereas communities that primarily rely on wood have a far greater incidence of IDD. Chemical analyses of the fuels indicate that the coal is markedly enriched in iodine. Burning the coal in the home to dry crops mobilizes the iodine and may provide a significant health benefit in preventing IDD. We use this example not to advocate the use of coal to prevent IDD but to illustrate that there is still much to learn about the impact of coal use on human health.

HEALTH IMPACTS OF IN-GROUND COAL

An unusual situation exists in the Balkans where there may be health problems caused by coal in the ground. Lignite has been cited as a contributory factor in a severe, debilitating kidney disease with associated urinary tract cancers (18, 19, 20). The disease, known as Balkan endemic nephropathy (BEN), occurs in clusters of villages in the former Yugoslavia and Romania. Since records were kept in the 1950s, as many as 100 000 people in the endemic villages are believed to have died from kidney failure and related health problems. In all of the endemic villages a common factor is that the primary source of drinking water is wells completed in lignite aquifers. Analysis of the well waters has revealed that wells in BEN villages have greater concentrations and numbers of organic compounds compared to control sites. Many compounds observed in the well water from BEN villages are potentially toxic (e.g., heterocyclic compounds and aromatic amines, and similar compounds have been water-leached from these lignites in the laboratory. It has been postulated that these organic compounds, leached from the lignites, are significant contributory factors in causing BEN (21). Recent studies have demonstrated a similar suite of organic compounds in water from wells underlain by lignites in Louisiana in the United States. This area is known to have one of the highest incidents of renal and pelvic cancers in the United States. In Portugal, the region where lignites were formerly mined coincides with the highest incidence of kidney disease in the country.

HEALTH IMPACTS OF UNCONTROLLED FIRES

There are tens of thousands of uncontrolled burning coal seams and coal waste piles around the world (22). They are especially prevalent in China, India, and South Africa (Figs. 2a and 2b). These fires, which are started intentionally or by spontaneous combustion, mine fires, and lightning strikes, release enormous amounts of pollutants that are a potential environmental and human health hazard. On a global scale, the emissions of large volumes of greenhouse gases from burning coal beds may contribute to climate change that alters ecosystems and patterns of disease occurrence. On regional and local scales, the emissions from burning coal beds and waste banks of acidic gases, particulates, organic compounds, and trace elements can contribute to a range of respiratory and other human health problems. The health impacts of uncontrolled coal fires are poorly understood. Although there are few published reports of health problems caused by these emissions, the potential for problems can be significant (23). In India, large numbers of people have been displaced from their homes because of health problems caused by emissions from burning coal beds. Potentially toxic elements such as arsenic, fluorine, mercury, and selenium are commonly enriched in coal deposits. As described previously, volatilization of these elements from coal has caused severe health problems in China. Burning coal beds also can volatilize these elements, which then can be inhaled, or adsorbed on crops and foods, taken up by livestock or bioaccumulated in birds and fish. Emissions from these fires also include high concentrations of benzene, toluene, xylene, and ethylbenzene (24). This is a potentially significant coal-related health problem that needs further study.

Black Lung Disease

Although the incidence of coal worker's pneumoconiosis (CWP: black lung disease), a progressive, debilitating respiratory problem caused by inhalation of coal dust, has decreased dramatically in the United States, it still takes a heavy toll on coal miners in developing countries. For example, an estimated 600 000 Chinese coal miners are suffering from CWP. The number of Chinese coal miners suffering from CWP is estimated to increase by about 70 000 each year. For more than 100 years it has been assumed that black lung disease was caused by the inhalation of the black pulverized particles of coal. Recent research, however, has shown that CWP may be initiated not by the coal particles but by inhalation of pulverized pyrite, a common coal mineral (25). The pyrite dissolves in the lung fluids, releasing iron sulfate and strong acids that irritate the lung tissues. Particles (coal dust, quartz, clay, pyrite, etc.) that then contact the irritated tissues may then cause the fibrosis leading to decreased oxygen exchange capacity. Thus, knowledge of the mineral composition of the coal may be a key parameter in anticipating the incidence of CWP. Information on the mineralogy of the coal being mined may provide essential data needed to protect the health of the miners in cost-effective ways, thus reducing the enormous financial burden of health care and lost productivity.

IS FLY ASH A HEALTH THREAT?

Combustion of coal produces enormous amounts of fine-grained respirable particles called fly ash. Worldwide several hundred million tons of fly ash is generated annually.

The trace element concentration of the fly ash is commonly enriched by about a factor of 10 compared with coal—mercury, selenium, and fluorine are exceptions because of their volatility. Moreover, the finer particle sizes (those more readily inhaled and retained in the lung) have the highest concentrations of most trace elements. Thus, exposure to coal fly ash on a regular basis could present a significant health threat. Fortunately, most modern coal burning power plants have sophisticated pollution control equipment that captures up to 99.5% of the fly ash produced during combustion. Environmental and health problems can be minimized by proper use or disposal of these coal combustion by-products. As mentioned previously, following extensive studies, the US Environmental Protection Agency concluded that, with the possible exception of mercury, there was no compelling evidence of health impacts caused by the emission of trace elements from coal-burning electric generating utilities (27).

There is one aspect of fly ash chemistry that deserves further attention. Recent studies have shown that some fly ash samples contain a very high proportion (as much as 50%) of hexavalent chromium, a very potent carcinogen (26). Moreover, all of this hexavalent chromium is water soluble and would readily be liberated in lung and stomach fluids.

RADIOACTIVITY FROM COAL: AN UNLIKELY PROBLEM

Finally, not all of the health concerns attributed to coal are valid. Periodically, there have been reports in the scientific and public literature about the threat of radioactivity from coal and coal combustion products. One of the more serious accusations is that young boys playing near disposal sites of coal combustion by-products will be made sterile by the radiation. This is pure fabrication. Although there are coals with relatively high concentrations of uranium, these are rare and none are currently being mined in the United States. The levels of radiounuclides in coal and coal combustion by-products are generally low to modest, commonly in the same range as many surficial rocks and soils (27). Radon, a daughter product of uranium decay, however, may present a legitimate health concern to coal miners working in poorly ventilated mines.

CONCLUSIONS

The direct health problems caused by coal and coal use are generally local and potentially severe. Nevertheless, once identified, practical solutions are available. For people living in areas where high quality coal is burned in modern boilers using the best available pollution control technology and sensible coal combustion by-product disposal practices, the health threat is probably minimal. More research is necessary to assess the effects of long-term, low level exposure to effluents from coal-burning power plants.

References and Notes

1. Finkelman, R.B., Orem, W., Castranova, V., Tatu, C.A., Belkin, H.E., Zheng, B., Lerch, H.E., Maharaj, S.V. and Bates, A.L. 2002. Health impacts of coal and coal use: possible solutions. *Int. J. Coal Geol. 50*, 425–443.
2. Finkelman, R.B., Belkin, H.E. and Centeno, J.A. 2006. Health impacts of coal: should we be concerned? *Geotimes*, Sept. *2006*, p. 30–34.
3. Wilson, R., Colome, S.D., Spengler, D. and Wilson, D.G. 1980. *Health Effects of Fossil Fuel Burning*. Ballinger, Cambridge, MA. 392 pp.
4. Davis, Devra. 2002. *When Smoke Ran Like Water*, Basic Books, New York. 316 pp.
5. Freese, Barbara. 2003. *Coal: A Human History*. Perseus, Cambridge, MA. 308 pp.
6. Grebb, S.F., Eble, C.F., Peters, D.C. and Papp, A.R. 2006. *Coal and the Environment*. American Geologic Institute Environmental Awareness Series 10, American Geologic Institute, Alexandria, VA. 64 pp.
7. EPA (U.S. Environmental Protection Agency). 1996. *Study of Hazardous Air Pollutant Emissions from Electric Utility Steam Generating Units*. Interim final report. EPA-453/R-96-013a.

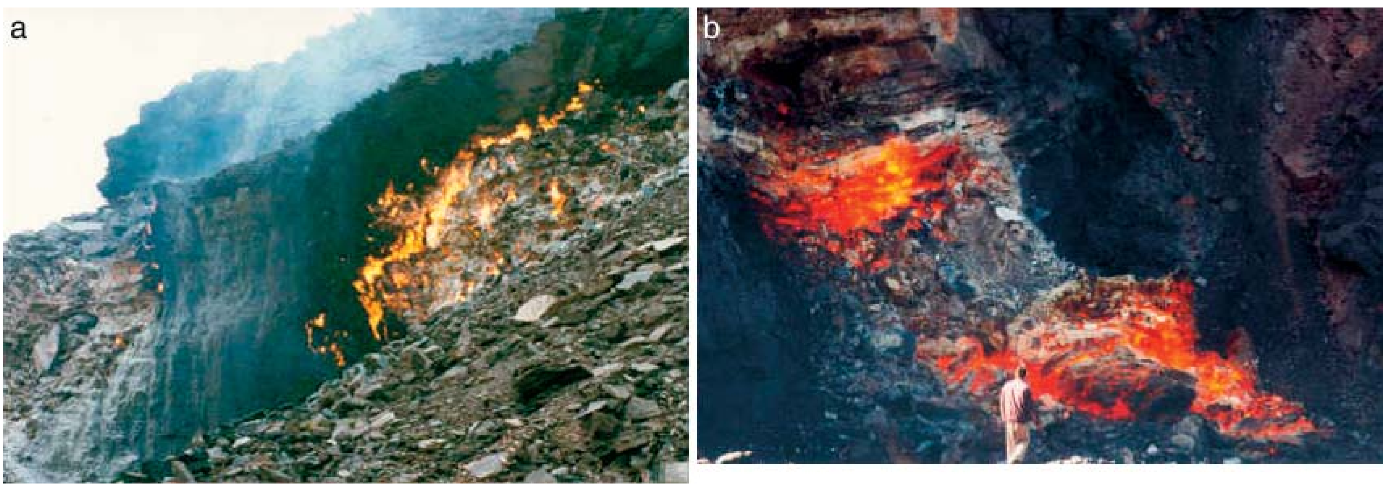

Figure 2. (a) Jharia coalfield, India. (b) Surface mine fire, northern China

8. Bencko, V. and Symon, K. 1977. Health aspects of burning coal with a high arsenic content. *Environ. Resour. 14*, 378–385.
9. Zheng, B., Yu, X., Zhand, J. and Zhou, D. 1996. Environmental geochemistry of coal and endemic arsenism in southwest Guizhou, PRC. *30th International Geologic Congress Abstracts*, *Vol. 3*, p. 410.
10. Belkin, H.E., Zheng, B., Zhou, D. and Finkelman, R.B. 1997. *Preliminary results on the geochemistry and mineralogy of arsenic in mineralized coals from endemic arsenosis in Guizhou Province, PRC*. Proceedings of the Fourteenth Annual International Pittsburgh Coal Conference and Workshop. CD-ROM, pp. 1–20.
11. Belkin, H.E., Warwick, P., Zheng, B., Zhou, D. and Finkelman, R.B. 1998. *High arsenic coals related to sedimentary rock-hosted gold deposition in southwestern Guizhou Province, People's Republic of China*. Fifteenth Annual International Pittsburgh Coal Conference CD-ROM.
12. Bragg, L.J., Oman, J.K., Tewalt, S.J., Oman, C.L., Rega, N.H., Washington, P.M. and Finkelman, R.B. 1998. *U.S. Geological Survey Coal Quality (COALQUAL) Database:* Version 2.0. U.S. Geological Survey Open-File Report 97-134.
13. Zheng, B. and Huang, R. 1989. Human fluorosis and environmental geochemistry in southwest China. *Developments in Geoscience, Contributions to 28th International Geologic Congress*, 1989, Washington, D.C. Science Press, Beijing, China. pp. 171–176.
14. Ando, M., Tadano, M., Asanuma, S., Matsushima, S., Wanatabe, T., Kondo, T., Sakuai, S., Ji, R., Liang, C. and Cao, S. 1998. Health effects of indoor fluoride pollution from coal burning in China. *Environ. Health Perspect. 106*, 239–244.
15. EPA (Environmental Protection Agency). 1998. Mercury emissions and electric utilities. (http:www.epa.gov/ttn/oarpg/hg17th.html) February 24, 1998.
16. Zheng, B., Hong, Y., Zhao, W., Zhou, H., Xia, W., Su, H., Mao, D., Yan, L. and Thornton, I. 1992. The Se-rich carbonaceous siliceous rock and endemic selenosis in southwest Hubei, China. *Chin. Sci. Bull. 37*, 1725–1729.
17. Belkin, H.E., Kroll, D., Zhou, D.-X., Finkelman, R.B. and Zheng, B. 2003. Field test kit to identify arsenic-rich coals hazardous to human health. Abstract in *Natural Science and Public Health—Prescription for a Better Environment*. U.S. Geological Survey Open-file Report 03–097. Unpaginated.
18. Wang, B., Finkelman, R.B., Belkin, H.E. and Palmer, C.A. 2004. A possible health benefit of coal combustion. *Abstracts of the 21st Annual Meeting of the Society for Organic Petrology, Vol. 21*, p. 196–198.
19. Tatu, C.A., Orem, W.H., Finkelman, R.B. and Feder, G.L. 1998. The etiology of Balkan endemic nephropathy: still more questions than answers. *Environ. Health Perspect. 106*, 689–700.
20. Orem, W., Tatu, C., Pavlovic, N., Bunell, J., Lerch, H., Paunescu, V., Ordodi, V., Flores, D. et al. 2007. Health effects of toxic organic substances from coal: Toward "panendemic" nephropathy. *Ambio 36*, 98–102.
21. Feder, G.L., Radovanovic, Z. and Finkelman, R.B. 1991. Relationship between weathered coal deposits and the etiology of Balkan endemic nephropathy. *Kidney Int.*, *40*, (Suppl. 34), 9–11.
22. Stracher, G.B. and Taylor, T.P. 2004. Coal fires burning out of control around the world: thermodynamic recipe for environmental catastrophe. *Int. J. Coal Geol. 59*, 7–17.
23. Finkelman, R.B. 2004. Potential impacts of burning coal beds and waste banks. *Int. J. Coal Geol, 59*, 19–24.
24. Pone, J.D.N., Stracher, G.B., Finkelman, R.B., Hein, K.A.A. and Annegarn, H.J. 2005. *The environmental impact of coal fires: spontaneous combustion in South Africa*. ERSEC (Ecological Research for Sustaining the Environment in China) International Conference on Understanding, Extinction and Prevention of Spontaneous Coal Seam Fires. Book of Abstracts and Program, Beijing, 2005, pp. 94–95. UNESCO CD.
25. Huang, X., Li, W., Attfeld, M.D., Nadas, A., Frenkel, K. and Finkelman, R.B. 2004. Mapping and prediction of coal workers' pneumoconiosis with bioavailable iron content in bituminous coals. *Environ. Health Perspect. 113*, 964–968.
26. Sheps, S., Finkelman, R.B., Councell, T.B. and Cohen, H. 1999. Leaching of chromium from coal fly ash: European coal geology. *Proceedings of the 3rd European Coal Conference*, Nakoman, E. (ed). pp. 475–480.
27. Zielinski, R.A. and Finkelman, R.B. 1997. *Radioactive Elements in Coal and Fly Ash: Abundance, Forms, and Environmental Significance*. U.S. Geological Survey Fact Sheet FS-163-97.

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