

THE EMERGING MEDICAL AND GEOLOGICAL ASSOCIATION

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ABSTRACT

The impact on human health by natural materials such as water, rocks, and minerals has been known for thousands of years but there have been few systematic, multidisciplinary studies on the relationship between geologic materials and processes and human health (the field of study commonly referred to as medical geology). In the past few years, however, there has been a resurgence of interest in medical geology. Geoscientists working with medical researchers and public health scientists have made important contributions to understanding novel exposure pathways and causes of a wide range of environmental health problems such as: exposure to toxic levels of trace essential and non-essential elements such as arsenic and mercury; trace element deficiencies; exposure to natural dusts and to radioactivity; naturally occurring organic compounds in drinking water; volcanic emissions, etc. By linking with biomedical/public health researchers geoscientists are finally taking advantage of this age-old opportunity to help mitigate environmental health problems. The International Medical Geology Association has recently been formed to support this effort.

Introduction

Emerging diseases can present the medical community with many difficult problems. However, emerging disciplines may offer the medical community new opportunities to address a range of health problems including emerging diseases. One such emerging discipline is medical geology, a rapidly growing discipline that has the potential of helping medical communities to address a wide range of environmental health issues. To support this effort a new organization, the International Medical Geology Association (www.medicalgeology.org), has been formed and a new text book (1) has been produced.

Background

Medical geology can be considered as a compliment of environmental health dealing with the impacts of geologic materials and processes

(that is, the natural environment) on human and animal health. Medical geology attempts to bring together geoscientists and medical/public health researchers to address health problems caused by or exacerbated by geologic materials such as trace elements, rocks, minerals, natural dust, water, and geologic processes such as volcanic eruptions, earthquakes.

Medical geology is not strictly an emerging discipline but rather a re-emerging discipline. The relationship between geologic materials such as rocks and minerals and human health has been known for centuries. Ancient Chinese, Egyptian, Islamic, and Greek texts describe the many therapeutic applications of various rocks and minerals and many health problems that they may cause. More than 2,000 years ago Chinese texts describe 46 different minerals that were used for medicinal purposes. Arsenic minerals for example, orpiment (As_2S_3) and realgar (AsS) were extensively featured in the materia medica of ancient cultures. Health effects associated with the use of these minerals were described by Hippocrates (460–377 B.C.) as “. . . as corrosive, burning of the skin, with severe pain . . .”

Practitioners of medical geology have four principal responsibilities.

- To identify the environmental causes of known health problems and, in collaboration with biomedical/public health researchers, seek solutions to prevent or minimize these problems.
- To identify geochemical anomalies in soils, sediments, and water that may impact on health.
- To reassure the public when there are unwarranted environmental health concerns deriving from geologic materials or processes.
- To evaluate the beneficial health affects of geologic materials and process.

There have been many pioneering collaborations between geoscientists and medical scientists (2–6) on environmental health issues, but these studies were largely driven by the interests and enthusiasm of individual scientists. What is different and exciting is that medical geology is now receiving institutional support from many organizations in many countries.

One of the more important developments is the emergence of an Association devoted to promoting medical geology globally. Formed in 2003, the International Medical Geology Association (IMGA) has nearly 1,000 corresponding members from more than 70 countries. The Association maintains a website (www.medicalgeology.org), produces a newsletter, sponsors short courses, organizes conferences and technical sessions at scientific meetings, provides support to help students and young professionals participate in the short courses and confer-

ences, encourages national, regional and local working groups, and publishes books and articles on medical geology. In short, the IMGA is responsible for promoting medical geology to all sectors of the global society. One of the principal objectives of the Association is to forge links between geoscientists and biomedical/public health researchers and between developed and developing countries with the goal of finding practical solutions to environmental health problems.

Among the environmental health problems that geologists are working with the medical community to address are: exposure to toxic levels of trace essential and non-essential elements such as arsenic and mercury; trace element deficiencies; exposure to natural dusts and to radioactivity; naturally occurring organic compounds in drinking water; volcanic emissions, etc. Geoscientists have also developed an array of tools and databases that can be used by the environmental health community to address vector-borne diseases, to model pollution dispersion in surface and ground water, and also can be applied to some aspects of industrial pollution and occupational health problems. Below are selected examples of health problems that have been, or are being addressed by teams of medical and geoscientists.

Trace Element Exposure: Deficiency and Toxicity

Diseases due to Trace Element Deficiencies: The connection between geologic materials and trace element deficiency can clearly be shown for iodine. Iodine Deficiency Disorders (IDD) includes goiter (enlargement of the thyroid gland), cretinism (mental retardation with physical deformities), reduced IQ, miscarriages, and birth defects. Goiter is still a serious disease in many parts of the world. China alone has 425 million people at risk of IDD. In all, more than a billion people, mostly living in the developing countries, are at risk of IDD. In all the places where the risk of IDD is high, the content of iodine in drinking water is very low because of low concentrations of iodine in bedrock. A recent study has indicated that iodine volatilized from residential coal combustion in Guizhou Province China may be substantially reducing the incidence of IDD in the region (7).

Selenium is an essential trace element having antioxidant protective functions as well as redox and thyroid hormone regulation properties. However, selenium deficiency (due to soils low in selenium), has been shown to cause severe physiological impairment and organ damage such as a juvenile cardiomyopathy (Keshan disease) and muscular abnormalities in adults (Kaschin-Beck disease) (Figure 1). In the 1960s scientists suspected that the diseases were of geological origin and in

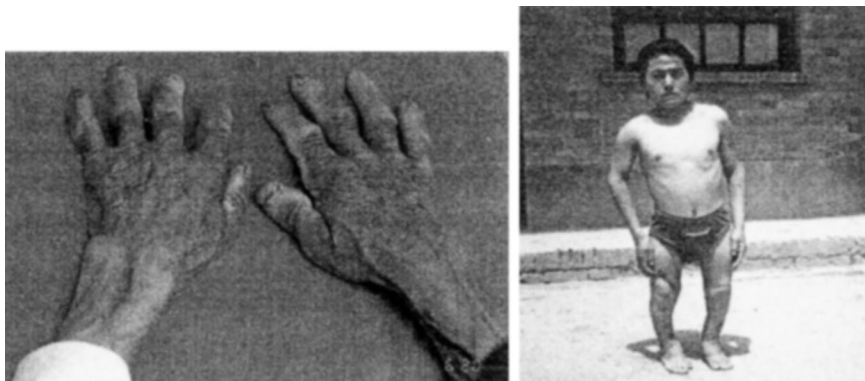


FIG. 1. Photos demonstrating cases with severe muscular abnormalities associated with selenium deficiency in China (Kashin-Beck disease). These photographs were taken by Prof. Dr. Wang Zhilun (China) a leading researcher on selenium deficiency disorders.

the 1970s the probable solution was found. The diseases were always located in areas with low selenium soils. The use of selenium in prevention and treatment of the diseases was a great success.

Toxicity of Essential and Non-essential Elements. Toxicity effects from exposure to excess amount of trace elements have been also described as due, in part, to natural geological sources. One of the most studied trace elements in this regard has been fluorine. Fluoride (F^-), the ionic form of fluorine, can stimulate bone formation and it also has been demonstrated to reduce dental caries at doses of at least 0.7 mg/L in drinking water. However, excess fluoride exposure can cause fluorosis of the enamel (mottling of the teeth) and bone (skeletal fluorosis).

Health effects from chronic exposure to non-essential metals and metalloids such as arsenic have been also described as an area of research on medical geology. Arsenic and arsenic containing compounds are human carcinogens (8). Exposure to arsenic may occur through several anthropogenic sources, including mining, pesticide, pharmaceutical, glass and microelectronics, but the most prevalent sources of exposure today has been by natural sources. Exposure to arsenic occurs via the oral route (ingestion), inhalation, and dermal contact. Drinking water contaminated by arsenic remains a major public health problem. Acute and chronic arsenic exposure via drinking water has been reported in many countries of the world, where a large proportion of drinking water is contaminated with high concentrations of arsenic. General health effects that are associated with arsenic exposure include cardiovascular and peripheral vascular disease, developmental anomalies, neurologic and neurobehavioural disorders, diabetes, hearing loss, portal fibrosis, hematologic disorders

(anemia, leukopenia and eosinophilia) and multiple cancers. There are significantly higher standardized mortality rates and cumulative mortality rates for cancers of the skin, lung, liver, urinary bladder, kidney, and colon in many areas of arsenic pollution (9–11) (Figure 2).

Global implications and medical geology examples of chronic arsenic and fluorine poisoning. In Bangladesh, India, China, Taiwan, Vietnam, Mexico, and elsewhere, high levels of arsenic in drinking water have caused serious health problems for many millions of people (12). Geoscientists from several countries are working with public health officials to seek solutions to these problems. By studying the geological and hydrological environment, geoscientists are trying to determine the source rocks from which the arsenic is being leached into the ground water. They are also trying to determine the conditions under which the arsenic is being mobilized. For example, is the arsenic being desorbed and dissolved from iron oxide minerals by anerobic (oxygen-deficient) groundwater or is the arsenic derived from the dissolution of arsenic-bearing sulfide minerals such as pyrite by oxygenated waters? The answers to these questions will allow the public health communities around the world identify aquifers with similar characteristics and more accurately determine which populations may be at risk from arsenic exposure.

In China, geoscientists are working with the medical community to seek solutions to arsenic and fluorine poisoning caused by residential burning of mineralized coal and briquettes. Chronic arsenic poisoning affects least 3,000 people in Guizhou Province, P.R. China. 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. 2), and Bowen's disease (dark, horny, precancerous lesions of the skin). Chili peppers dried over open coal-burning stoves may be a principal



FIG. 2. Photos showing arsenic-induced lesions of the skin. From left to right: Keratotic (ulceration) lesions of the foot, leg and hands. Photos: J. A. Centeno.

vector for the arsenic poisoning. Fresh chili peppers have less than one part-per-million (ppm) arsenic. In contrast, chili peppers dried over high-arsenic coal fires can have more than 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 3,000 ppm arsenic), and from inhalation of indoor air polluted by arsenic derived from coal combustion. The arsenic content of drinking water samples does not appear to be an important factor.

Detailed chemical and mineralogical characterization of the arsenic-bearing coal samples from this region (13) indicate arsenic concentrations as high as 35,000 ppm! Typically coals have less than 20 ppm arsenic. Although there were a wide variety of As-bearing mineral phases in the coal samples, much of the arsenic was bound to the organic component of the coal. This observation was important for two reasons. Firstly, because the arsenic is in the organic matrix, traditional methods of reducing arsenic, such as physical removal of heavy minerals, primarily As-bearing pyrite, would not be effective. Secondly, because the visually observable pyrite in the coal was not a reliable indicator of the arsenic content, the villagers had no way of predicting the arsenic content of the coals that they mined or purchased. To overcome these problems a field test kit for arsenic was developed (14). This kit gives the villagers the opportunity to analyze the coal in the field and identify the dangerous high-arsenic samples as well as the safer low-arsenic coals.

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. Typical symptoms of fluorosis include mottling of tooth enamel (dental fluorosis) and various forms of skeletal fluorosis including osteosclerosis, limited movement of the joints, and outward manifestations such as knock-knees, bow legs, and spinal curvature. Fluorosis combined with nutritional deficiencies in children can result in severe bone deformation.

The etiology of fluorosis is similar to that of arseniasis in that the disease is derived from foods dried over coal-burning stoves. Adsorption of fluorine by corn dried over unvented ovens burning high (>200 ppm) fluorine coal is the probable cause of the extensive dental and skeletal fluorosis in southwest China. The problem is compounded by the use of clay as a binder for making briquettes. The clay used is a high-fluorine (mean value of 903 ppm) residue formed by intense leaching of a limestone substrate.

Geophagia is also of concern in medical geology. Geophagy or geoph-

agia can be defined as the deliberate ingestion of soil, a practice that is common among members of the animal kingdom, including certain human populations. Soil may be eaten from the ground but in many situations there is a cultural preference for soil from special sources such as termite mounds. Geophagia is considered by many nutritionists to be either a learned habitual response in which clays and soil minerals are specifically ingested to reduce the toxicity of various dietary components or as an in-built response to nutritional deficiencies resulting from a poor diet. Geophagy is attracting renewed and serious interest within the scientific research community.

There can also be potentially hazardous exposure to natural gases such as radon. Geology is the most important factor controlling the source and distribution of radon. Relatively high levels of radon emissions are associated with particular types of bedrock and unconsolidated deposits, for example some, but not all, granites, phosphatic rocks, and shales rich in organic materials. The release of radon from rocks and soils is controlled largely by the types of minerals in which uranium and radium occur. Radon levels in outdoor air, indoor air, soil air, and ground water can be very different. Radon released from rocks and soils is quickly diluted in the atmosphere. Concentrations in the open air are normally very low and probably do not present a hazard. Radon that enters poorly ventilated buildings, caves, mines, and tunnels can reach dangerously high concentrations.

Naturally Occurring Organic Compounds In Drinking Water

Balkan endemic nephropathy (BEN) is an irreversible kidney disease of unknown origin, geographically confined to several rural regions of Bosnia, Bulgaria, Croatia, Romania, and Serbia. The disease occurs only in rural areas, in villages located in alluvial valleys of tributaries of the lower Danube River. It is estimated that several thousand people in the affected countries are currently suffering from BEN and that thousands more will be diagnosed with BEN in the next few years.

Many factors have been proposed as etiological agents for BEN, including: bacteria and viruses, heavy metals, radioactive compounds, trace element imbalances in the soil, chromosomal aberrations, mycotoxins, plant toxins, and industrial pollution (15). Recent field and laboratory investigations support an environmental etiology for the disease, with a prime role played by the geological background of the endemic settlements (15–17). In this regard, there is a growing body of evidence suggesting the involvement of toxic organic compounds

present in the drinking water of the endemic areas. These compounds are believed to be leached by groundwater from low rank Pliocene lignite deposits, and transported into shallow household wells or village springs. Analysis of well and spring water samples collected from BEN endemic areas contain a greater number of aliphatic and aromatic compounds, and in much higher abundance ($>10\times$) compared to water samples from nonendemic sites. Many of the organic compounds found in the endemic area water samples were also observed in water extracts of Pliocene lignites, suggesting a possible connection between leachable organics from the coal and organics in the water samples.

The population of villages in the endemic areas uses well/spring water almost exclusively for drinking and cooking, and is therefore potentially exposed to any toxic organic compounds in the water. The presumably low levels of toxic organic compounds present would likely favor relatively slow development of the disease over a time interval of 10 to 30 years or more. The frequent association of BEN with upper urinary tract (urothelial) tumors suggests the action of both nephrotoxic and carcinogenic factors, possibly representing different classes of toxic organic substances derived from the Pliocene lignites. Pliocene lignites are some of the youngest coals in the Balkans and are relatively unmetamorphosed in the endemic areas. They retain many of the complex organic compounds contained in the decaying plant precursors (15,17) and many kinds of potentially toxic organic compounds may be leached from them.

In the Pliocene lignite hypothesis for BEN etiology, however, other factors besides the presence of low rank coals must also be in play. The hypothesis also implies many or all of the following circumstances: the right hydrologic conditions for leaching and transport of the toxic organic compounds from the coal to the wells, a rural population largely dependent on untreated well water, a population with a relatively long life span (BEN commonly becomes manifest in people in their 40s and 50s), a relatively settled population for long exposure to the source of nephrotoxic/carcinogenic substances, and a competent and established medical network for recognition of the problem and proper, systematic, diagnosis.

It may be that BEN is a multifactorial disease, with toxic organics from coal being one necessary factor in the disease etiology. The challenge to researchers is to integrate studies among disparate scientific disciplines (medicine, epidemiology, geology, hydrology, geochemistry) in order to develop a reasoned conceptual model of the disease etiology of BEN.

Naturally Occurring Dusts

Exposure to mineral dusts can cause a wide range of respiratory problems. These exposures can be due to local conditions such as the dusts generated by mining hard rocks or coal, use of fine-grained mineral matter in sand-blasting, and formation of smoke plumes from fires (both natural and man-made). Dust exposure can affect broad regions such as the dust stirred up by earthquakes in the arid regions of the southwestern U.S. and northern Mexico. This dust carries spores of a fungus (*coccidioidis immetus*) that causes Valley Fever, a serious respiratory problem that can lead to fatigue, cough, fever, rash, including damage to internal organs and tissues such as skin, bones, and joints. Dust exposure can even take on global dimensions. Ash ejected

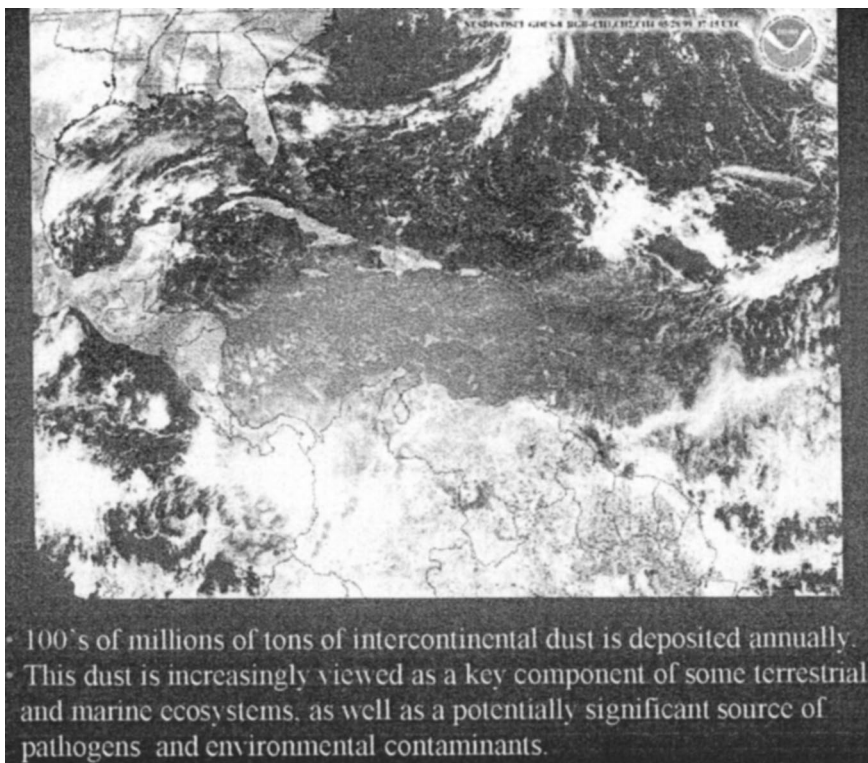


FIG. 3. This satellite image shows a dust cloud from North Africa moving across the Atlantic Ocean, over northern South America and then over the Caribbean and the southern U.S. These dust storms occur several times a year resulting in increased incidence of asthma and allergies in the Caribbean region. The dust is not exclusively fine mineral grains. Researchers have found more than 140 different organisms hitchhiking from Africa to the Western Hemisphere.

from volcanic eruptions can travel many times around the world and recent satellite images have shown wind blown dust picked up from the Sahara and Gobi deserts blown more than halfway around the world (Figure 3). Of greatest concern for effects upon human health are the finer particles of the respirable (inhalable) dusts. In this regard, considerable work is being conducted in identifying dust particles derived from soils, sediments and weathered rock surfaces.

Asbestos is a term that represents a diverse group of minerals that have several common properties; they separate into long thin fiber, are heat resistant, and are chemically inert. In the 1980s it was recognized that exposure to respirable asbestos fibers can cause severe health problems such as mesothelioma, lung cancer, and asbestosis. Many mines producing commercial asbestos were closed and a concerted effort was made to remove asbestos from schools, work places, and public buildings.

Unfortunately, the problem did not end there. Recently, it was found that small amounts of asbestos associated with commercial deposits of vermiculite, a micaceous mineral used for insulation, packaging, kitty litter, and other applications, had caused significant health problems in the mining community of Libby, Montana, USA (18). Lung abnormalities (such as pleural thickening or scarring) occurred in about 18 percent of the adults tested.

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DISCUSSION

Luke, Cincinnati: Do any of these toxic substances have a physiological role in the body? I ask because there might be transport mechanisms that are relevant.

Finkelman, Reston: Of course, there is selenium, iodine, and fluorine. They are all essential, but some people are suffering from deficiencies as well as excess. Again, I am a geologist. We have many competent medical researchers that are working on these issues with me and I would defer those kinds of questions to my colleagues.