Medical Geology: An Emerging Discipline

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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. Medical Geology is a rapidly growing discipline that has the potential of helping the medical community in the Asia Pacific Region and elsewhere to pursue a wide range of environmental health issues. In this article we provide an overview of some of the health problems being addressed by practitioners of this emerging discipline.

BACKGROUND

Silverman (1997) defined environmental health as the impact of environmental degradation on human populations. 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 animal and human 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, water, and geologic processes such as volcanic eruptions, earthquakes and dust.

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, orphiment (As_2S_2) and realgar (As_2S_3), were extensively featured in the materia medica of ancient cultures. Health effects associated with the use of these minerals were described by Hippocrates (460-377B.C.) as "… as corrosive, burning of the skin, with severe pain…"

There have been many pioneering collaborations on environmental health issues between geoscientists and medical scientists (Bencko and Vostal, 1999; Cronin and Sharp, 2002; Centeno et al., 2002), but these studies have largely been 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.

Practitioners of Medical Geology have five principal responsibilities.

- To identify geochemical anomalies in soils, sediments, and water that may impact on health.
- 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 evaluate the beneficial health affects of geologic materials and process.
- To reassure the public when there are unwarranted environmental health concerns deriving from geologic materials or processes.
- To forge links between developed and developing countries to find solutions for 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 can be applied to some aspects of industrial pollution and occupational health problems.

TRACE ELEMENT EXPOSURE: DEFICIENCY AND TOXICITY

Trace elements play essential roles in the normal metabolism and physiological functions of animals and humans. Of these, some 22 elements are known or suspected to be "essential" for humans and other animals. Some are required in fairly large amounts (e.g., grams per kilogram of diet), and are therefore referred to as "macronutrients"; others are required in much smaller amounts (e.g., microgram-to-milligrams per kilogram of diet and are referred as "micronutrients". Sixteen elements are established as being essential for good health. Some (calcium, phosphorus, magnesium, and fluoride) are required for structural functions in bone and membranes; some (sodium, potassium, and chloride) are required for the maintenance of water and electrolyte balance in cells; some (zinc, copper, selenium, manganese, and molybdenum) are essential constituents of enzymes or serve as carriers (iron) for ligands essential in metabolism; and some serve as essential components of a hormone (iodine) or hormone-like factor (chromium). Because these are all critical life functions, the tissue levels of many "nutritionally essential elements" tend to be regulated within certain ranges, which are highly dependent on several physiological processes, chiefly by homeostatic control of enteric absorption, tissue storage and/or excretion. Changes in these physiological processes may exacerbate the effects of short-term dietary deficiencies or excesses of trace elements.

The sources of trace elements are varied. Food derived from soils is a major, significant route; however, other sources such as the deliberate eating of soil (geophagia) and water supplies may also contribute to dietary intake of trace elements. Diseases due to trace element deficiencies as well as excesses have been described for example, for iodine, copper, zinc, selenium, molybdenum, manganese, iron, calcium, arsenic, and cadmium. Endemic distributions of diseases directly related to the geographic patterns of soil deficiencies in selenium and iodine have been described in at least two general cases, the juvenile cardiomyopathy "Keshan Disease"and the iodine deficiency diseases goiter and myxedematous cretinism, respectively. In the following paragraphs, examples of adversed health effects due to trace element deficiencies and excesses will be described. Environmental chronic exposure to non-essential elements such as arsenic will also be described.

Diseases due to Trace Element Deficiences: The connection between geologic materials and trace element deficiency can clearly be shown for iodine. Iodine Deficiency Disorders (IDD) include goiter (enlargement of the thyroid gland), cretinism (mental retardation with physical deformities), reduced IQ, miscarriages, and birth defects. In ancient China, Greece and Egypt as well as among the Incas, people affected by goiter, were given sea weed to provide the needed iodine. Goiter is still a serious disease in many parts of the world. China alone has 425 million people (40 % of the world's population) 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.

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) (see Figure 1). In the 1960s scientists suspected that the disease was of geological origin and in the 1970s the probable solution was found. The disease was always located in areas with low selenium soils. The use of selenium in prevention and treatment of the disease was a great success.

Figure 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.

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 (IARC, 1987). 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, dermal contact and the parenteral route to some extent. Drinking water contamination 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: 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 (Centeno et al., 2002; Centeno et al., 2002; Tchounwou, 2003) (Figure 2).

Figure 2: Photos showing arsenic-induced lesions of the skin. From left to right: Keratoric (ulceration) lesions of the foot, leg and hands. Photos: JA Centeno.

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 (Kinniburgh and Smedley, 2001). 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), Bowen's disease (dark, horny, precancerous lesions of the skin. Chili peppers dried over open coal-burning stoves may be a principal 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 (Belkin and coworkers, 1997) indicate arsenic concentrations as high as 35,000 ppm! Typically coals have less than 20 ppm arsenic and coals from Malaysia have less that 5 ppm arsenic (USGS unpublished data). 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 was 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 (Belkin et al., 2003). 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 geophagia 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 attaining renewed and serious interest within the scientific research community.

One particularly interesting case of high element exposure is “sickness country” in Australia. This area in the Kakadu region of the Australian Outback has been known by the aborigines as an area that will cause sickness. Hence the area is regarded by the aborigines as taboo and should not be entered.

Geochemical researchers may have found the reason for the sickness. The bedrock in the region consists of granites and volcanic rocks. These rock types contain elevated amounts of certain elements. The “sickness country” contains localized areas of unusually high natural levels of thorium, uranium, arsenic, mercury, fluorine, and radon in groundwater and drinking water. The aborigines had also used ochre as color pigment in painting. The ochre was shown to contain extremely high contents of uranium, lead, arsenic, and mercury. The naturally high levels of toxic elements in the land and water systems thus constitute a health hazard recognized eons ago by the local people.

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 OCCURING 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 (Tatu et al., 1998). 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 (Feder et al., 1991; Tatu et al., 1998; Orem et al., 1999). 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 (>10x), 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 (Feder et al., 1991; Orem et al., 1999), 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 (coccidiomycosis 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 form 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 halfway around the world. Of greatest concern for effects upon human health are the finer particles of the respirble (inhalable) dusts. On this regard, considerable work is beung 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 (Van Gosen and others, 2002). Lung abnormalities (such as pleural thickening or scarring) occurred in about 18 percent of the adults tested.

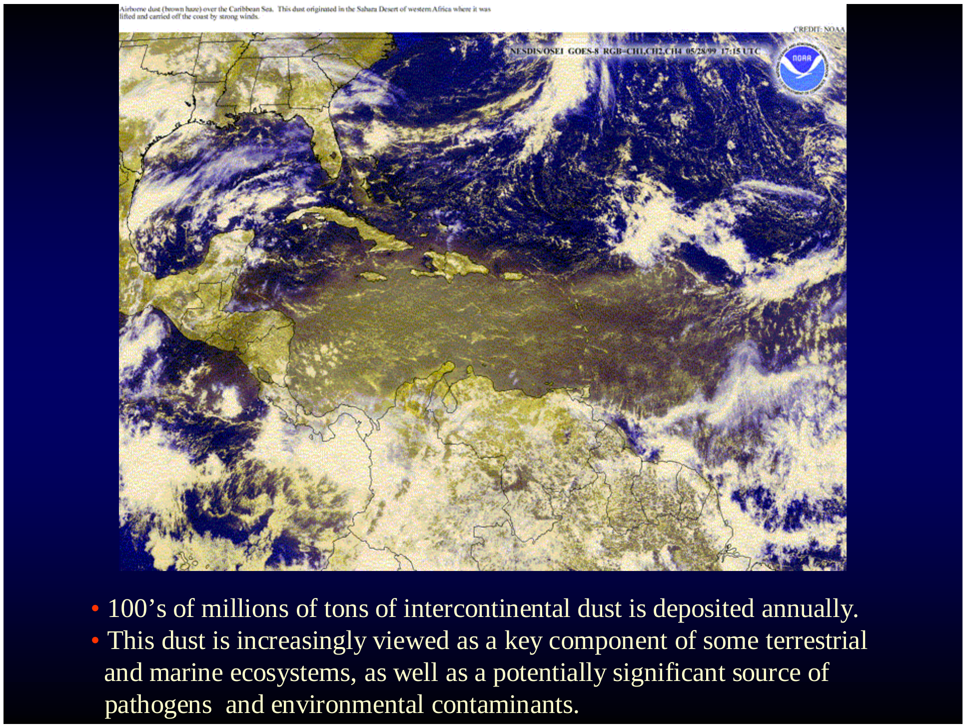

Figure 3. This satellite image shows a dust cloud from North Africa moving across the Atlantic Ocean, over northern South America and then over the Caribbean and the southern U.S. These dust storms occur several times a year resulting in increased incidence of asthma and allergies in the Caribbean region.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

CONCLUSIONS

Medical Geology should be considered as a component of Malaysia's National Health Action Plan (NEHAP; Pillay et al., 2003). Pillay et al. state that "Environmental health is the science of protecting human health from the damaging effects of physical, chemical and biological agents in the environment. This science strives to identify harmful agents, determining exposures relating to deteriorating health conditions and to develop sound principles, strategies, programs and approaches to eliminate or minimize health risks." Medical Geology has the same objectives but focuses on the naturally occurring physical and chemical agents in the environment. Thus, for NEHAP to be most effective the

Malaysian geoscience community should be included as one of the key players or agencies involved in environmental health activities.

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